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               REPORT OF SIGNIFICANT ACCOMPLISHMENTS.(U)
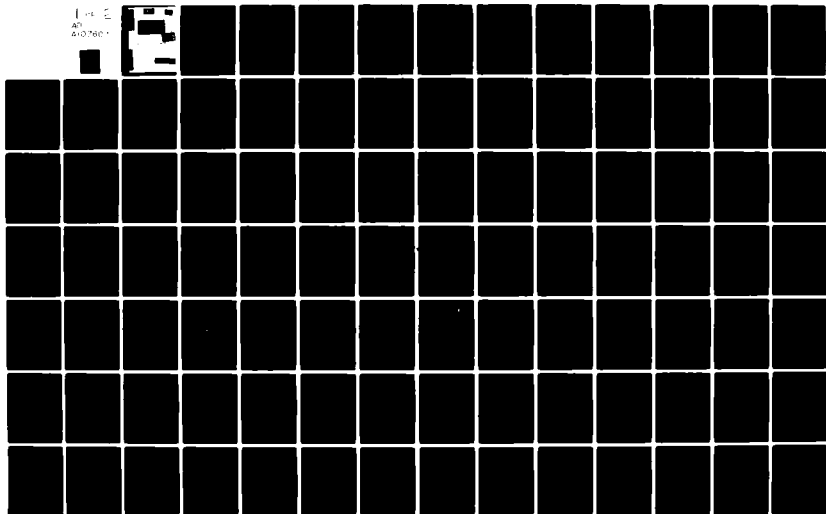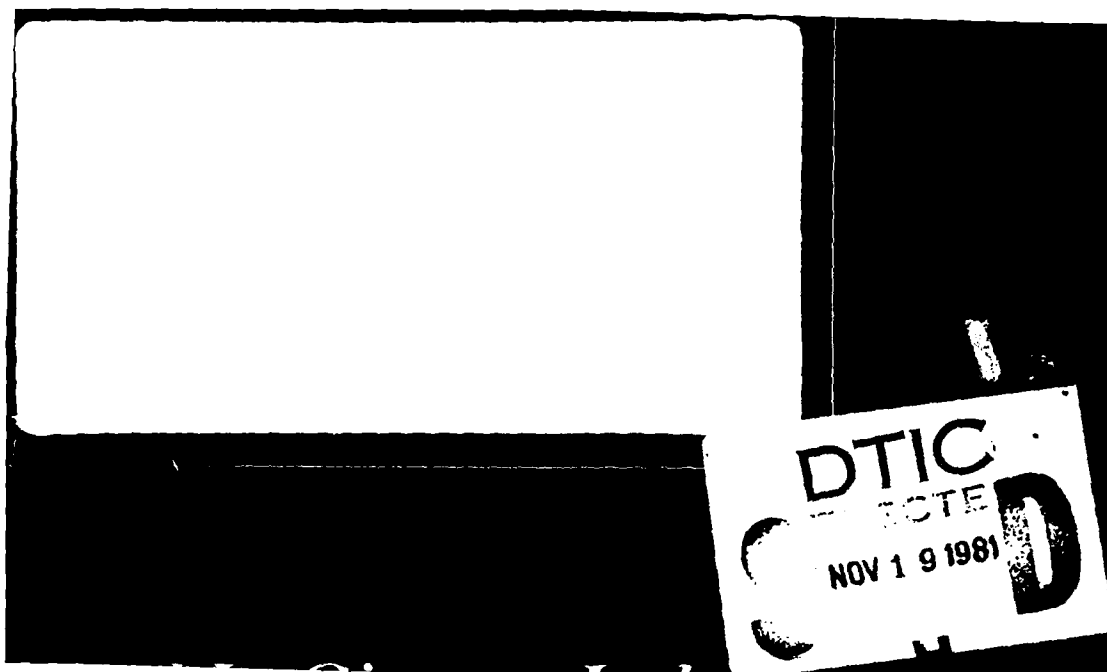   APR 81 A E SIEGMAN, B A AULD, M R BEASLEY   N00014-75-C-0632
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ANNUAL PROGRESS REPORT

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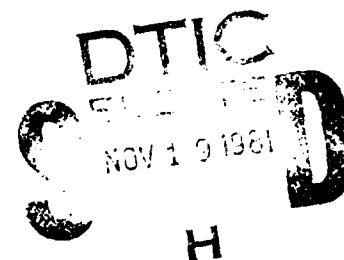REPORT OF SIGNIFICANT ACCOMPLISHMENTS

Joint Services Electronics Program

Contract N00014-75-C-0632

1 April 1980 through 31 March 1981

G.L. Report No. <u>3315</u>

Edward L. Ginzton Laboratory
Stanford University
Stanford, CA 94305

Submitted by A.E. Siegman on behalf
of the faculty and staff of the
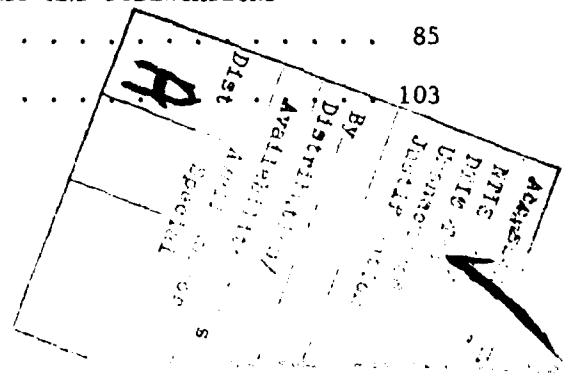Edward L. Ginzton Laboratory

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Joint Services Electronics Program

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REPORT OF SIGNIFICANT ACCOMPLISHMENTS

(1 April 1980 — 31 March 1981)

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I. INTRODUCTION

SUMMARY AND OVERVIEW

This annual report covers work done by the Edward L. Ginzton
Laboratory JSEP Program at Stanford University, under Contract N00014-
75-C-0632, for the period 1 April 1980 to 31 March 1981. Significant
progress is reported in high-temperature superconducting Josephson
junctions, programmable acoustic wave imaging and signal-processing
devices, fiber directional couplers and fiber optic signal processing,
acoustic wave processes in new acoustic materials, and measurement
methods for ultrafast optical phenomena. The significant accomplish-
ments in each of these five JSEP Work Units are briefly summarized in a
"Review of Significant Accomplishments," section at the front of this
report, followed by a more detailed annual progress report for each of
the six projects.

The reader of this report will note some common features of all
six of these projects, as of other research activities in this Laboratory,
including

- an emphasis on new physical concepts and interactions, and on
  the basic physical understanding of those interactions,
  coupled with

- a strong orientation toward new devices and toward finding
  practical device applications for these basic physical
  phenomena, coupled with

- an emphasis on developing new technology, new techniques and
  processes, for achieving these goals.

The emphasis on basic physics in this work means a heavily scientific
orientation toward finding, understanding and explaining new physical

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phenomena, using all the tools of fundamental physics, quantum theory and other sophisticated scientific theories where these are needed. The device orientation means that, although new basic scientific information is valued for its own sake, there is also a strong drive to identify potential new device applications for this knowledge, and to develop these device capabilities at least to the point of feasibility demonstration. The researchers are heavily motivated to carry new basic scientific ideas far enough to see them exploited.

The emphasis on technology means such things as sophisticated new thin film preparation techniques, preparation of new materials, growth of crystals in novel fiber forms, construction of new lasers; all of these done in our own Laboratory (or associated Stanford facilities) with our own tools. The crucial materials or samples or instruments in the majority of our projects in fact are made or prepared in-house, not purchased outside, often by novel techniques developed here and not yet available anywhere else. These techniques, as they are developed and their importance shown, are then distributed to industry and elsewhere by publications, by visitors to our Laboratory, and of course most of all by our graduating students.

This emphasis on new technology also means, of course, a constant struggle to maintain the facilities and capability of our Laboratory research facilities. The problem is not so much in buying the latest and most sophisticated instruments as instruments. It is rather in acquiring and supporting the laboratory and scientific shop tools and facilities-- and maintaining the laboratory personnel skills -- which will enable us to build for ourselves still newer instruments, devices and techniques. This

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capability is vital for continued progress at the frontiers, but is also a continual struggle to maintain and develop.

Four of the Work Units summarized in this report are being continued under JSEP support. The research under Work Unit #5, Measurements of Ultrafast Physical Phenomena (A.E. Siegman), is being redirected, with the previous work being continued under other support, while this Work Unit proceeds along a new direction (Picosecond Raman Spectroscopy of Electronic Solids). Work Unit #3, Research on Fiber Optic Interactions with Application to High Speed Signal Processing (H.J. Shaw) has been terminated, since the outstanding work on single mode fibers in this group is now being supported by other government and industrial sources.

Five journal publications were published under JSEP support during the period being reported, with four other manuscripts submitted or in press. At least half a dozen conference presentations and talks also reported on various aspects of the work.

II. REVIEW OF SIGNIFICANT ACCOMPLISHMENTS

A brief review of significant accomplishments during the past year for each of the current Work Units is given in this section. More details on each of these projects will be found in the longer Annual Progress Reports for each of the Work Units, which follow this section.

Work Unit #1: HIGH-T_c SUPERCONDUCTING WEAK-LINK JOSEPHSON JUNCTIONS AND CIRCUITS, Professor M.R. Beasley

During the past year we produced the first successful superconducting Josephson junction capable of operating reliably at temperatures up to 16.5 K (where cheap, small-scale cryogenic refrigerators are available) and in fact with good performance over a temperature range of 2 K to 16.5 K. All previous high-temperature Josephson devices have been highly idiosyncratic, restricted in their operation to a narrow temperature range near the transition temperature T_c , and have typically exhibited only feeble and strongly temperature-dependent Josephson behavior.

The present devices are SNS (superconductor-normal-superconductor) $Nb_3Sn/Cu/Nb_3S_n$ Josephson microbridges fabricated in our laboratory using a new variant of "step-edge patterning." They exhibit well-developed Josephson behavior of $2\ K < T < 16.5\ K$. The fabrication technique employed is a generic one and should be extendable to any high-temperature superconductor. The electrical characteristics of our new devices appear similar but generally superior to our earlier, lower temperature Nb/Au/Nb SNS bridges for which we have developed good theoretical models. These theoretical models should help give us the theoretical foundation for further progress in these devices.

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Work Unit #2: ACOUSTIC SURFACE WAVE SCANNING OF OPTICAL IMAGES,

Professor G.S. Kino

During the past year we have demonstrated a novel active and programmable surface acoustic wave device using zinc oxide (ZnO) acoustic waveguides on a semiconducting silicon substrate. Surface acoustic wave (SAW) devices which perform nonlinear functions such as convolution and correlation between two simultaneous rf acoustic signals are now in widespread use, based in large part on earlier work in this Laboratory. Our new device permits simultaneous convolution and correlation of two such signal which can be read into the device at different times. This accomplishment (and extensions of it which we are now developing) are heavily dependent on ZnO film technology developed in our group. We have also developed theoretical explanations, and a new design for focusing acoustic wave couplers.

Work Unit #3: RESEARCH ON FIBER OPTIC INTERACTIONS WITH APPLICATION TO

HIGH SPEED SIGNAL PROCESSING, Professor H.J. Shaw

A fiber optic delay line memory has been demonstrated. The delay line utilizes single mode fiber allowing very large bandwidth. The delay line is a solid-state device, constructed entirely of single-mode fiber components. It is thus not only small and rugged, but has much lower insertion loss than comparable systems using classical bulk optical components for closing the recirculating fiber path and for injecting and extracting signals. This device was made possible by the use of efficient single mode fiber directional couplers developed previously under this project.

Work Unit #4:   NONLINEAR INTERACTIONS OF ACOUSTIC WAVES WITH DOMAINS IN

FERROIC MATERIALS,   Professor B.A. Auld

This project is studying the basic nonlinear acoustic properties of
novel "ferroic" materials (i.e., ferroelectric-cum-ferroelastic materials)
with potential applications in acoustic waveguiding, steering, and signal
processing devices. During the past year ten boules of one such material,
gadolinium molybdate (GMO), were grown, together with several preliminary
fiber samples of this material. A novel technique using laser probing
for measuring the nonlinear acoustic resonances of ferroic acoustic
resonators was also demonstrated, and will now become a useful research tool
for studying further materials properties.

Work Unit #5:   MEASUREMENTS OF ULTRAFAST PHYSICAL PHENOMENA

Professor A.E. Siegman

During the past year the optical apparatus for this work unit, including
three separately tunable dye lasers pumped by a common Nd:YAG laser, was
completed and put into full operation. Laser-induced transient gratings
were produced and diffracted probe signals observed in test samples.
Full experimentation with the system can now begin. Several publications
on related developments in pulsed laser technology were also completed and
published.

Work Unit #A: OPTICAL AND NONLINEAR OPTICAL STUDIES OF SINGLE CRYSTAL

FIBERS, Professor R.L. Byer

During the past year we completed (in collaboration with Professor Robert Feigelson of the Stanford Center for Materials Research) and Professor John Shaw, Ginzton Laboratory, a novel apparatus using a CO_2 laser for growing single crystal optical fibers of novel and useful materials. So far we have grown and evaluated fibers in diameters from 35 to 500 microns and lengths up to 15 cm, of two orientations of $LiNbO_3$, three orientations of Nd:YAG, and two orientations of sapphire. The physics of single crystal growth in fiber form is extremely interesting, and the device possibilities for optical (and acoustic) waves trapped in fibers of these widely used optical materials are equally interesting.

Studies of the unique domain characteristics, poling properties, and other optical properties of many of these fibers, especially the $LiNbO_3$ fibers, are now under way. Random fluctuations in fiber diameter have also been identified as a major problem with present fibers. Improved growing techniques (using actually a smaller CO_2 laser for the fiber growth process) are now being implemented.

III. <u>JSEP Sponsored</u>[*]

<u>Publications and Papers</u>

A.E. Siegman, "Laser Induced Grating Techniques for Picosecond Spectroscopy," Report of Workshop on Picosecond Spectroscopy (sponsored by DARPA), La Jolla Institute, La Jolla, California, May 7-8, 1980. (Partially supported by AFOSR.)

Wolfram E. Schmid, "Pulse Stretching in a Q-switched Nd:YAG Laser," IEEE J. Quant. Electr. <u>QE-16</u>, 790-794 (July 1980).

J.B. Green, B.T. Khuri-Yakub, and G.S. Kino, "A New Narrow Bandwidth-High Efficiency Zinc Oxide on Silicon Storage Correlator," J. Appl. Phys. <u>52</u>, 1, 505-506 (January 1981).

G.S. Kino, "Signal Processing with the Storage Correlator," presented at the SPIE Symposium at San Diego, California, July 30, 1980.

J.B. Green, G.S. Kino, and B.T. Khuri-Yakub, "Focused Surface Wave Transducers on Anisotropic Substrates: A Theory Developed for the Waveguided Storage Correlator," Preprint (November 1980).

J.E. Rothenberg, J.F. Young, and S.E. Harris, "High Resolution XUV Spectroscopy of Potassium Using Anti-Stokes Radiation," to appear in Optics Letters August 1981 issue.

Rick Trebino, "Second-Harmonic-Generation Rings and Refractive-Index Measurement in Uniaxial Crystals," Applied Optics <u>20</u>, 12, 2090-2096 (15 June 1981).

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[*] Totally or partially

IV. INDIVIDUAL WORK UNIT RESEARCH PROGRESS

Unit 1

HIGH-T_c SUPERCONDUCTING WEAK-LINK JOSEPHSON JUNCTIONS AND CIRCUITS

M. R. Beasley
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A. Research Plan and Objectives

The underlying, long term objective of this program is to explore the feasibility of high-T_c and/or hard Josephson junction superconducting thin-film circuits; to establish the relevant physics, fabrication procedures, and operating characteristics of such devices; and hopefully to lay the ground work for a superconducting integrated circuit technology based on these materials. This objective requires the development of practical high-T_c and/or hard Josephson devices and also the passive circuits elements necessary for a complete circuit technology. Success in this program would lead to devices capable of operating at substantially higher temperatures ($\sim$ 10-15 K) and/or more rugged circuits resistant to damage due to thermal cycling, handling, and hostile field environments.

Toward this general objective we have been developing superconducting weak-link (i.e., non-tunneling) Josephson junctions using refractory and high-T_c superconducting materials and by necessity thin-film deposition, microlithography, and processing technologies suitable for such materials. Specifically we have been concentrating our efforts on the A15-type superconductors, for example Nb_3Sn ($T_c \sim$ 18 K) with related work on elemental $Nb(T_c = 9$ K) in order to more easily test some of our fabrication techniques.

From the theoretical point of view[1.1] when considering refractory
and high-T_c superconducting materials the most attractive type of
weak-link Josephson junctions appear to be planar SNS (superconductor/
normal metal/superconductor) or SSemiS (superconductor/semiconductor/
superconductor) bridges, although it must be noted that granular
superconducting weak links have recently shown interesting performance.[1.2]
A satisfactory theory of such devices has not yet been developed,
however, so it is hard to assess their relative advantages and
disadvantages. In this program we are focusing on SNS bridges.
These bridges are like the usual SSS superconducting microbridges
but where the bridge region itself is a normal metal while the banks
are superconductors. The rationale for such devices is that by
making the bridge region itself from a normal metal (e.g., Cu, Au,
or Ag) one can circumvent the extremely small (< 100 $\overset{\circ}{A}$) bridge
dimensions theoretically required to obtain ideal Josephson behavior
in a totally superconducting high-T_c bridge. In such SNS bridges
the dimensions need only be submicron and ideal Josephson behavior
should be available over the entire temperature range $0 < T < T_c$.

To achieve such structures in practice we have been using
electron-beam evaporation to make suitable thin-film bilayers (e.g.,
Nb_3Sn or Nb on top of Cu or vice versa) out of which the desired
submicron planar SNS (e.g., $Nb_3Sn/Cu/Nb_3Sn$) bridges are formed.

[1.1] K. K. Likharev, Rev. of Mod. Phys. 51, 102 (1979).

[1.2] See for example, J. H. Claassen, Appl. Phys. Lett. 36, 771 (1980).

The fabrication procedures are then appropriately modified in light of the observed electrical properties of the junctions. More specifically the problem is to fabricate a short ($\leq$ 1 μm) normal metal bridge connecting two superconducting banks while ensuring good contact at the S/N interfaces and not degrading the superconductivity (e.g., reducing T_c) of the banks through damage in the fabrication process. At the same time we have been developing theoretical models for such devices based on the Usadel, Ginzburg-Landau and Time-Dependent-Ginzburg-Landau Theories of superconductivity.

B.   Progress and Accomplishments

In the earlier phases of this project we explored various techniques for actually forming the desired submicron bridge structures and mastered the necessary lithography and etching procedures. Key to this work was our demonstration that plasma etching was an ideal processing technique. Specifically that it not only provided the desired spatial resolution and material selective properties but also that it did not damage the superconducting materials involved leading to a reduced transition temperature. With this technology we successfully produced Nb/Cu/Nb and Nb/Au/Nb bridges that exhibited good SNS behavior over the entire temperature range $0 < T < T_c \approx 9$ K. These devices were the best SNS Josephson devices made to date. The proved the refractory SNS device concept and allowed us to critically test the theory of such devices.

During the past year we have completed our theoretical analysis
of these devices and proceeded agressively toward our orignial goal
of a high-T_c SNS devices. Both have been successful. On the
theoretical side we have found that the usual idealized theory of
SNS devices developed by Likharev does not properly account for
the specific geometry and S/N interfacial properties encountered
in real bridges. By suitably modifying this theory we have developed
an improved theory that phenomenologically accounts very well
for the observed electrical properties of these devices, specifically
the magnitude and temperature dependence of the $I_c R$ product and
the I-V characteristics. Two papers describing the experimental
and theoretical aspects of this work have been submitted for
publication.[1,3] A microscopic justification for our phenomenological
approach will require further study.

On the experimental side we have finally succeeded in our
original objective of making high-T_c SNS microbridges. The crucial
new element required was the introduction of so-called "step-edge
patterning" in our processing to define the bridge length. The
idea here is to use a vertical step in the substrate (See figure)
and the shadowing effect off-normal-indicence angles of deposition
to deposit the two superconducting banks with a small gap (down
to $\approx$ 500 $\overset{\circ}{A}$) between them, followed by deposition of the normal
metal out of which the bridge can be formed by conventional

[1,3] R. B. van Dover, A. de Lozanne, R. E. Howard, M. L. McLean
and M. R. Beasley, Appl. Phys. Lett. 37, 838 (1980);
R. B. van Dover, A. de Lozanne, and M. R. Beasley, to be
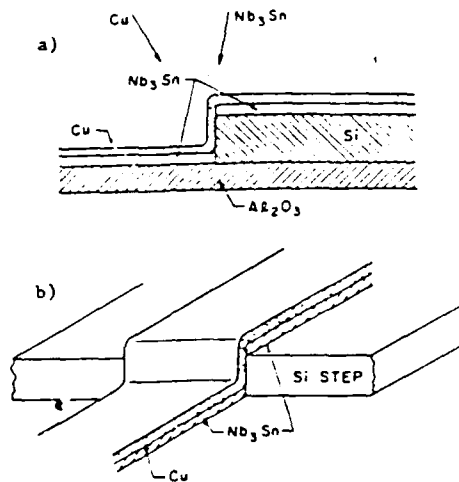published in Journ. of Appl. Phys.

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a)

b)

Fig. 1 Schematic of the $Nb_3Sn/Cu/Nb_3Sn$ micro-
bridges. a) Cross section. The film thicknesses
for the bridges reported here are, Cu:100nm,
Nb_3Sn:100nm and Si:126nm. The directions of eva-
poration are shown by the arrows on top. b) The
width of the bridge is approx. 3μm.

lithography. The use of step-edge patterning has solved two important problems. First it allows the fabrication of very short bridges in a controllable way. Second, since the bridge length is defined without etching, it permits one to put the normal metal on top where it can be deposited on the more favorable (upper) surface of the superconductor and avoids the deterioration of the normal metal film experienced previously when it was necessary to heat the film to high temperatures in order to deposit a good superconducting film on top. The resulting $Nb_3Sn/Cu/Nb_3Sn$ SNS microbridges have exhibited well-defined and robust Josephson behavior from 2 K up to 16.5 K. Occasional bridges have exhibited resistances up to 1 Ω and $I_c R_N$ products up to 1 mV which is outstanding performance for such devices.

C. Publications (under this JSEP Program)

Previously Reported

1. R.B. van Dover, R.E. Howard, and M.R. Beasley, "Fabrication and Characterization of S-N-S Planar Microbridges," IEEE Trans. on Magnetics MAG-15, 574 (1979).

2. R.B. van Dover, A. de Lozanne, R.E. Howard, W.L. McLean, and M.R. Beasley, "Refractory Superconductor S-N-S Microbridges," Appl. Phys. Lett. 37, 838 (1980).

Impending Publications

3. M.R. Beasley and C.J. Kircher, "Josephson Junction Electronics·
    Materials Issues and Fabrication Techniques," to appear in .he
    Proceedings of the 1980 NATO Summer School on the Science and
    Technology of Superconducting Materials, S. Foner and
    B. Schwartz, Eds., Sintra, Portugal.

4. R.B. van Dover, A. de Lozanne and M.R. Beasley, "S-N-S
    Microbridges: Fabrication, Electrical Behavior and Modeling,"
    submitted to Journal of Applied Physics.

5. A. de Lozanne, M. Di Iorio and M.R. Beasley, "Properties of
    High T_c SNS Microbridges," to be presented at the LT-16
    Conference, Los Angeles, California, August 1981.

Unit 2

ACOUSTIC SURFACE WAVE SCANNING OF OPTICAL IMAGES

G. S. Kino
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(J. B. Green)

A. Introduction

At the present time our work focuses on developing acoustic surface wave devices, utilizing the interaction between surface acoustic waves and charge carriers in a semiconductor. Most of our device designs involve the use of piezoelectric zinc oxide which is rf sputtered onto a silicon substrate. Due to the piezoelectric nature of the zinc oxide, electric fields are generated by the acoustic surface waves propagating along the device. These electric fields penetrate into the silicon substrate and interact with the charge carriers near the silicon surface.

Our work now centers around two types of devices:

(1) A programmable active delay line in which signals can be read into the device by means of a charge transfer device (CTD) on the silicon substrate underneath or adjacent to the ZnO layer. After programming the device in this way, we could then use the device in a wide variety of signal processing applications including, but in no way restricted to, adaptive and inverse filtering. This device is an excellent example of the uses to which sophisticated LSI technology can be put in sophisticated real-time applications involving real-time analog and digital signal processing.

(2) An acoustic surface wave waveguide storage correlator.

B. Progress and Accomplishments

We feel that a basic building block for surface wave correlators and programmable delay lines is a narrow, waveguided acoustic surface wave device. Narrow beamwidth devices possess an inherent advantage over wider beamwidth devices since the acoustic power density in the propagation path is proportionally higher, resulting in a more efficient device operation. Additionally, narrow beamwidth devices offer the advantage of high fabrication densities, which offer the potential of constructing two-dimensional devices for imaging and signal processing applications. The device which we have recently investigated is a $\Delta v/v$ waveguided monolithic ZnO on Si storage correlator. A device such as this offers the advantage of high efficiency and straightforward fabrication utilizing the techniques well familiar to those involved in standard IC processing.

The waveguide storage correlator, illustrated in Fig. 1, employs a piezoelectric ZnO layer deposited on Si. Interdigital transducers are used at each end of the device to inject or receive acoustic surface wave signals. In the central region, a row of $p-n$ diodes is fabricated in the silicon underneath the acoustic beam path and metal films (top plate electrode and waveguide metallizations) are deposited on top of the zinc oxide. Since the acoustic surface wave velocity is slightly lowered in the presence of the gold film, the surface wave tends to propagate only in the region defined by the gold films; therefore the waveguiding effect is achieved.

In order to understand the operation of this device, consider what happens when a short pulse of voltage V is applied to the top plate. The
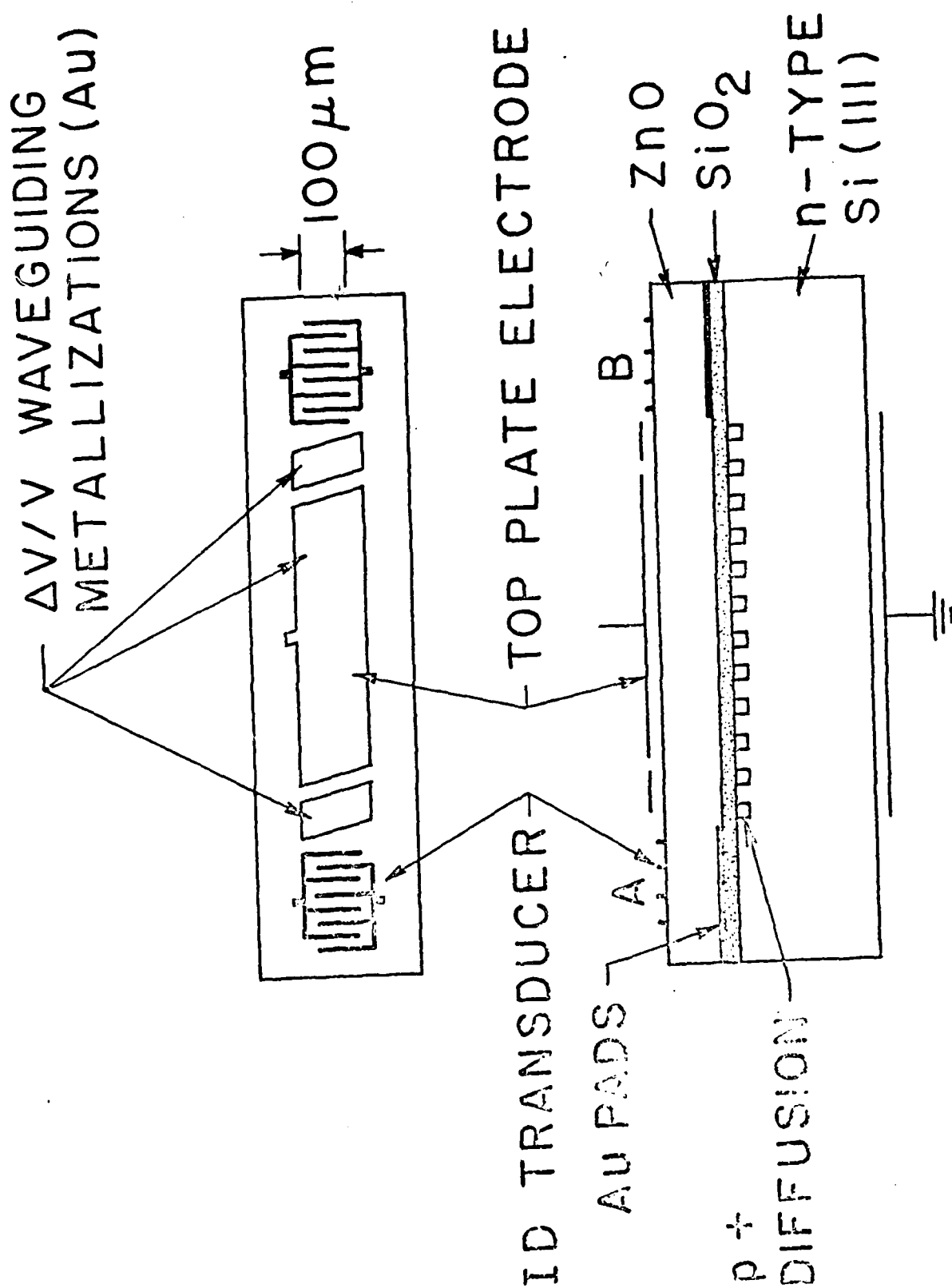
ΔV/V WAVEGUIDING METALLIZATIONS (Au)

100μm

TOP PLATE ELECTRODE

ZnO
SiO₂
n-TYPE Si (III)

B

A

ID TRANSDUCER

Au PADS

P⁺ DIFFUSION

Figure 1
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pulse "turns on" each diode so that the capacity between the top plate and an individual diode becomes charged to a potential close to V . After the pulse is turned off, the capacity remains charged. Clearly then the device can store an analog signal. If at the same time an acoustic surface wave signal is passing under the plate when the diode is turned on, the signal stored in the capacitor consists of the sum of the acoustic surface wave signal and the applied pulse. A spatial pattern of charge corresponding to the surface wave signal is stored along the length of the device. At a later time, a further "reading" pulse applied to the "top plate" turns on the diodes once more, but the potential at which they turn on depends on the signal stored in the capacitors. Thus, a spatially varying signal is excited along the length of the device which, in turn, excites acoustic surface waves which can be received on either interdigital transducer. If a more general form of reading signal is applied, the correlation of this signal with the original signal read into the device is obtained as an output from one transducer, and the convolution of the two signals is obtained from the other transducer.

The device itself has been operated in several different modes, but basically it functions as a highly flexible signal processing device which correlates signals either read into it at the same time or read into it at different times.

The results obtained from a waveguided correlator of this type have been extremely encouraging and showed a correlation efficiency F_T^{corr} = -53 dBm where F_T^{corr} is defined as

$$F_T^{corr} \equiv 10 \log (P_{e3}/P_{e1}P_{e2})$$

P_{e1}, P_{e2}, and P_{e3} are, respectively, the input acoustic power, the read-out power applied to the top-plate electrode, and the output power, all expressed in mW. This terminal correlation efficiency F_T^{corr} = -53 dBm is 13 dB better than that reported for any other Rayleigh wave ZnO on Si storage correlator. A paper on this device has been published in the Journal of Applied Physics.[1]

At the present time we are attempting to further improve the bandwidth and efficiency of the waveguided correlator by development of a new interdigital transducer design. This involves using a curved transducer approximately 1 mm wide to focus an acoustic surface wave beam into one end of the narrow waveguide (see Fig. 2). It has been necessary to develop a new theory for the design of a curved transducer which takes account of focusing in an anisotropic medium. Our design theory, presented at the 1980 Ultrasonics Symposium in Boston, Massachusetts, predicts to second order that the effective focal length of the curved transducer will shift in relation to the amount of parabolic anisotropy present in the medium of surface wave propagation.[2] Figure 3 shows most graphically the effect that the material anisotropy has on the focusing properties of the curved transducer by comparing the transducer SAW beam profiles both at the transducer's center of curvature (expected focal spot) and at the true focal plane. The parameter b is a measure of the material anisotropy and is defined by the parabolic approximation to the slowness curve:

$$k = k_0(1 + b\theta^2)$$

ΔV/V WAVEGUIDE METALLIZATION AND
TOP-PLATE ELECTRODE (Au)

1mm

100 μm
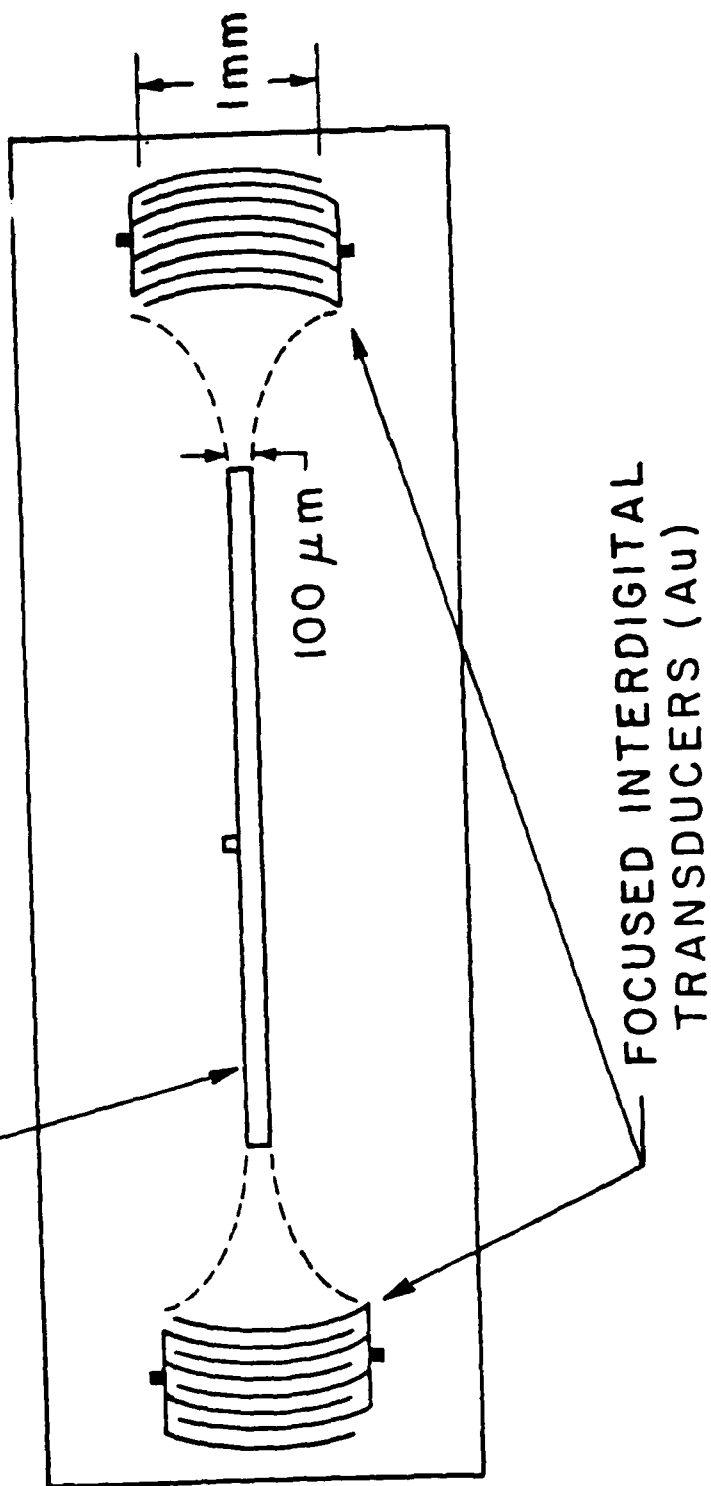
FOCUSED INTERDIGITAL
TRANSDUCERS (Au)

TOP VIEW OF FOCUSED IDT WAVEGUIDE CORRELATOR

Figure 2

TRANSVERSE RESPONSE AT CENTER OF CURVATURE
OF FOCUSED TRANSDUCER

b = 0.36
$\lambda = 32\,\mu$
R = 5 mn

TRANSVERSE RESPONSE AT FOCAL PLANE

b = 0.36
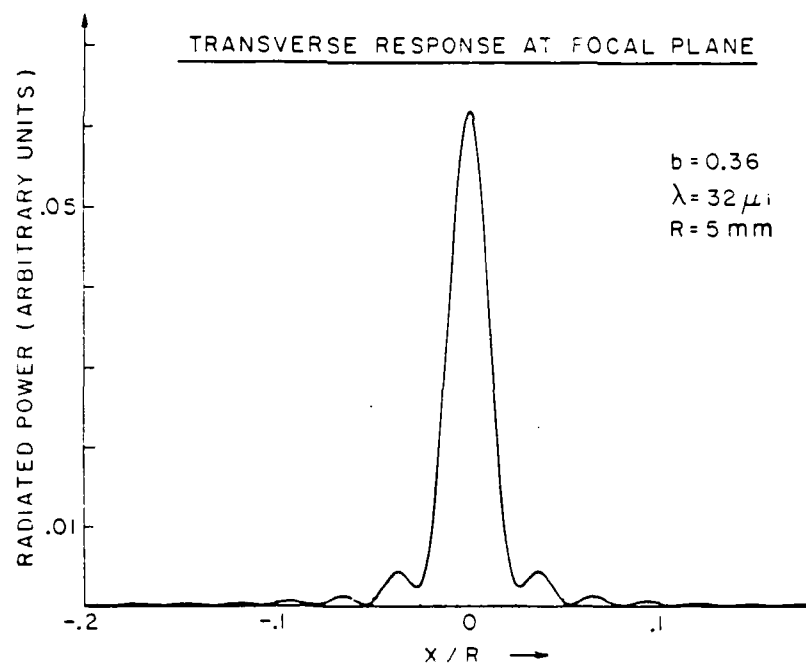$\lambda = 32\,\mu$i
R = 5 mm
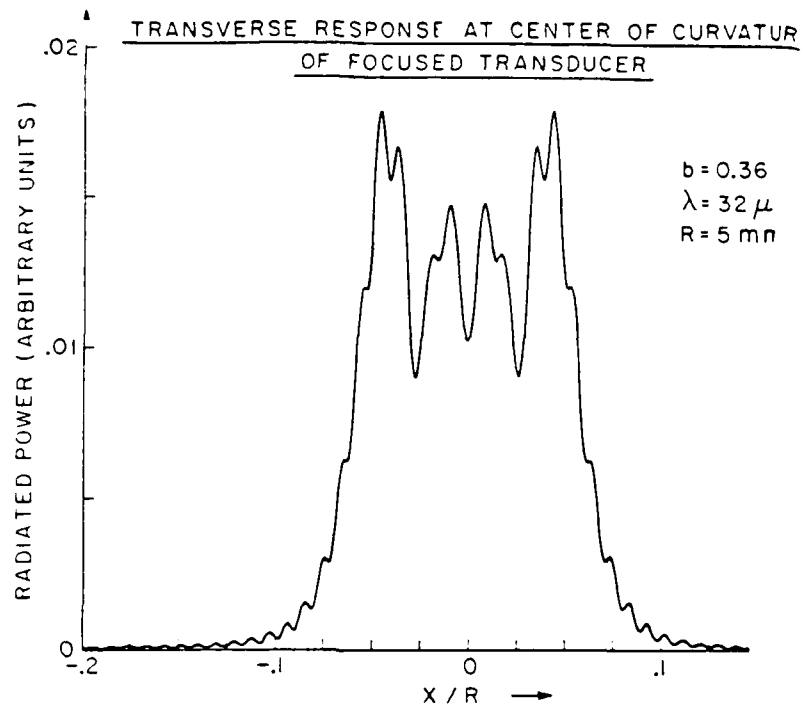
Fig. 3.

Figure 4 shows the radiated power contours for the same transducer design as in Fig. 3.

We have fabricated a $LiNbO_3$ elastic convolver using this focused transducer concept and have obtained very encouraging results. The convolver showed a convolution efficiency F_T^{con} = -73 dBm with an insertion loss of -20 dB . This higher than usual insertion loss is believed to be caused by inefficient waveguide excitation by the focused interdigital transducers.

In order that we may more accurately understand the mechanisms of loss in our surface acoustic wave convolvers and correlators, we have set up a laser system to probe our devices and provide us with a map of surface wave amplitude and phase at any point in the propagation path. The system is based on a Michelson interferometer where one arm of the interferometer has its optical length modulated by the surface undulations of the device under scrutiny. The optical beams in both arms of the interferometer are modulated using a Bragg cell in order to provide stability against spurious path length variations.

Programmable SAW-CTD Storage Device

The programmable delay line concept involves constructing an adaptable monolithic SAW filter which can be programmed from an external source. To do this, we intend to combine the features of the acoustic surface wave storage correlator and a charge transfer device (CTD) on one silicon substrate and therefore avoid the pitfalls of hybrid technologies which limit the number of taps which can be realistically employed.

RADIATED POWER CONTOURS FOR A FOCUSED TRANSDUCER

RADIUS OF CURVATURE R = 5mm
ANGULAR APERTURE α_1 = 0.2 RAD
λ = 32 μm
b = .36 [(11$\bar{2}$) PROPAGATION ON <111> Si]

X / R →

-0.2   0   0.2

-3dB CONTOUR
-6dB   "
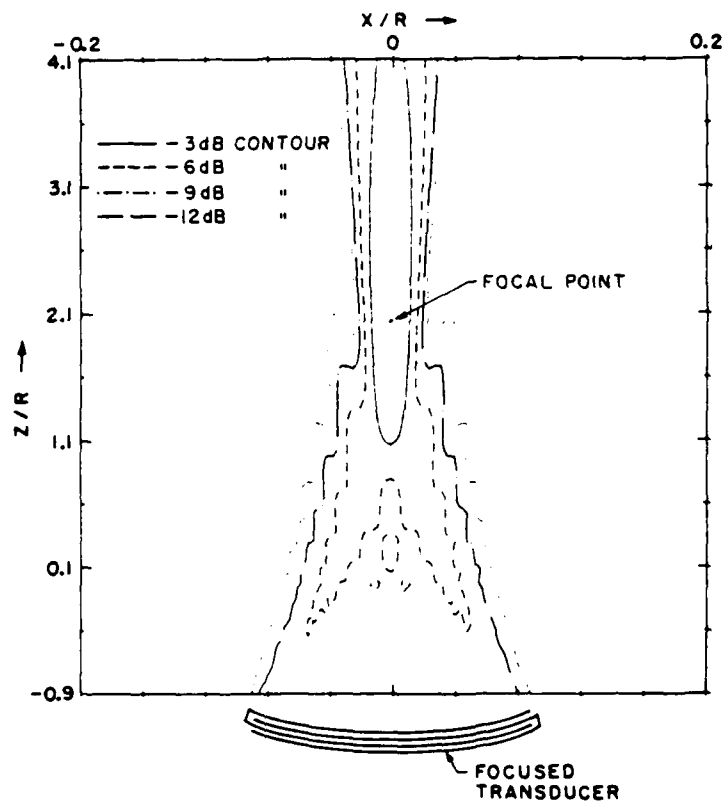-9dB   "
-12dB   "

FOCAL POINT

FOCUSED
TRANSDUCER

Fig. 4.

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The basic principles of operation of this device follow directly from that of the storage correlator. Figure 5 shows a simplified view of the device. We see here that it is very similar to the storage correlator except for the important difference that each diode is connected to a MOSFET, the drains of all the individual MOSFETS being connected to a common input-output line. The gates of the MOSFETS themselves are controlled by a shift register. We see that this device employs far more sophisticated semiconductor techniques than just the diffusion of simple diodes. It is capable of processing high-frequency signals (from the surface acoustic waves), while controlling the processing with relative low-frequency signals (by way of the shift register/multiplexer arrangement). It is also possible to use such a configuration as a system for reading in and processing a signal at high speed using surface acoustic waves and reading out the processed signal at low speeds using the CTD portion of the device.

At the present time, photo-sensitive devices have been developed which read out the charge produced by light incident on a row of diodes from an illuminating source, such as one line of a TV image. Thus, the basic devices exist which can switch from an input-output line to any one of a row of diodes.

One such commercial device which we experimented with is made by Reticon Corporation. This device (RL 512 S) is a solid state line scanner in which a series of 512 FET switches are used to connect individual diodes to an input-output line. These switches are addressed one after the other by a controlling signal inserted into a tapped shift register with one tap per switch. The beauty of using this sophisticated device lies in the fact that

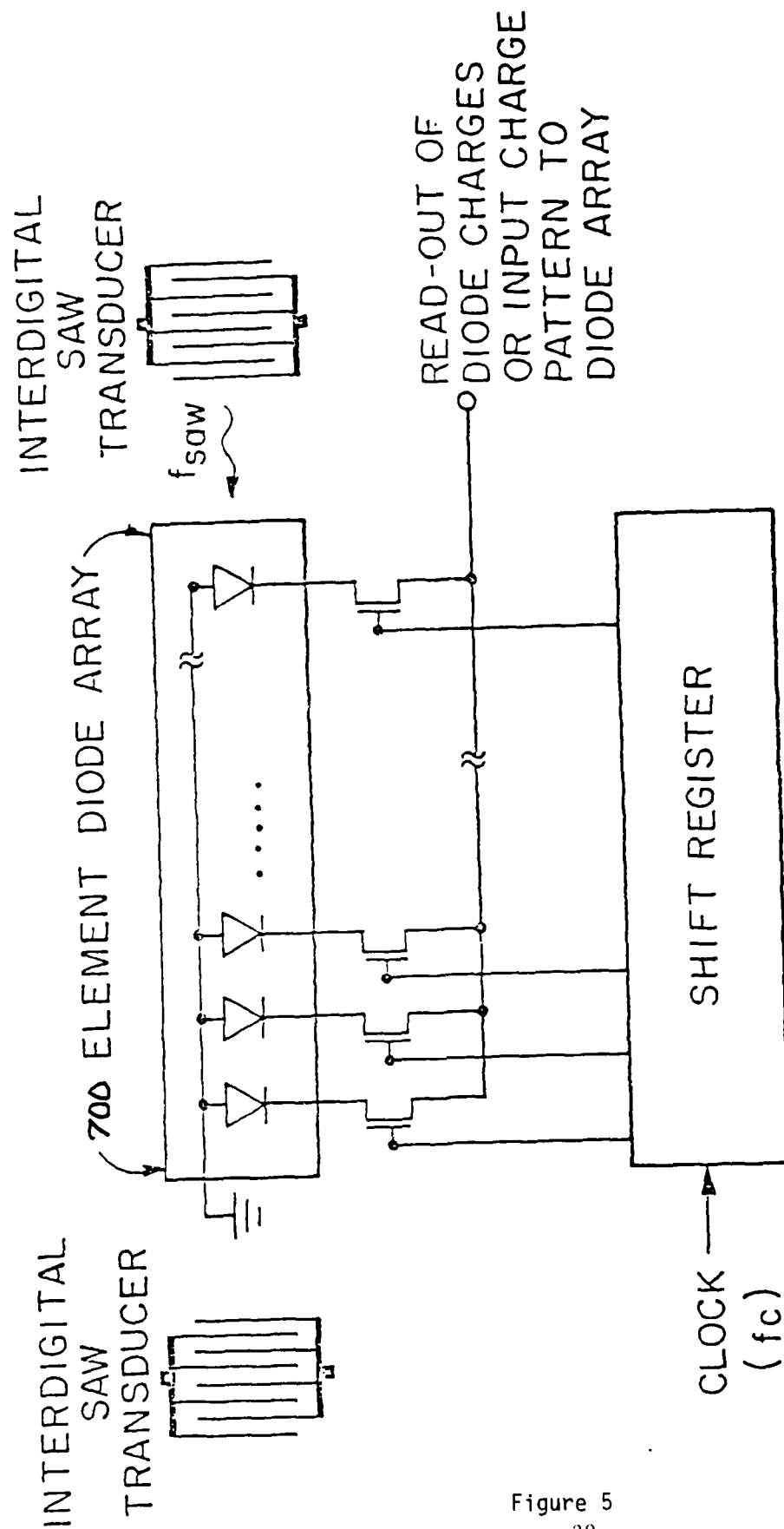INTERDIGITAL SAW TRANSDUCER

f_{saw}

READ-OUT OF DIODE CHARGES OR INPUT CHARGE PATTERN TO DIODE ARRAY

700 ELEMENT DIODE ARRAY

SHIFT REGISTER

CLOCK (f_c)

INTERDIGITAL SAW TRANSDUCER

$f_{saw} >> f_c$

SCHEMATIC OF SAW/FET DEVICE

Figure 5
- 29 -

in order to convert it to an adaptable SAW filter, we need, in principle, only to deposit a zinc oxide layer with a metal film laid on top of it (with associated surface wave transducers) on top of the diode array. Thus, we are not only able to read a signal into (or out of) the diodes at the surface wave frequency (64 MHz) but also address the diodes slowly at the frequency of the CTD multiplexer (less than 2 MHz).

As one simple example, we might read in a coded signal through the CTD into the diodes. This forms a set of taps with variable weighting on the acoustic surface wave delay line. Therefore, if a signal is read into the acoustic surface wave delay line and read out of the top plate on the high-frequency terminal, the device acts as a programmable tapped delay line. Thus, we should be able to make programmable filters, variable delay devices, etc. by reading a low-frequency analog signal into the device. As this low-frequency analog signal can in turn be controlled from a shift register or RAM through a D-to-A converter, we now have the possibility of constructing a range of coded surface wave devices whose codes are obtainable from a digital memory.

A major difficulty in using the Reticon device has occurred in our ability to deposit high-quality zinc oxide over the diode array. During the last year our zinc oxide technology has progressed to the point where we can reliably deposit extremely high-quality zinc oxide over thermally grown silicon dioxide, but we have experienced considerable difficulty in performing the zinc oxide deposition on top of the chemical vapor deposited (CVD) silicon dioxide as is found over the diode array on the Reticon device. This is due to the more irregular structure of the CVD silicon dioxide as compared to

thermally grown silicon dioxide. In order to surmount this unyielding problem with the Reticon device, we decided that it was in our best interest to pursue the development of our own, custom-made multiplexed FET arrays. With the invaluable aid of the Stanford Integrated Circuits Laboratory, we have developed an array that is much more suited to our previously established goals. By doing this we have accomplished several objectives:

(1) The Stanford device design has 700 taps as compared to the 512 tap Reticon device. An increase in the number of taps makes the device a more powerful signal processor;

(2) The tap spacing in the Stanford device has been reduced as compared to the Reticon device, thus allowing higher frequency (100 MHz) surface acoustic wave propagation.

(3) The Stanford device is fabricated in a way to insure complete compatibility with the acoustic surface wave concept. In other words, the topography of the device is well suited for the rf sputter deposition of a ZnO layer.

At the present time we feel that we are quite close to obtaining a fully operational SAW/FET. We have evaluated our zinc oxide films grown on the Stanford device design by way of x-ray diffraction scans and interdigital transducer impedance curves. The results of both of these diagnostic techniques lead us to believe that the Stanford SAW/FET is topographically compatible with the deposition of reasonably high-quality ZnO films.

Recently we have discovered that the ZnO sputter deposition lowers by approximately one volt the threshold voltage of the MOSFET's present in the shift registers of the SAW/FET. Although this has the effect of changing

enhancement mode transistors into depletion mode FET's, proper device operation can still be achieved by the application of a suitable offset to the substrate potential. We have in fact fabricated a SAW/FET complete with zinc oxide that has shown to work as a simple shift register, albeit only with strangely offset clock voltages. We feel though that this minor problem might be easily rectified by an improved silicon nitride passivation of the device prior to the zinc oxide deposition. Based on the above results, we feel very confident that we will have a completely operational device in a short period of time.

We believe that these concepts are merely the first of a wide range of devices which could be constructed with entirely new configurations and system architecture if the necessary LSI and VLSI silicon technology were available. We have described here, for instance, only a device controlled from a shift register input; a still more flexible valuable time delay signal processing device could be made if the control were directly made from a RAM input rather than the shift register. Yet other possibilities arise by using amplifiers in the acoustic analog system rather than passive diodes. Thus, with a sophisticated VLSI technology available, a new signal processing technique can be devised to carry out analog or digital signal processing in real time at relatively high frequencies (in the UHF range).

C. Publications and Papers Citing JSEP Sponsorship

1. J. B. Green, B. T. Khuri-Yakub, "A New Narrow-Bandwidth High Efficiency Zinc Oxide on Silicon Storage Correlator," J. Appl. Phys. 52 (1), January 1981, pp. 505-506.

2. G. S. Kino "Signal Processing with the Storage Correlator," presented at the SPIE Symposium at San Diego, California, July 30, 1980.

3. J. B. Green, G. S. Kino, and B. T. Khuri-Yakub, "Focused Surface Wave Transducers on Anisotropic Substrates: A Theory Developed for the Waveguided Storage Correlator," Proceedings of Ultrasonics Symposium (September 1980).

Unit 3

RESEARCH ON FIBER OPTIC INTERACTIONS WITH
APPLICATION TO HIGH SPEED SIGNAL PROCESSING

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(S. A. Newton)

A. Introduction

The aim of this project has been the study of optical fiber systems
for high speed signal processing. Our approach has been to work toward
the development of recirculating delay lines, and the key fiber optic
components that make these delay lines possible.

Systems of this kind (Fig. 1) have been developed using closed loops
of coaxial cable or waveguide as recirculating delay lines for the storage
of signals modulated onto microwave rf carriers. Such systems are used
for temporary storage and retrieval of broadband microwave signals in ECM
applications. Analogous systems using surface acoustic wave delay lines
at UHF frequencies have been developed,[1] and have been applied here earlier,
under a JSEP project, to signal processing operations.[2] Systems using bulk
acoustic wave delay lines have also been developed as transient memory
stores for digital signal processing.[3] In our present approach, the micro-
wave coax or waveguide delay line is replaced with a fiber optic waveguide,
with prospects for much larger bandwidth and delay time per circulation.

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[1] L. A. Coldren and H. J. Shaw, Proc. IEEE 64, 5, 598-609 (May 1976).

[2] C. M. Fortunko and H. J. Shaw, Trans. IEEE SU-21, 1, 40 (January 1974).

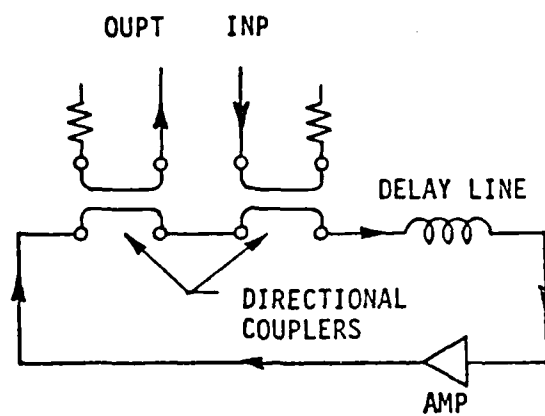[3] E. K. Sittig and J. F. Smits, Bell System Tech. Journal, 659 (March 1969).

- 35 -

Fig. 1--Schematic of recirculating delay line.

B. Approach

The approach is to use long, single mode optical fibers, taking advantage of the low attenuation available in such fibers (fractional dB per kilometer) for storing long signal trains. Fibers can be coiled with very large numbers of turns to provide a long propagation path occupying small volume and having very high information capacity and processing speed. Even with the existing attenuation one can get storage times of many microseconds. One hundred microseconds, for example, would correspond to perhaps 15 dB. With the use of optical amplifiers for recirculation of the signal, one can obviously do much better. Another project being conducted here under other sponsorship is concerned with developing optical amplifiers. However, even in the absence of an amplifier one can still get very interesting performance. Also, the exceptionally low dispersion per unit time delay in single-mode fibers means that extremely high data rates can be transmitted via single mode fiber. As a result, delay line devices that use single-mode fiber can have time-bandwidth products that greatly exceed those achievable in similar devices that use conventional technologies.

A key component required is a directional coupler suitable for single mode fibers, which can inject or extract a propagating signal in a fiber without breaking into the fiber. Such a coupler for fiber-to-fiber coupling, with controllable coupling and very low insertion loss, was developed earlier under the present contract.

C. Single Mode Fiber Recirculating Delay Line

The experimental delay line consisted of a single strand of single mode fiber of 200 meter length, which provides a delay of 1 μs per transit. The

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[4]R. A. Bergh, G. Kotler, and H.J. Shaw, Electronics Letters 16, 7, 260-261 (March 21, 1980).

directional couplers indicated in Fig. 1 are of the type demonstrated earlier under this program,[4] and which is now being further developed under another program in the laboratory. Basically, this device consists of two quartz substrates whose flat surfaces are mated face-to-face through a layer of oil. Each substrate carries a length of single mode fiber, a portion of whose cladding has been removed by mechanical polishing, exposing the evanescent fields of the fiber cores. Coupling between the two parallel and adjacent fibers takes place over a distance of approximately 1 mm, and is adjusted to any desired value by translating one substrate with respect to the other in the direction perpendicular to the fibers. Coupler loss is only a few percent.

The delay loop was closed upon itself by carefully cleaving the fiber ends, butting them together and using a drop of index matching oil to eliminate any discontinuity at the splice. The completed system is shown schematically in Fig. 2.

In order to test the system an electro-optic cell was used to pulse modulate a low power He-Ne laser (633 nm). The resulting short pulses (~ 2 ns width) were injected into the loop via the input coupler. The couplers are adjusted for a relatively low coupling which maximizes the number of circulations. Thus a large fraction of the input power is discarded at the input coupling point. However, that light which is coupled into the loop tends to remain there, subject to the losses encountered during each circulation: coupling and insertion loss at each coupler, coupling loss at the splice, and propagation loss around the loop. The output coupler samples the signal on each pass and guides it to the detector.

DELAY LOOP (1 μs)

SPLICE

INPUT →

DETECTOR

INPUT
COUPLER
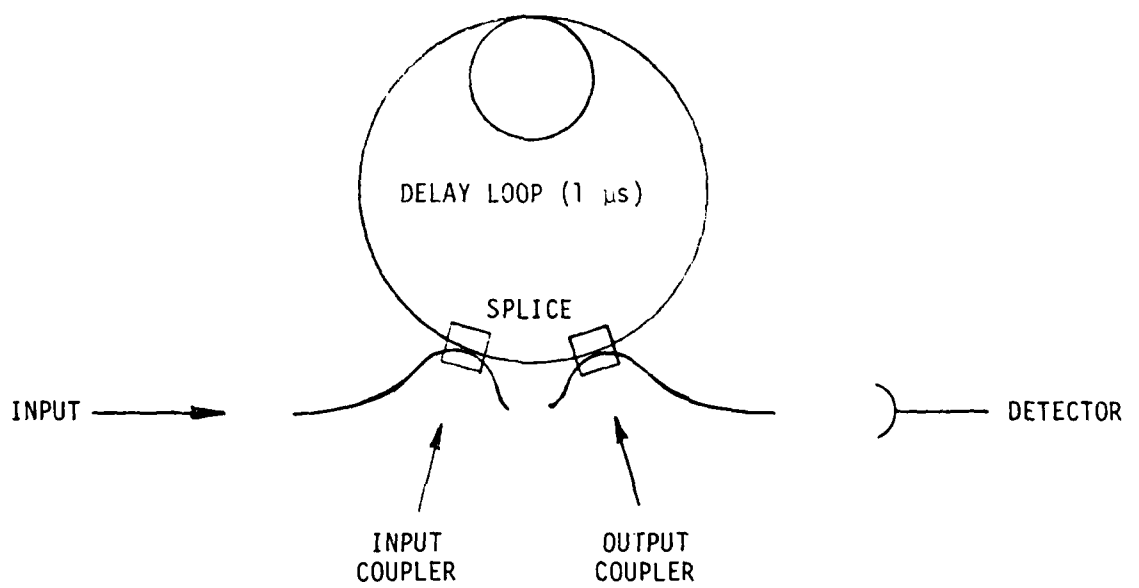
OUTPUT
COUPLER

Fig. 2--Schematic single mode fiber recirculating delay line.

This system shows a large improvement over the earlier hybrid system, giving the same number of observable recirculations, namely six, with a reduction in laser output power by a factor of 50. Furthermore, in the present system the limitation on circulations is not associated with the fiber circuitry, but with the laser source and detector system available when the measurement were made.

D. Conclusions

The use of integrated fiber optic circuitry has significantly improved the performance of the recirculating delay line, and forms the basis for future developments being carried out here under other support. More efficient detection and processing of the output signal are to be applied. Also, a significant amount of loss occurs at the fiber splice. The development of less lossy and more permanent methods of fiber splicing will greatly enhance the performance of this system as well as others that use single mode fibers. The injected input power for a given source could be greatly increased if the input coupler were switchable on a time scale that is short compared to the transit time around the loop. Such a switchable coupler is presently under study in this laboratory. The inclusion of an amplifier in the circuit to compensate for loop losses would greatly increase the circulation times and the utility of the device. Such a fiber amplifier is presently being developed in this laboratory under another program.

E. Publications and Papers Citing JSEP Sponsorship

1. R. A. Bergh, G. Kotler, and H. J. Shaw, "Single-Mode Fibre Optic Directional Coupler," Electronics Letters 16, 7, (March 27, 1980), pp. 260-261.

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Unit 4

NONLINEAR INTERACTIONS OF ACOUSTIC WAVES

WITH DOMAINS IN FERROIC MATERIALS

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A.   Introduction

Ferroic materials (ferromagnetic, ferroelectric and ferroelastic) have the unique property of exhibiting switchable configurational states with distinct macroscopic material properties. These states are not only switchable but also have a latching property, or memory. That is to say, once the material is switched it remains in the switched state until further addressed by an electric or mechanical signal. Furthermore, different regions of a single specimen of ferroic material may be in different configurational states. These regions of distinctly different configurational states, called domains exhibit distinct physical properties and the boundaries between domains, or domain walls, are therefore surfaces of abrupt change in material properties. The existence of switchable and latching boundaries of this nature provide a basis for a variety of optical and acoustical devices such as diffraction and phase matching gratings, directional couplers, filters and memory stores. The goal of this project is to study the nonlinear interaction of acoustic waves with domains (primarily in ferroelastics and ferroelectric-ferroelastics) with a view of gaining a better understanding of the physics involved and then evaluating the potential of such materials for new device applications.

The general research plan focuses on (1) the nonlinear acoustic properties of ferroic materials, particularly the influence of domain walls on these nonlinearities, (2) the influence of domain wall structure on acoustic parametric processes and harmonic generation and, (3) the interaction between a domain wall and the static forces generated by nonlinear elastic "rectification" of an acoustic wave. We are concentrating our efforts on two materials - gadolinium molybdate (GMO), a ferroelectric-ferroelastic, and neodymium penta- or ultra-phosphate (NPP), a pure ferroelastic.[4.1,4.2] The latter material, which is currently arousing great interest with regard to miniature infrared laser applications but is not commercially available, is being furnished to us in a cooperative effort by Dr. W. Zwicker of Phillips Laboratories. Another related activity at Stanford is being developed by the Crystal Technology Group in the Stanford Center for Materials Research. This concerns a new technique for growing thin single crystal fibers of ferroelectric and ferroelastic materials and studying the properties of domains in these fibers. We are currently continuing to interact closely with this group.

With regard to potential device applications of the materials and phenomena under study, these all involve the use of periodic arrays of grating, created and aligned by either the nonlinear acoustic methods referred to above or electrical poling techniques above the Curie temperature. Specifically of interest are acousto-optic diffraction gratings for signal processing, phase matching for collinear phase

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[4.1]H.P. Weber, B.C. Tofield, and P.F. Liano, Phys. Rev. B11, 1152 (1975).
[4.2]J.P. Budin, A. Milatos-Roufas, N.D. Chien, and G. LeRoux, J. Appl. Phys. 46, 2867 (1975).

matched optical harmonic generation and gratings for distributed feedback lasers. The latter aspect of the potential is of particular interest in connection with the miniature NPP lasers noted above.

B.   Progress and Accomplishments

In last years progress report it was noted that experiments on domain wall motion induced by a nonlinearly generated static elastic stress had not met with success. Three areas of basic investigation were proposed to explain and overcome these negative results: (1) a study of reasons why the threshold for domain wall motion might be higher than expected - i.e., because of material imperfections, edge cracks, and the fact that nonlinear stresses generated in the resonators used for the experiment are spatially nonuniform; (2) a detailed exami- nation of the nonlinear elastic properties of ferroelastic materials in order to base predictions of the intensity of the rectified elastic field on measured rather than estimated third order elastic constants; (3) reconsideration of the nature of the interaction of domain walls with the nonlinear elastic field.

During the reporting period March 1980 to March 1981, attention has been focused on item (2) above, on preparing our own samples of GMO in both boule and fiber form, and on improving our technology of resonator fabrication. With regard to items (1) and (3) and also to advancing basic physical knowledge of nonlinear elasticity in ferroelastics, it has been arranged for a visiting scientist specializing in ferroic materials, P. Toledano of the University of Picardie, to spend six months at Stanford (July through December 1981). As a guide to future experiments, he will perform fundamental calculations on third order

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elastic constants and domain wall motion in ferroelastics.

(i)   Third Order Elastic Constants in Ferroelastic Materials

The reason for expecting unusual nonlinear elastic effects
in a ferroelastic material is very simple. It is based on consideration
of the free energy as a function of the strains. Since the elastic
constants are equal to the various second derivatives of the free energy
with respect to the strains, the level of elastic nonlinearity can be
quickly estimated from the shape of the free energy curves. In particu-
lar, a purely parabolic curve has constant second derivatives and,
therefore, strain-independent elastic constants. The free energy func-
tion of a ferroelastic has a double minimum, corresponding to its two
equilibrium states, and should therefore be strongly nonlinear. These
elementary considerations are complicated by the fact that a ferroelas-
tic may be either proper or improper, depending on the nature of the
order parameter of the ferroic transition (i.e. mechanical or
electrical). Furthermore, even in a proper ferroelastic (such as NPP),
the order parameter may be an internal optical mode displacement rather
than elastic strain and this should have a substantial effect on the
degree of elastic nonlinearity. These questions have been discussed
with Prof. G.R. Barsch of The Pennsylvania State University, who has
studied nonlinear elasticity both theoretically and experimentally in
some of the intermetallic ferroelastics. It is verified by his work
that these particular ferroelastics do exhibit unusually large third
order elastic constants. As yet, no corresponding studies have been
made of ferroelastic insulators (such as NPP, a proper ferroelastic, and
GMO, an improper ferroelastic).

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Pending the arrival of Prof. Toledano, a purely experimental study of the nonlinear elastic properties of GMO and NPP has been initiated. Basic measurement methods for determining third order elastic constants are observation of changes in the second order constants as a function of hydrostatic pressure, and observation of acoustic wave second harmonic generation (SHG). The second approach, followed here, uses either the standard traveling wave method or a resonator method developed under this program. In the traveling wave technique an acoustic delay line is fabricated from the material under study, with the fundamental and second harmonic outputs detected by means of a capacitive pickup. The newly developed resonator technique has two advantages from our point of view: (1) it is more sensitive because of resonance build up of the second harmonic signal, and (2) it measures nonlinearity in the presence of sample boundaries, as required for domain wall interation experiments.

Several acoustic SHG experiments have been performed during the past year. Two resonators were fabrication in order to test the resonant SHG concept - a face-shear mode quartz resonator and an extensional mode PZT (lead zirconate titanate ceramic) resonator. In the first case no second harmonic was observed because the electrode design provided insufficient coupling to the second harmonic resonance. The PZT resonator, on the other hand, showed a strong harmonic output. Subsequent to this work, during the stay of a visiting scientist Dr. D. Hauden from one of the National Research Center Laboratories in France, the idea was conceived of using a laser probe to measure directly the fundamental and second harmonic acoustic displacements at the surface of the sample. This is a modification of the capacitive pickup technique mentioned

above, but with a number of practical advantages. It does not require critical mechanical assembly, it is adaptable to any traveling wave or resonant sample geometry, and it allows remote probing of a sample placed in an oven or cryostat - an important feature for the study of materials with a ferroelastic phase transition. Attempts to realize this new experimental method led to the invention of a novel phase-heterodyning technique for isolating the second harmonic signal generated acoustically in the crystal. In essence, the optical probe technique is based on phase modulation of a laser beam reflected from the vibrating acoustic sample. Since phase modulation is a nonlinear process, harmonics of the acoustic drive frequency are generated by the modulation process, as well as by elastic nonlinearity in the sample. The method developed for separating these contributions involves secondary phase modulation of the light beam by a "local oscillator" frequency, using an electro-optic modulator. This produces mixed frequency side bands of the desired signal, which can be separated by the following electrons. (In June 1981 the method was successfully realized with the PZT resonator referred to above and is the subject of a publication submitted to Electronics Letters.)

(ii)   Composite Resonator Design and Fabrication

Observation of nonlinear domain-wave interactions in a ferroelastic resonator requires choice of a geometry favoring both domain wall motion and simple standing wave resonances. This choice is complicated by the fact that ferroelastics have low order crystal symmetries and, consequently, complicated elastic behavior. Since domain walls are most easily injected and displaced in thin plate samples, this

geometry was selected for study, with the elastic vibration spectrum analyzed by Mindlin theory.[4.3] Figure 1 shows a mode spectrum for NPP. This is typical of plate resonator spectra for other materials and illustrate the three types of resonance modes encountered: (1) Extensional E, (2) Flexure F, and (3) Width Shear. The two mode-types of interest are flexure and width shear, since only these have a shear strain component that interacts strongly with the domain wall. Earlier work on this program was directed toward use of the width shear mode for domain-wave interactions. It is clear from the figure, however, that the flexure family has much cleaner behavior, and the resonators currently under study are all of this type. Since NPP is a nonpiezoelectric crystal, it can be used only in a composite resonator structure - with some suitable piezoelectric driver attached to it. This has been realized by bonding a thin elongated plate Lithium Niobate (LN) resonator to the NPP resonator, Fig. 1, thereby effecting a coupling between the modes of the two plates. Figure 2 illustrate this coupling by comparing the resonance frequency of the uncoupled LN plate with that of the LN-NPP composite. It is seen that the coupled NPP resonances are clearly visible.

(iii) Crystal Growth

Crystals of NPP used in this work are provided to us in a cooperative effort with Dr. W. Zwicker of Phillips Laboratories. During the past year we have embarked, in collaboration with Dr. R. Feigelson of the Stanford Center for Materials Research, on a program of growing *our own* GMO. This latter activity has two parts; one the growth of

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[4.3] P. Lee, J. Appl. Phys. **42**, 4139 (1971).
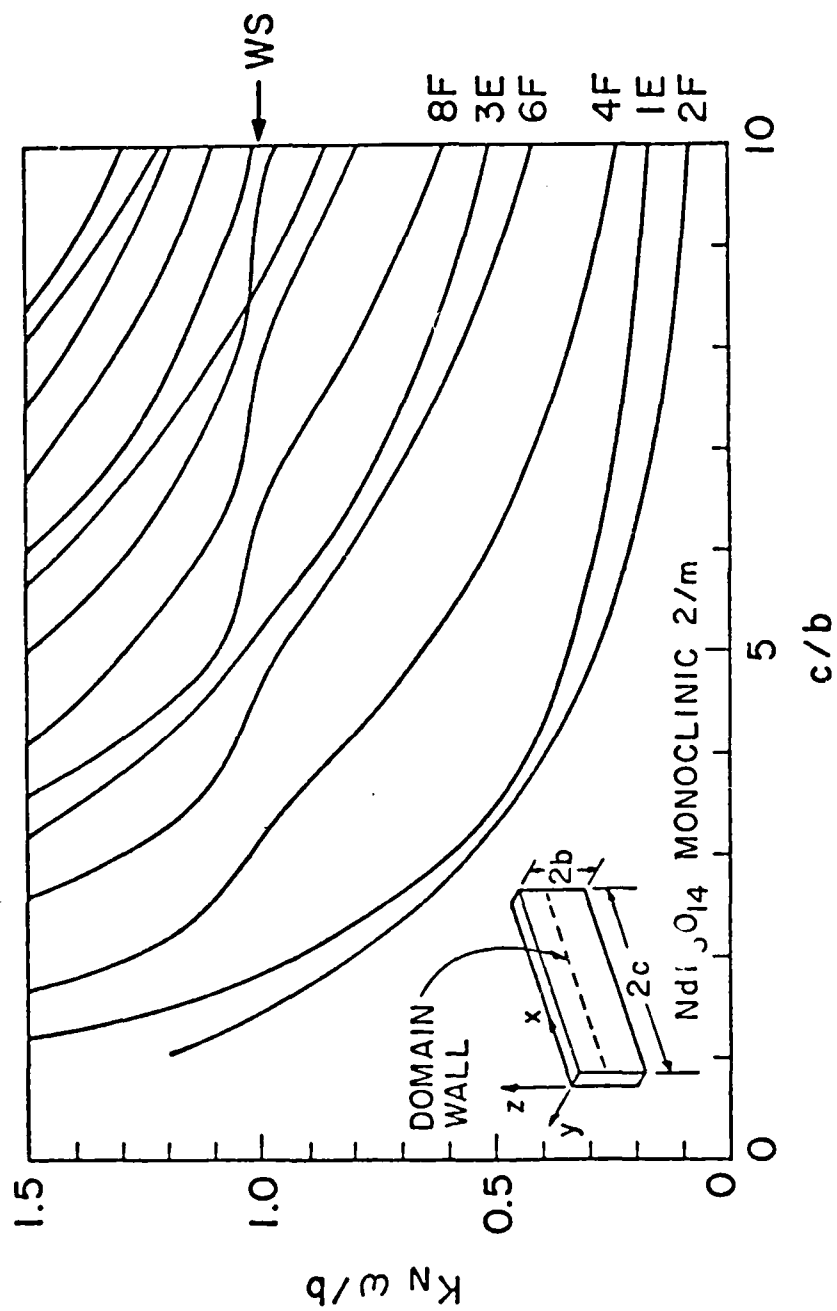
Fig. 1.—Theoretical frequency spectrum of extensional, flexure and width shear modes in a thin plate NPP resonator.
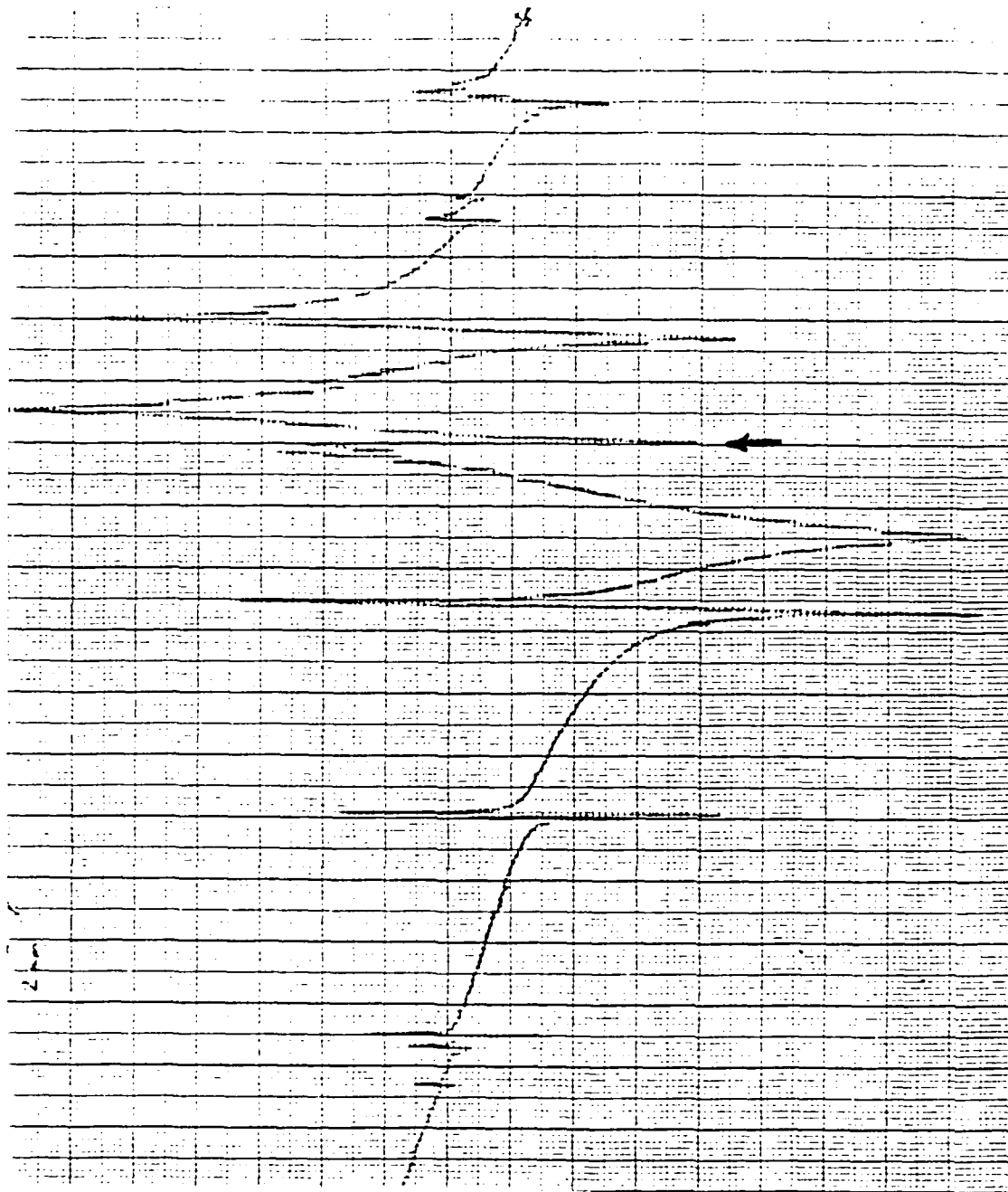
Fig. 2(a)--Measured frequency spectrum of a Lithium Niobate (LN) thin plate resonator in the configuration of Fig. 1 with c/b = 1.

Coupled
LN-NPP
Resonance

Fig. 2(b) --Measured frequency spectrum of an NPP resonator with c/b = 5 bonded to the LN driver resonator of Fig. 2(a). Comparison of the two curves shows NPP resonances superposed on Fig. 2(a).
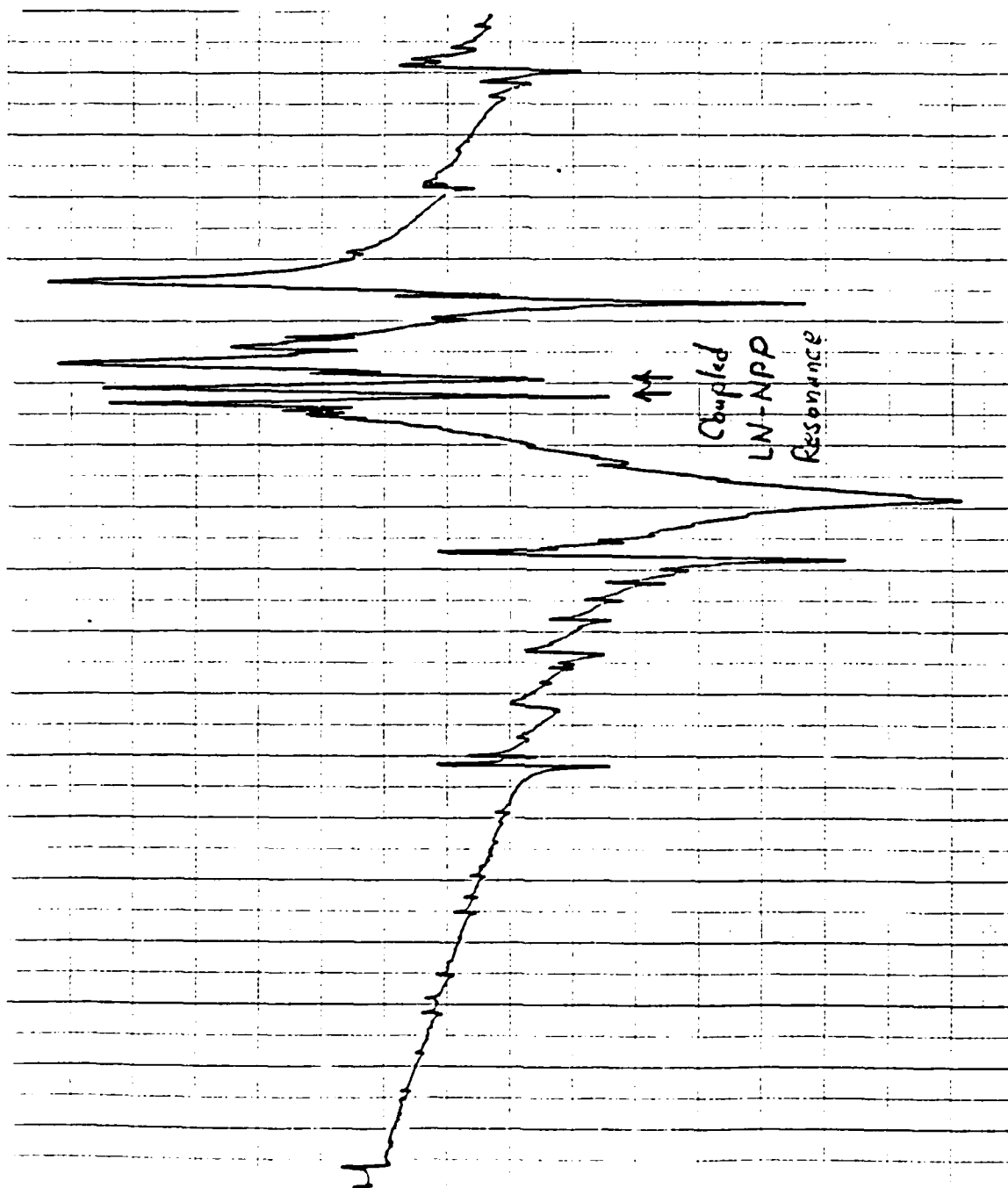
boules by the standard Czochralski method and the other the growth of single crystal fibers by a laser melting and pulling technique. During the year, ten GMO boules were grown, attempting to reproduce and adapt to our laboratory the procedure described by Brixner[4.4] Quality improved generally but the process is not yet under control with respect to simultaneous control of the problem areas: diameter control, interface shape, cellular growth, and precipitates.

The GMO fiber growth activity, related to a general program on single crystal fibers at Stanford, is motivated by a desire to avoid some of the difficulties in Czochralski growth and also, by directly preparing samples in small cylindrical geometries, to avoid some of the difficult subsequent steps required in preparing small ferroelastic devices. Since GMO is electro-optic, as well as ferroelastic, it has the additional attraction of being a candidate for optical fiber devices. Several fibers have been pulled from a GMO seed but examination showed that they were highly nonuniform. This was found to be due to noncongruent melting, with the molybdenum evaporating rapidly in the laser heating. Several techniques have been tried for maintaining excess molybdenum, including fabrication of a seed with a solid molybdenum core. None of these has been successful and a solution will be looked for by using a hot-pressed powder seed with molybdenum enrichment. It should be noted that these difficulties are not unexpected, as GMO is the first noncongruently melting crystal attempted under this fiber growth activity.

[4.4]L.H. Brixner, J. Crystal Growth 18, 297-302 (1973).

C. Publication and Papers

Impending Publications

1. B.A. Auld, S. Ayter, M. Tan and D. Hauden, "Filter Detection of
    Phase-Modulated Laser Probe Signals," submitted to Electronics
    Letters, July 1981.

2. B.A. Auld and M. Fejer, "Elastic Nonlinearity and Domain Wall
    Motion in Ferroelastic Crystals," to be presented at tre Fifth
    National Meeting on Ferroelectricity, The Pennsylvania State
    University, August 17-21, 1981.

Unit 5

MEASUREMENTS OF ULTRAFAST

PHYSICAL PHENOMENA

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(Rick Trebino)

A. Introduction

The general objective of this group is to develop and apply new laser

methods for the measurement of ultrafast physical, chemical and biological

processes - an area which has come to be known as picosecond spectroscopy.

The particular objective of this project is to demonstrate and make use

of a novel technique we recently proposed[1] which should permit the

measurement of sub̲picosecond physical phenomena using a tunable laser-

induced grating method.

Over the past few years our group has successfully measured several

ultrafast processes (partially under JSEP support) using picosecond

laser pulses in a transient laser-induced grating technique.[2-7] In this

pulsed technique two picosecond pulses from the same laser arrive at an

experimental sample at the same time, but from two different directions,

creating a transient interference pattern and producing a transient

hologram or grating of excited states in the sample. The diffraction of

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5.1 A.E. Siegman, "Proposed Measurement of Subpicosecond Excited-State
Dynamics Using a Tunable-Laser-Induced Grating," Appl. Phys. Lett. 30,
21-23 (15 January 1977).

5.2 D.W. Phillion, D.J. Kuizenga, and A.E. Siegman, "Rotational Diffusion
and Triplet State Processes in Dye Laser Solutions," J. Chem. Phys. 61,
3828 (1 November 1974).

a separate variable-delay probing pulse by this grating is then measured as a function of the delay between excitation and probe pulses. By observing the diffracted intensity versus delay time in this manner, we have measured both fast relaxation times and orientational rotation times (10^{-8} to 10^{-11} sec) in organic dye molecules,[2,3] and also fast transport or diffusion processes of excited electronic states in organic molecular crystals.[4,5] Very interesting microwave acoustooptic effects have also been observed.[6]

Many important physical processes have characteristic times in the subpicosecond range. In the <u>tunable</u> laser-induced grating technique being developed under this project the excitation beams are cw (or long-pulse) lasers which have an adjustable frequency difference f_d between them, with f_d in the $0.1 - 100$ cm^{-1} range. These two beams produce a moving interference pattern, whose fringes sweep through the sample at the frequency f_d. The excited-state pattern induced in the sample then follows or does not follow these moving fringes, depending upon whether the excited state response time τ is short or long compared

[5.3] Donald W. Phillion, Dirk J. Kuizenga, and A.E. Siegman, "Subnanosecond Relaxation Time Measurements Using a Transient Induced Grating Method," Appl. Phys. Lett. <u>27</u>, 85 (15 July 1975).

[5.4] D.D. Dlott, M.D. Fayer, J.R. Salcedo, and A.E. Siegman, "Energy Transport in Molecular Solids: Application of the Picosecond Transient Grating Technique," in <u>Picosecond Phenomena</u>, edited by C.V. Shank, E.P. Ippen, and S.L. Shapiro, Springer-Verlag, Berlin, 1978, 240-243.

[5.5] J.R. Salcedo, A.E. Siegman, D.D. Dlott, and M.D. Fayer, "Dynamics of Energy Transport in Molecular Crystals: The Picosecond Transient Grating Method," Phys. Rev. Lett. <u>41</u>, 131-134 (10 July 1978).

[5.6] J.R. Salcedo and A.E. Siegman, "Laser Induced Photoacoustic Grating Effects in Molecular Crystals," IEEE J. Quant. Electr. <u>QE-15</u>, 250-256 (April 1979).

to the frequency f_d. In particular, for $f_d > 1/\tau$ the excited states will not be able to follow the moving fringes. The grating pattern will then be washed out, and the probe diffraction will disappear. The "break frequency" in a plot of diffracted probe intensity versus difference frequency f_d between the excitation beams should yield the time constant τ. For simple cases the relation between lifetime and break frequency is

$$f_d(cm^{-1})\tau(psec) \approx 5.3 \quad .$$

Thus, a time constant of 0.1 psec (100 femtoseconds) corresponds to 50 cm^{-1} of tuning, which is easily achieved with modern dye lasers. This technique should become most useful just where conventional pico-second or subpicosecond pulse techniques become impossibly difficult.[7]

B. Progress To Date: Theory

We are planning to apply the tunable laser-induced grating method eventually to a wide variety of physical systems, including:

-- rotational and fluorescent lifetimes in organic dye solutions and in large molecular complexes.

-- excited-state and carrier lifetimes in semiconductors.

-- exciton diffusion processes in one-dimensional organic crystals.

-- vibrational relaxation processes in liquids.

-- lifetime measurements in dyes used for laser Q-switches mode-lockers, and optical Kerr cells.

5.7 A.E. Siegman, "Grating Spectroscopy," Invited paper, Conference on Dynamical Processes of Excited States in Solids, Madison, Wisconsin, June 18-20, 1979.

We have reviewed the literature on subpicosecond phenomena[8] in these

systems. Of particular interest to us initially are organic dye

solutions and semiconductors. We thus plan to do our initial experiments

with a dye solution and then focus on obtaining important results relevant

to semiconductor physics.

An advantage of the tunable laser induced grating method over similar

recently proposed methods[9,10] is its inherent flexibility: three separate

lasers of different wavelengths produce the excitation and probe beams while

other techniques provide for only two separate wavelengths. As a result

many beam geometries are possible. The most commonly used and best

understood beam geometry in grating experiments - involving all nearly

copropagating beams (see Fig. 1a) - proved problematic in our preliminary

experiments because of obscuration of the weak signal beam radiation by

Rayleigh-scattered pump beam light. We have performed an in-depth theoretical

analysis[11] of all possible beam geometries that result in phasematched

5.8 Erich P. Ippen and Charles V. Shank, "Sub-Picosecond Spectroscopy,"
Physics Today, 41-47 (May 1978).

5.9 T. Yajima, "Nonlinear Optical Spectroscopy of an Inhomogeneously Broadened
Resonant Transition By Means of Three-Wave Mixing," Opt. Comm. 14, 378-382
(July 1975).

5.10 J.J. Song, J.H. Lee, and M.D. Levenson, "Picosecond Relaxation Measure-
ments by Polarization Spectroscopy in Condensed Phases," Phys. Rev. A17,
1439-1447 (April 1978).

5.11 Rick Trebino, James P. Roller, and A.E. Siegman, "Beam Geometries in
Four-Wave Mixing and Induced Grating Experiments," to be published. (This
work was also partially supported by the Air Force Office of Scientific
Research).

(a) Forward probed, small excitation-beam-angle

(b) Backward probed, small excitation-beam-angle

(c) Large excitation-beam-angle (Forward vs. backward probe direction is unimportant for this type of geometry)
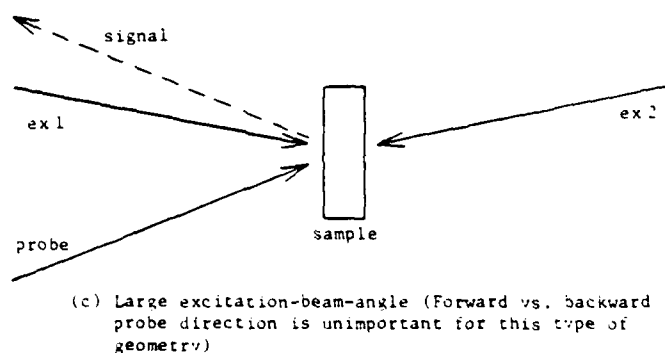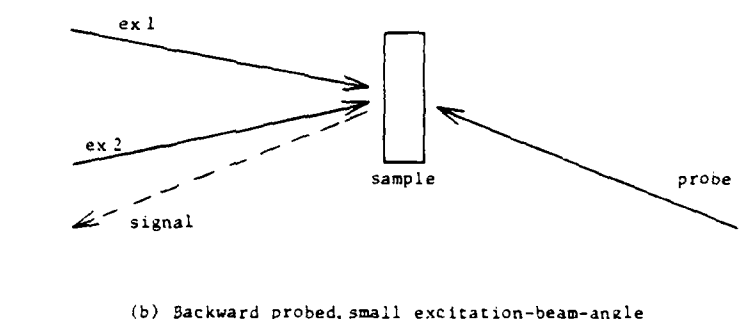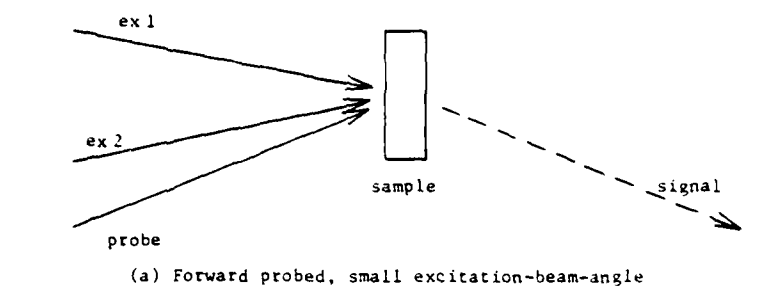
Fig. 1: Beam geometries in four-wave mixing and induced-grating experiments. Ex 1 and ex 2 refer to excitation beams that form the grating. The probe beam diffracts off this grating to produce the signal beam. Each figure is representative of a class of geometries

interactions in four-wave mixing and induced-grating experiments.
We have found the appealing geometry (see Fig. 1b) that employs nearly
copropagating excitation beams to form a grating which is probed by a
nearly counterpropagating probe beam (used effectively in transient
grating studies[2-7] to reduce scattered excitation beam light) to be
inappropriate for our technique due to probe beam Bragg-angle variation by
a large amount as the excitation beam frequency difference is scanned, a
phenomenon we have termed "Bragg angle instability." Our analysis has
further revealed that a class of geometries employing nearly counter-
propagating excitation beams (see Fig. 1c) offers many advantages over the
previously mentioned geometries with respect to the problems of scattered
light, Bragg angle instability, and alignment difficulty. An additional
problematic effect, the formation of thermal gratings,[12] can result in
enhanced signal intensity for stationary gratings and, possibly, to spurious
results. The above class of geometries allows very closely spaced grating
fringes so that thermal diffusion can significantly reduce the contribution
to the signal intensity of thermal gratings (particularly in solids)
yielding more easily interpreted results.

C. Progress To Date: Experiment

Dye Laser Development

Three YAG-pumped pulsed dye lasers employing a design developed at
Rice University (see Fig. 2), which uses a reflective beam

[5.12] E.J. Heilweil, R.M. Hochstrasser, and H. Souma, "Application of the
Phase Conjugate Configuration in Nonlinear Spectroscopy," Opt. Comm. 35,
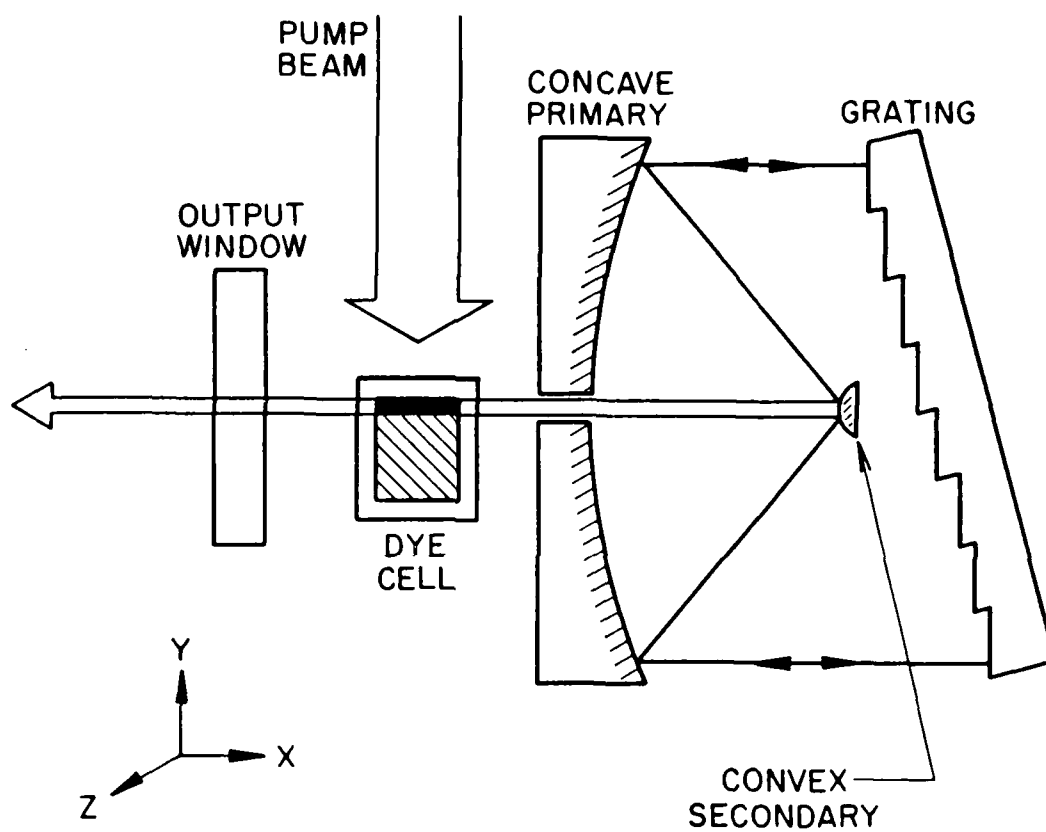227-232 (Nov. 1980).

Fig. 2:   Schematic diagram of the Cassegrain
dye laser

expander[13] and a grating in the Littrow configuration, were first built
but found to be inadequate for our purposes due to several unforeseen
design flaws. These flaws, many of which were observed during high
power operation (required for our experiments), included the need to
replace optics during wavelength scans, a diffraction grating damage
mechanism during alignment, and all drawbacks of the Hänsch design[14]
including alignment difficulty, the presence of much amplified spontaneous
emission, and inefficiency due to long cavity length.

We have since set up several pulsed dye laser designs in our laboratory
for the purposes of comparison on more than a dozen performance parameters.
A resulting publication[15] reviews the state-of-the-art of pulsed dye
laser engineering and indicates that the best overall design is the recent
achromatic-prism-beam-expander design of Klauminzer,[16] while the inexpensive
and easy-to-align grazing-incidence design[17] offers extremely narrow linewidth
at a cost in efficiency. We have found that a slightly less oblique grating
incidence angle results in significantly improved efficiency in the grazing-
incidence design with, for our purposes, a tolerable increase in linewidth.
In addition, the use of holographic gratings with skewed-gaussian groove

5.13 E.J. Beiting and K.A. Smith, "An On-axis Reflective Beam Expander for
Pulsed Dye Laser Cavities," Opt. Comm. 28, 355-358 (March 1979).

5.14 T.W. Hänsch, "Repetitively Pulsed Tunable Dye Laser for High Resolution
Spectroscopy," Appl. Opt. 11, 895-898 (April 1972).

5.15 Rick Trebino, James P. Roller, and A.E. Siegman, "A Comparison of the
Cassegrain and Other Beam Expanders in High-Power Pulsed Dye Lasers,"
submitted for publication in J. Quant. Electron.

5.16 G.K. Klauminzer, U.S. Patent No. 4,127,828 (Nov. 28, 1978).

5.17 M.G. Littman and H.J. Metcalf, "Spectrally Narrow Pulsed Dye Laser
Without Beam Expander," Appl. Opt. 17, 2224-2227 (July 1978).

shape developed recently by Jobin-Yvon has further improved the performance of the grazing incidence design, and therefore we have converted back to it with these modifications.

Grating Experiments

We have now performed preliminary grating experiments in the liquid samples CS_2 and the organic dyes DODCI and Rhodamine 6G. Stationary gratings have been induced and probed with .5 mJ of tunable dye laser radiation in the range 560-590 nm and also with 10mJ of fixed-frequency radiation at 532 nm. Signal beams were detected, and diffraction efficiencies on the order of 10^{-4} were observed with 532 nm excitation radiation and 10^{-5} with the less intense 560-590 nm excitation radiation. Gratings induced with one color have been successfully probed with another distinct color. We are at present attempting to detect much weaker diffracted signals from moving gratings formed by excitation beams from two separate dye lasers as required by the technique in order to measure ultrashort lifetimes.

D. Additional Work: Second-Harmonic-Generation Rings
and Refractive Index Measurement

The non-collinear phasematching requirement in the four-wave mixing/ induced grating interaction is similar to interactions in second-harmonic-generation (SHG) in which non-collinear three-wave mixing occurs. The most common example of such mixing in SHG involves the k-vector of the main (unfocused) fundamental beam mixing vectorially with a (scattered) off-axis fundamental wave to yield, in a phasematched manner, a relatively strong second harmonic wave. Many scattered wave directions yielding phase-matched SHG usually exist giving rise to interesting ring-shaped patterns near the spot of the main beam on an observation screen. In a type II SHG

crystal, as many as three off-center rings can be observed simultaneously (see Fig. 3).

These rings have been understood since 1962 when Giordmaine[18] treated a simple special case. We have catalogued and derived simple expressions for the ring centers and radii for all of the non-collinear ring-producing processes for both positively and negatively birefringent uniaxial SHG crystals.[19] We have also observed that measurements of these parameters for various values of the crystal tilt angle will yield extremely accurate relative values (better than one part in 10^6) for the four relevant crystal indices of refraction. The important quantity, the temperature derivative of the difference between ordinary and extraordinary indices of refraction of a crystal is particularly easy to obtain with great accuracy using ring parameter measurements.

5.18 J.A. Giordmaine, "Mixing of Light Beams in Crystals," Phys. Rev. Lett. 8, 19-20 (Jan 1, 1962).

5.19 Rick Trebino, "Second-Harmonic-Generation Rings and Refractive-Index Measurement in Uniaxial Crystals," Appl. Opt. 20, 2090-2096 (June 15, 1981).

$\theta_0 = 59.0°$
$\Delta n = 0.00124$

$\theta_0 = 56.0°$
$\Delta n = 0.00021$
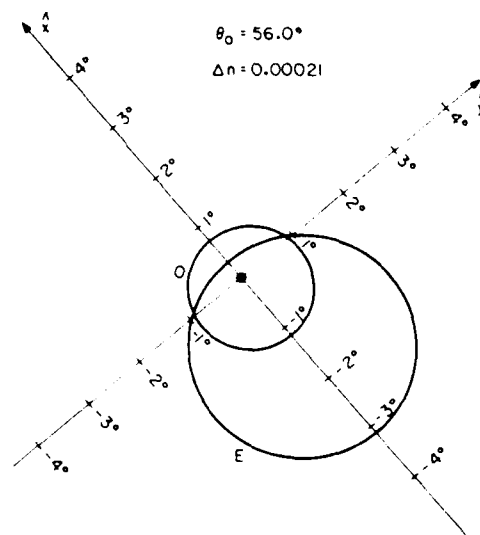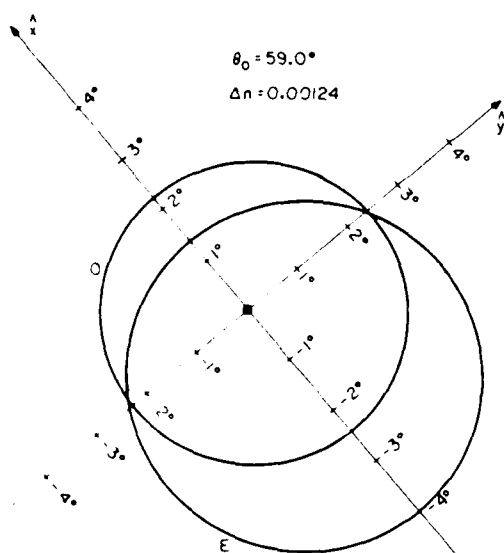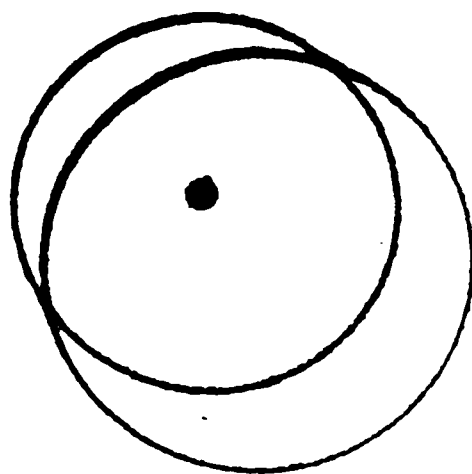
Fig. 3: Two of the three SHG rings produced in a Type II KD*P
doubling crystal. (Third ring is larger and dimmer than
these two rings). Fundamental radiation wavelength used
for these photographs is 1.064 μm and the wavelength of
the second harmonic is 532 nm. The sequence illustrates
the ring evolution as the crystal is tilted by a few
degrees through the phasematching angle. Below each

$\theta_0 = 55.3°$

$\Delta n = -0.00003$

$\theta_0 = 54.2°$

$\Delta n = -0.00043$
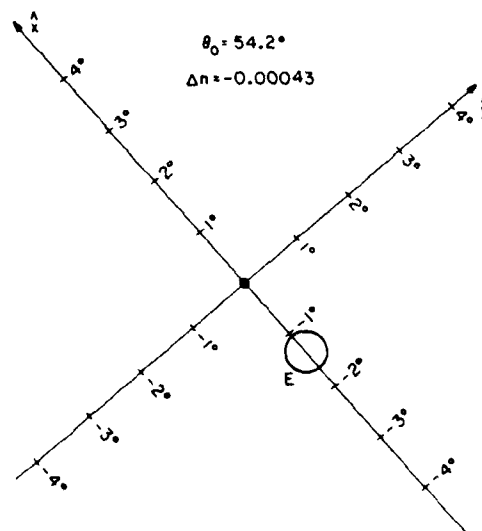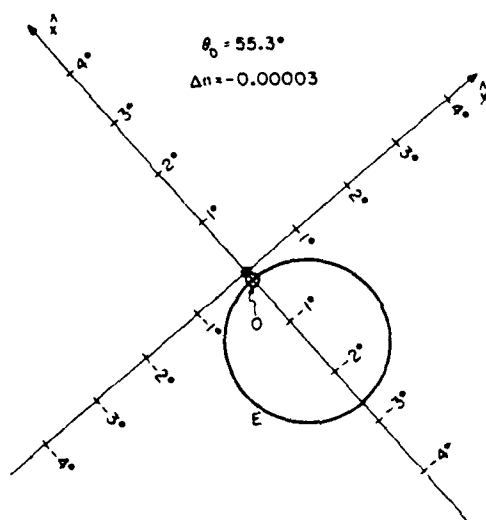
photograph, the theoretically predicted ring patterns are illustrated. The angle between the laser propagation direction and the crystal c-axis is denoted by θ_0 and $\Delta n = \frac{1}{2}[n_o(1.06\mu) + n_e(1.06\mu,\theta_0)] - n_e(532\text{ nm},\theta_0)$ is the "index mismatch" of the process.

E. Publications and Papers

1. A.E. Siegman, "Laser Induced Grating Techniques for Picosecond
    Spectroscopy," Report of Workshop on Picosecond Spectroscopy
    (sponsored by DARPA), La Jolla Institute, La Jolla, California,
    May 7-8, 1980. (Partially supported by AFOSR).

2. Wolfram E. Schmid, "Pulse Stretching in a Q-switched Nd:YAG Laser,"
    IEEE J. Quant. Electr. QE-16, 790-794 (July 1980).

3. Rick Trebino, "Second-harmonic-generation Rings and Refractive-index
    Measurement in Uniaxial Crystals," Appl. Optics 20, 2090-2096
    (15 June 1981).

Unit A

OPTICAL AND NONLINEAR OPTICAL STUDIES OF

SINGLE CRYSTAL FIBERS

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(M. Fejer)

INTRODUCTION

This project is concerned with the growth of single crystal fibers, the evaluation of their linear and nonlinear optical properties, and the development of optical and nonlinear optical fiber devices. The unique combination of single crystal material properties and fiber geometry offers intriguing capabilities in a variety of optical devices. Three materials successfully grown at Stanford this year typify the broad range of potential applications. The large nonlinear coefficients of $LiNbO_3$ suggest a number of modulators, signal processors and parametric sources. Miniature lasers made from Nd:YAG fibers[1] have been known for several years. They might also be used as in-line amplifiers in conjunction with conventional glass fiber systems. Sapphire's high melting point, mechanical strength, resistance to chemical attack and favorable optical and thermal properties make it an excellent candidate for monitoring temperature or optical radiation in hostile environments and for guiding high power optical beams.

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[1] J. Stone and C.A. Burrus, "Self-Contained LED-Pumped Single-Crystal Nd:YAG Fiber Laser," Fiber and Integrated Optics 2, 19 (1979).

The efficient realization of these sorts of devices, particularly those involving parametric processes, require the growth of fibers with good optical and structural uniformity and the ability to launch and preserve low order propagation modes. Our efforts this year have been oriented toward achieving these goals.

CURRENT PROGRESS

A. Fiber Growth

The first generation constructed under non-JSEP support was completed in autumn 1980. The crystal growth research group directed by Dr. R.S. Feigelson, Center for Materials Research, Stanford University, has succeeded in growing several materials in addition to the three mentioned in the Introduction, including one, calcium scandate, that had not previously been obtained in single crystal form, using this station.

Fibers have been grown with diameters ranging from 500 microns down to 35 microns in lengths up to 15 cm. Growth rates are typically 1 - 10 mm/min, though faster rates are currently being investigated. Oriented fibers have been grown, including [111], [110], [100] Nd:YAG, [100], [001] LiNbO$_3$; and [100], [001] sapphire. The fibers tend to exhibit cross sections similar to those of Czolchralski grown bulk boules, e.g., [111] Nd:YAG has a hexagonal cross section, [100] LiNbO$_3$ is elliptical. Preliminary optical and X-ray investigations indicate that the fibers are single crystal, though photomicrographs show larger diameter Nd:YAG fibers have core defects similar to those in bulk grown boules.

The major problem with the current system is growth instability which leads to fibers with diameters varying by 5% over 5 mm lengths and 10% or more over larger lengths. Scanning electron micrographs have shown that the diameter variations have a broad spectrum ranging from millimeter periods down to submicron. Estimates based on coupled mode theory suggest that these random diameter fluctuations will have to be reduced by at least an order of magnitude if tolerable levels of mode onversion, loss and phase matching are to be achieved.

A number of components of the current fiber growth system and process are implicated in the diameter control problem. Figure 1 is a schematic of the current system. A 1 mm square rod, chucked to a lead screw, is fed into the common focus of the two beams from a 50 watt CO_2 laser. A seed crystal, chucked to another lead screw, is dipped into the molten bead formed on the rod, then withdrawn at a constant rate to pull the fiber. The diameter reduction from rod to fiber is determined by the ratio of feed to pull speeds. Typically, a diameter reduction of 2-5 is feasible. Thus 3-5 regrowth cycles yield a fiber in the 50-100 μ range.

A primary cause of the diameter fluctuations is the square feed rod used in the initial growth cycle. It is necessary to rotate the square rod to maintain a uniform melt. Since it is impossible to make the rod rotate precisely concentrically with the seed, a "candy cane" spiral appears on the fiber surface. Ideally, the initial feed rod would be circular with a 0.5 mm or smaller diameter, with an accurately maintained cross-section along its entire length. After an extended search we located several Swiss manufacturers of watch bearing grinding machines capable

of producing the necessary rods; we are in the process of obtaining formal price quotations. We have also located a local shop which may be able to grind the feed rods. In addition, improved beam alignment and focussing mechanisms intended to improve thermal symmetry in the melt have been designed and assembled, and will be installed in the system.

The higher frequency diameter variations are probably associated with laser power fluctuations, particularly when the laser is operated near threshold during small diameter fiber growth. The theoretical analysis of the fiber system thermal response indicates time constants of $0.1 - 0.01$ second can be expected, which is consistent with the periodicity of the observed diameter variations. We have incorporated a feedback system to stabilize the laser power, but it is limited by the slow time constant of the thermal detector used to monitor the laser output. To eliminate this problem, we have assembled a detector based on a commercial pyroelectric element and an 8 kHz resonant scanner, which, combined with suitable demodulation electronics provides a bandwidth in excess of 1 kHz. This detector will be incorporated into the growth system within the next several months. In addition, we have designed an attenuator system with three fixed levels and minimal beam walk and beam steering that will allow well above threshold operation of the laser for all fiber diameters.

In the present system configuration, the growth zone is not fully isolated from ambient conditions. This exposes the fiber to the perturbative influence of drafts and convective air currents. The CMR group is designing a controlled atmosphere chamber which should alleviate these problems, and also permit growth in inert atmospheres, oxygen, or vacuum.

We hope that the aggregate effect of these modifications will be a substantial improvement in the open loop growth stability of the fiber diameter. Once this goal is achieved, it would be useful to incorporate feedback to the laser power based on an error signal derived from the fiber diameter. To this end we have assembled a prototype diameter measurement system with a resolution of ~ 0.75 micron and a measurement rate of 1 kHz, based on a similar system published by Smithgall.[2] The optics used in this system would be considerably complicated by the long working distance entailed by the controlled atmosphere chamber. We are therefore studying improved signal processing methods which would relax constraints on the optical system, and perhaps yield a considerable increase in sensitivity. If this method is successful, it could be of value as a commercial device. Consideration is also being given to the purchase of a commercial diameter measurement system, but none has appeared optimal thus far.

While we expect these modifications will considerably improve fiber quality, a more comprehensive solution entails construction of a new growth station. The new system will utilize the same basic growth technique as the first generation station, but will incorporate refinements in many of the subsystems. A 20 watt waveguide CO_2 laser with active thermal and output power stabilization is more compact than the laser currently in use and should provide better power and beam pointing stability.

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[2] D.H. Smithgall, L.S. Watkins, R.E. Frazee, Jr., "High-speed Non-contact Fiber-diameter Measurement System Using Forward Light Scattering," Applied Optics 9, 2395 (1977).

We have designed a novel optical system for focussing the 10.6 micron radiation onto the fiber in a 360° symmetric distribution. This is an improvement over the two-beam, rotating periscope,[3] or ellipsoidal[4] focussing systems previously used in laser drawn fiber stations. The diffraction limited f/2 optics will allow focussed spot size as small as 20 micron, important for well controlled growth of small diameter fibers. The symmetric energy distribution will alleviate the problem of coldspots in the growth zone, a potential source of instability.

The feed rod and fiber will be translated with a capstan and pinch roller design that offers several advantages over the lead screws used previously:

(1) Maximum fiber length is no longer limited by the length of the lead screw.

(2) The controlled atmosphere chamber no longer requires mechanical feedthroughs.

(3) The DC motors driving the capstans are encoded and phaselocked to a crystal controlled oscillator, allowing stable and convenient adjustment of the growth rate.

(4) Post growth annealing is easily accomplished.

All the components for this system were ordered this summer. We expect to have it operational this fall. Funds for construction of the system were from the current JSEP program and from AFOSR support.

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[3] J.F. Midwinter, Optical Fibers for Transmission (John Wiley and Sons, New York, 1979).

[4] U.C. Paek, "Laser Drawing of Optical Fibers," Applied Optics 13, 1383 (1974).

Oriented Seed

CO_2
Laser beams

Molten Zone

Source
Crystal

Feed

Fiber

Molten Zone

Source Crystal

Feed
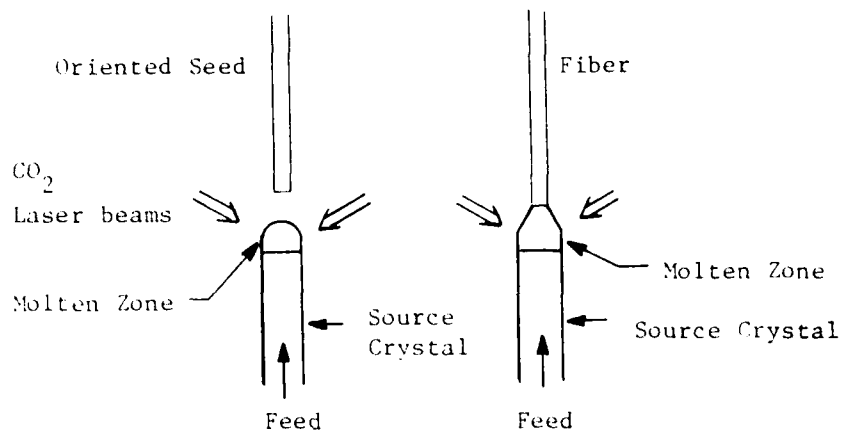
Figure 1.

B.   Fiber Characterization and Preparation

As higher quality fibers become available, it will become important
to characterize their properties. We have begun to assemble the instru-
mentation necessary for these measurements.

A fiber diameter measurement system has already been described in
connection with use in feedback control of the growth process. In addi-
tion to this use, a statistical record of diameter variations will be
useful as a diagnosis for understanding growth perturbations,[5] and for
the prediction of mode conversion and loss phenomena. The scanning
electron microscope at the Center for Material Research has been used
for the characterization of surface flaws below the resolution of the
current diameter measurement system.

An important parameter for ferroelectric fibers like $LiNbO_3$ is
the distribution of domains of spontaneous polarization. We have
assembled a device based on the measurement of the pyroelectric coef-
ficient[6] which is capable of resolving domain distribution both along
the fiber axis and across its endface, with 20 micron resolution. A
determination of the domain distribution in an a-axis $LiNbO_3$ fiber
showed an interesting configuration. The domains were layered trans-
versely to the c-axis rather than parallel to the c-axis as is generally
the case in bulk crystals. The explanation for this behavior is not yet
clear, though it is probably related to the large surface area to volume
ratio of the fiber geometry.

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[5] R.E. Jaeger, "Fiber Drawing Process: Characterization and Control,"
in B. Bendow, ed., Fiber Optics, Advances in Research and Development,
(Plenum Press, N.Y., 1978).

[6] A. Hadni, J.M. Bassia, X. Gerbaux, R. Thomas. "Laser Scanning
Microscope for Pyroelectric Display in Real Time," Applied Optics 15,
2150 (1976).

Nonlinear interactions do not proceed efficiently in randomly poled materials, so it will be necessary to pole the $LiNbO_3$ fibers before using them in any nonlinear device. The second generation growth station will be equipped with platinum electrodes so that electric fields can be applied to the fiber immediately after crystallization or in a post-growth reheating.

It is also important to know the radial and axial variations of the index of refraction. Ideally there would be no axial variations, as these represent inhomogeneities in the fiber. The radial variation is of course critical in establishing the modal propagation properties of the fiber. Nonuniform radial distribution of nonstoichiometric constituents, e.g., Nd in Nd:YAG, could be determined by an index profile measurement. In co-operation with the Shaw group, we have assembled a system similar to that described by Eickhoff[7] which can measure index variations of five parts in ten thousand with several micron resolution.

The index profiling method is based on an accurate measurement of Fresnel reflectivity, so it is necessary to prepare very flat faces on the fiber. Selective launching of low order modes also requires accurately flat fiber ends, so we are attempting to master fiber polishing techniques. We have acquired a commercial fiber polishing unit, and retrofitted a metallurgical microscope to permit interferometric determination of fiber end quality. Our initial polishing efforts have led to fibers with insufficiently flat ends. The rounding appears to be associated with difficulties in rigidly mounting the fibers, which is, in turn, aggravated by the

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[7] W. Eickoff and E. Weidel, "Measuring Method for the Refractive Index Profile of Optical Glass Fibers," Opt. and Quant. Elec. 7, 109 (1975).

nonconstant diameter of the fiber. We are currently investigating

several potential solutions to this problem.

DEVICES

A.   Experiment

Because of the inadequate diameter control thus far obtained, we have

not devoted much effort to experimental investigation of fiber devices.

We have succeeded in launching and preserving low order modes in commercial

multimode glass fiber, and had some encouraging preliminary results with

mode launching in a $LiNbO_3$ fiber.

One simple but interesting proof of principle device we assembled

was a remote temperature sensor based on a sapphire fiber. Radiation

from a hot filament was focussed onto a 10 cm long fiber, whose output

was fed into a grating monochrometer. The ratios of the intensity of

two wavelengths gave temperature measurements that agreed to within 2K

with an optical pyrometer.

B.   Theory

An important topic is the effect of diameter perturbations on mode

mixing and radiation loss. This subject is treated extensively in the

literature,[8] but generally under the assumption of small core-cladding

index differences. Since this assumption will not be applicable to our

fibers until we develop suitable cladding techniques, we have extended

standard coupled mode theory to include the case of low order modes in

fibers with large index differences. In addition to providing the

diameter tolerance limits mentioned in the fiber growth section, this

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[8] D. Marcuse, Theory of Dielectric Optical Waveguides (Academic
Press. N.Y., 1974).

coupled mode theory suggests a technique with extremely interesting device potential. If our growth process advances to the point where it would be possible to introduce periodic diameter variations into a fiber by modulating the CO_2 laser output, distributed feedback devices of the type now used in integrated optics could be introduced into optical fibers.

We have also developed a fairly general theory of nonlinear interactions in fibers. In the absence of linear coupling the nonlinear problem is easy to solve. Under this assumption we have estimated the efficiency of various nonlinear devices, with results presented in Table 1. If our techniques for poling $LiNbO_3$ prove to be sufficiently controllable, it should be possible to periodically pole a fiber in order to take advantage of the large d_{33} coefficient. Efficiencies for this case are also listed in the table.

Solutions for the case of simultaneous linear coupling and nonlinear interaction are more difficult to obtain, but will be pursued in the coming contract period. We also intend to investigate the effect of strong anisotropy on fiber modes.

OBJECTIVES FOR THE COMING PERIOD

In the coming year we will continue our close cooperation with the Shaw and CMR group in upgrading the first generation growth station. We will also finish assembling the second generation growth station. Open loop growth characteristics will be determined and a suitable closed loop diameter control system designed.

Using the instrumentation developed this past year, it should be possible to rapidly evaluate the properties of the fibers which will

TABLE 1. Efficiencies of Nonlinear Processes in $LiNbO_3$ Fiber (%/W)

		Bulk 5 cm Confocal Focussing	50 μm Multimode Fiber 5 cm length	5 μm Singlemode Fiber 1 cm Length
SHG $1.06\ \mu m \rightarrow 0.532\ \mu m$	d_{31}	2.0	18	34
	d_{33}		14, (1 cm length)	24, (2 mm length)
Frequency Mixing $0.58\ \mu m + 1.06\ \mu m \rightarrow 1.28\ \mu m$	d_{31}	1.4	4	4
	d_{33}		70	0
$0.58\ \mu m + 0.75\ \mu m \rightarrow 2.56\ \mu m$	d_{31}	0.33	1	1
	d_{33}		18	18
Parametric Gain $\omega_p = 0.532\ \mu m\ \omega_s = 1.06\ \mu m$	d_{31}	2%	4	11
	d_{33}		70	190

aid in the growth of improved fibers.

Once fibers of sufficient quality become available, we intend to try some basic nonlinear interactions, in particular electrooptic modulation and doubling 1060 nm → 532 nm.

Longer term goals include the construction of more sophisticated nonlinear devices, e.g., a CW parametric oscillator, development of cladding techniques for better mode control, and investigation of periodic poling and periodic diameter variations. We will focus our attention on $LiNbO_3$ nonlinear optical devices and sapphire devices.

V. LABORATORY CONTRACT AND GRANT SUPPORT

(Edward L. Ginzton Laboratory)

SOURCE – CONTRACT-GRANT NO.	P.I.	TITLE	EXPIRATION DATE as of 4/1/81
1. Air Force Office of Scientific Research			
AFOSR-80-0145	Siegman	Laser Physics and Laser Techniques	1/31/82
F49620-78-C-0009	Geballe	Film Synthesis and New Superconductors	9/30/82
F49620-78-C-0098	Quate	Acoustic Microscopy for Nondestructive Evaluation of Materials	6/30/81
F49620-79-C-0217	Kino	Research on Nondestructive Evaluation	8/31/81
F49620-80-C-0023	Harris/Young	Research Studies on Radiative Collisional Processes	9/30/81
F49620-80-C-0040	Shaw/Chodorow	New Approaches to Optical Systems for Inertial Rotation Sensing	12/31/81
F49620-80-C-0091	Hanson/Byer	Advanced Instrumentation and Diagnostics for Chemically Reacting Flows	9/30/81
F49620-81-C-0047	Byer	Laser Physics and Spectroscopy	3/14/82
2. Army Research Office			
DAAG29-81-K-0038	Byer	Tunable Optical Sources	2/19/84
3. Electric Power Research Institute			
EPRI RP609-1	Kino/Shaw	Acoustic Techniques for Measuring Stress Regions in Materials	6/30/82
EPRI RP1395-3	Auld	Quantitative Modeling of Flaw Responses in Eddy Current Testing	12/31/81
4. Industrial Contracts			
Anaconda Copper Company	Shaw	Research on Fib ic Directions Cor	12/31/83
5. National Aeronautics and Space Administration			
NAG 1-182	Byer	High Energy Efficient Solid State Laser Sources	5/31/82
NAG 2-44	Harris/Siegman/Young	Studies on Lasers and Laser Devices	3/31/82
NCC 2-50	Byer	Ultra High Resolution Molecular Beam CARS Spectroscopy With Applications to Planetary Molecules	3/31/82

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SOURCE - CONTRACT-GRANT NO.	P.I.	TITLE	EXPIRATION DATE as of 4/1/81
NCC 2-120	Geballe	Investigation of the Properties of Doped Silicon on Sapphire for Far Infrared Bolometers	3/31/82

6. National Institutes of Health

NIH 2-R01-GM25217-04	Doniach	X-ray Studies of Ca and Tb Ions in Biological Systems	3/31/82
NIH 2-R01-GM25826-03	Quate	Acoustic Microscopy for Biomedical Applications	11/30/81

7. National Science Foundation

NSF CHE79-12673	Byer	Molecular Beam CARS Spectroscopy	7/31/81
NSF DMR79-11117	Beasley	Electromagnetic Properties of Layered Superconducting Structures	6/30/80
NSF DMR-8007934	Doniach	Theory of Cooperative Phenomena Superfluid Systems of Reduced Dimentionality	6/30/82
NSF DMR-80-22365	Harrison	Pseudopotential Methods in Physics	12/14/81
NSF DMR-8109583	Beasley	Two-Dimentional Superconductivity and Layered Superconducting Structures	6/30/82
NSF ECS 79-25811	Siegman	Cooling Water System (Equipment)	1/31/82
NSF ECS-80-10786	Quate	Research on Acoustic Microscopy With Superior Resolution	1/14/82
NSF ENG77-28528	Kino	Acoustic Wave Transducers	6/30/81
NSF PHY78-23532	Schawlow	Precision Optical Wavemeters	7/31/81
NSF PHY80-10689	Schawlow/Hansch	Spectroscopy and Quantum Electronics	5/31/82

8. Navy

N00014-75-C-0632	Siegman/Beasley	Optical and Acoustic Wave Research (JSEP)	3/31/82
N00014-76-C-0129	Kino	Acoustical Scanning of Optical Images	11/14/83
N00014-77-C-0412	Quate	Acoustic Microscopy at Cryogenic Temperatures	6/30/82
N00014-78-C-0283	Kino	Measurements of Surface Defects in Ceramics	2/28/82
N00014-78-C-0403	Schawlow/Harris	Advanced Laser Source Research	3/31/81
N00014-79-C-0222	Auld	Elastic Domain Wall Waves in Ferroelectric Ceramics and Single Crystals	1/31/82

SOURCE - CONTRACT-GRANT NO.	P.I.	TITLE		EXPIRATION DATE as of 4/1/81
N00014-81-K-0469	Doniach/Hodgson	Small X-ray Defraction of Immunoglobulin-Membrane Complexes		4/14/83
N00019-81-C-0131	Beasley/Geballe	RF Properties of Super- conducting A-15 Compounds		6/30/82

9. Department of Energy

DE-AT03-76ER71043	Beasley	Superconducting and Semi- conducting Properties of Electron Beam Evaporated Materials	133,675	1/31/83
DE-AT03-81ER10865	King	A Program for Research on High Frequency Transducers		3/31/84

10. Subcontracts

Ames Science Laboratory SC-11-009	Kino	Bulk Wave NDE of Structural Ceramics	9/30/81
Ames Science Laboratory SC-11-011	Auld	Quantitative Surface Flaw Characteristics	9/30/81
Batelle Industries B-96062-B-K	Auld	Design of a Novel Eddy- Current Probe	9/29/82
Lawrence Livermore Laboratory LLL 3488009	Byer	Define Algorithms Appropriate to a High Laser Wavelength Measuring Instrument	5/15/81
Lawrence Livermore Laboratory 3818301	Byer	Improved Solid State Laser Sources	6/1/82
Rockwell International Science Center B1-F00429-3	Auld	A Program of Research on Applica- tion of FMR Probe Techniques to Development of the Retirement-for Cause Concept	9/30/81
Westinghouse Electric Corporation 34-RP-23629-A	Geballe	Long Range Superconducting Material Research for Electric Power Transmission	10/31/82

VI. REPORTS AND PUBLICATIONS

EDWARD L. GINZTON LABORATORY FACULTY AND STAFF

G.L. No.	Report	Contract
3113	B.A. Auld, F. Muennemann, and D.K. Winslow, "Surface Flaw Detection with Ferromagnetic Resonance Probes," Interim Report for the period 1 October 1979 — 31 March 1980 (April 1980).	RISC 77-70946
3114	N.W. Carlson, "Identification of Excited States of Diatomic Sodium by Two-Step Polarization Labeling," Internal Memorandum and Special Research Report (June 1980).	NSF PHY77-09687
3115	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Seventeenth Monthly Report for the period 15 February — 15 March 1980.	EPRI RP1395-3
3116	K. Bennett and R.L. Byer, "A Computer-Controllable Wedged-Plate Optical Variable Attenuator," Preprint (April 1980). Also: Published in Applied Optics, Vol. 19, No. 14, 2408-2412 (15 July 1980).	F49620-77-C-0092 and DAAG29-77-G-0221
3117	Staff, "Acoustic Techniques for Measuring Stress Regions in Materials," Forty-Seventh Report for the period 1 February — 31 March 1980 (April 1980).	EPRI RP609-1
3118	T.J. O'Leary, "Photolysis of Hydrogen Bromide — Deuterium Bromide Mixtures at 2537 A," Preprint (April 1980).	NSF PHY77-09687
3119	S. Froyen, "Addendum to 'Universal LCAO Parameters for D State Solids'," Preprint (May 1980). Also: Published in Physical Review B, Vol. 22, No. 6, 3119-3121 (15 September 1980).	NSF DMR77-21384
3120	Staff, "Annual Progress Report," for the period 1 April 1979 — 31 March 1980 (April 1980).	N00014-75-C-0632

G.L. No.	Report	Contract
3121	Staff, "Acoustic Wave Transducers," Progress Report for the period January — March 1980 (Mary 1980).	NSF ENG77-28528
3122	Staff, "Acoustically Scanned Optical Imaging Devices," Management Report for the period 1 July — 30 September 1979 (May 1980).	N00014-76-C-0129
3123	Staff, "Acoustically Scannned Optical Imaging Devices," Management Report for the period 1 January — 31 March 1980 (May 1980).	N00014-76-C-0129
3124	Staff, "Investigation of Laser Dynamics, Modulation and Control by Means of Intra-Cavity Time Varying Perturbation," Final Report for the period 1 February 1966 through 28 February 1980 (May 1980).	NASA NGL-05-020-103
3125	R.W. Falcone and G.A. Zdasiuk, "Radiative Collisional Fluorescence Observed from Thermally Excited Atoms," Preprint (May 1980).

Also:
Published in Optics Letters, Vol. 5, No. 9, 365-367 (September 1980). | F49620-80-C-0023 |
| 3126 | J.E. Lawler, "Experimental and Theoretical Investigation of the Optogalvanic Effect in the Helium Positive Column," Preprint (May 1980).

Also:
Published in Physical Review A, Vol. 22, No. 3, 1025-1033 (September 1980). | N00014-78-C-0403 and NSF PHY77-09687 |
| 3127 | Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Eighteenth Monthly Report for the period 15 March — 15 April 1980 (May 1980). | EPRI RP1395-3 |
| 3128 | J. Eggleston and R.L. Byer, "Steady State Stimulated Raman Scattering by a Multi-Mode Laser," Preprint (May 1980).

Also:
Published in IEEE Journal of Quantum Electronics, Vol. QE-16, No. 8, 850-853 (August 1980). | F49620-77-C-0092 |

G.L. No.	Report	Contract
3129	W.T. Hill, III, "Intracavity Absorption Spectroscopy," Internal Memorandum and Special Research Report (July 1980).	NSF PHY77-09687
3130	John Chi-Chang Tsai, "Pressure Effects Measurement of Na_2 ($X^1\Sigma_g^+ - B^1\Pi_u$) with High Resolution Laser Spectroscopy," Internal Memorandum and Special Research Report (July 1980).	NSF PHY77-09687
3131	Staff, "Microwave Tubes," Final Report for the period 1 June 1977 to 30 September 1978 (June 1980).	AFOSR 77-3351
3132	Staff, "Studies on Lasers and Laser Devices," Final Report for the period 1 April 1979 — 31 March 1980 (May 1980).	NASA NSG-7619
3133	Staff, "Superconducting Tunneling and Tunneling Applications in High T_c A15 Superconductors," Final Technical Report (May 1980).	N00014-77-C-0439
3134	Shang Yuan Ren, "Extended Bond Orbital Theory of Piezoelectric and Transverse Charges," Preprint (June 1980). Also: Published in Physical Review B, Vol. 22, No. 6, 2908-2912 (15 September 1980).	NSF DMR77-21384
3135	C.E. Yeack, M. Chodorow, and C. C. Cutler, "Nonlinear Acoustic Off-axis Imaging," Reprint from Journal of Applied Physics, Vol. 51, No. 9, 4631-4636 (September 1980).	NSF ENG77-01119
3136	C.E. Yeack and M. Chodorow, "Oblique Incidence Reflection Acoustic Imaging," Reprint from Journal of Applied Physics, Vol. 51, No. 9, 4637-4644 (September 1980).	NSF ENG77-01119
3137	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Nineteenth Monthly Report for the period 15 April — 15 May 1980 (June 1980).	EPRI RP1395-3
	Staff, "Acoustic Techniques for Measuring ... Regions in Materials," Forty-Eighth ... r the period 1 April — 31 May 1980	EPRI RP609-1

G.L. No.	Report	Contract
3139	Staff, "Acoustic Microscopy for Non-destructive Evaluation of Materials," R & D Status Report for the period 1 February — 30 April 1980 (June 1980).	F49620-78-C-0098
3140	S.J. Poon and W.L. Carter, "Amorphous Superconductors Based on the 4d Series," Reprint from Solid State Communications, Vol. 35, 249-251 (1980).	F49620-78-C-0009
3141	H.C. Tuan, J.E. Bowers, and G.S. Kino, "Theoretical and Experimental Results for Monolithic SAW Memory Correlators," Preprint (June 1980). Also: Published in IEEE Transactions on Sonics and Ultrasonics, Vol. SU-27, No. 6, 360-369 (November 1980).	N00014-76-C-0129 and NIH GM17940-10
3142	J.B. Green, B.T. Khuri-Yakub, and G.S. Kino, "A New Narrow Bandwidth-High Efficiency Zinc Oxide on Silicon Storage Correlator," Preprint (June 1980). Also: Published in Journal of Applied Physics Vol. 52, No. 1, 505-506 (January 1981).	N00014-75-C-0632
3143	C.H. Chou, B.T. Khuri-Yakub, G.S. Kino, and A.G. Evans, "Defect Characterization in the Short Wavelength Regime," Preprint (June 1980).	RISC RI74-20773
3144	Staff, "Research Studies on Radiative Collisional Processes," Progress Report for the period 1 October 1979 — 30 June 1980 (July 1980).	F49620-80-C-0023
3145	N.W. Carlson, A.J. Taylor, and A.L. Schawlow, "Identification of Rydberg States in Na_2 by Two Step Polarization Labeling," Preprint (July 1980). Also: Published in Physical Review Letters, Vol. 45, No. 1, 18-21 (7 July 1980).	NSF PHY77-09687

G.L. No.	Report	Contract
3146	D.C. Wolfe, Jr., "On the Application of Optical Computed Tomography to Remote Air Pollution Measurement," Internal Memorandum and Special Research Report (July 1980).	F49620-77-C-0092
3147	Staff, "Research Studies on Radiative Collisional Processes," Interim Technical Report (June 1980).	F49620-80-C-0023
3148	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Twentieth Monthly Report for the period 15 May — 15 June 1980 (July 1980).	EPRI RP1395-3
3149	Staff, "Acoustic Microscopy at Cryogenic Temperatures," Annual Summary Report for the period 1 July 1979 — 30 June 1980 (July 1980).	N00014-77-C-0412
3150	C.C. Cutler, S.A. Newton, and H.J. Shaw, "Limitation of Rotation Sensing by Scattering," Preprint (July 1980). Also: Published in Optics Letters, Vol. 5, No. 11, 488-490 (November 1980).	F49620-80-C-0040
3151	G.S. Kino, "Signal Processing with the Storage Correlator," Preprint (July 1980). Presented at the SPIE Symposium at San Diego, California July 30, 1980.	N00014-76-C-0129, N00014-75-C-0632, NIH GM17940-10
3152	M.T. Resch, J. Tien, B.T. Khuri-Yakub, G.S. Kino, and J.C. Shyne, "Fracture Prediction by Rayleigh Wave Scattering Measurement," Preprint (July 1980). Also: Published in Mechanics of Nondestructive Testing (1980), pp. 197-213.	NSF DMK76-00726
3153	M. Endemann and R.L. Byer, "Remote Single-Ended Measurements of Atmospheric Temperature and Humidity at 1.77 μm Using a Continuously Tunable Source," Preprint (June 1980). Also: Published in Optics Letters, Vol. 5, No. 10, 452-454 (October 1980).	DAAG29-77-G-0181

G.L. No.	Report	Contract
3154	S.E. Harris, J.F. Young, R.W. Falcone, W.R. Green, D.B. Lidow, J. Lukasik, J.C. White, M.D. Wright, and G.A. Zdasiuk, "Laser Induced Collisional Energy Transfer," Preprint (July 1980). Presented at the 7th International Conference on Atomic Physics, Cambridge, Massachusetts, August 4-8, 1980.	F49620-80-C-0023 and N00014-78-C-0403
3155	S. Ayter and B.A. Auld, "Resonances and Crack Roughness Effects in Surface Breaking Cracks," Preprint (July 1980). Presented at the Review of Progress in Quantitative NDE, La Jolla, 1980.	RISC BO-F01243-3
3156	J.E. Rothenberg and S.E. Harris, "XUV Lasers by Quartet to Doublet Energy Transfer in Alkali Atoms," Preprint (August 1980). Also: Published in IEEE Journal of Quantum Electronics, Vol. QE-17, No. 3, 418-422 (March 1981).	N00014-78-C-0403
3157	Staff, "Administrative Supplement — Significant Scientific Accomplishments," (August 1980).	N00014-75-C-0632
3158	R.A. Bergh, H.C. Lefevre, and H.J. Shaw, "Single-Mode Fiber Optic Polarizer," Preprint (August 1980). Also: Published in Optics Letters, Vol. 5, No. 11, 479-481 (November 1980).	Anaconda Copper Company
3159	H.C. Lefevre, "Single-Mode Fibre Fractional Wave Devices and Polarization Controllers," Preprint (August 1980). Also: Published in Electronics Letters, Vol. 16, No. 20, 778-780 (25 September 1980).	Anaconda Copper Company
3160	R.C. Bray and C.F. Quate, "Recent Progress in Materials Studies with Acoustic Microscopy," Preprint (August 1960). Presented at DARPA/AFML Meeting at San Diego.	F49620-78-C-0098

G.L. No.	Report	Contract
3161	B.A. Auld and M. Riaziat, "Using Capacitive Probes in Electromagnetic Nondestructive Testing," Preprint (August 1980). Presented at the Review of Progress in Quantitative NDE, La Jolla, California.	RISC BO-F01243-3
3162	Staff, "To Study the RF Properties of Superconducting A-15 Compounds," Quarterly Progress Report for the period April — June 1980 (August 1980).	N00019-79-C-0618
3163	G. Pavlath and H.J. Shaw, "Stability of Fiber Optic Rotation Sensors Under Various Polarization Conditions," Preprint (August 1980).	F49620-80-C-0040
3164	Staff, "Acoustic Techniques for Measuring Stress Regions in Materials," Forty-Ninth Report for the period 1 June — 31 July 1980 (August 1980).	EPRI RP609-1
3165	Staff, "Acoustically Scanned Optical Imaging Devices," Semiannual Report No. 10, for the period 1 January — 30 June 1980 (August 1980).	N00014-76-C-0129
3166	Staff, "Acoustic Microscopy for Nondestructive Evaluation of Materials," Semiannual Technical Report for the period 1 February — 31 July 1980 (August 1980).	F49620-79-C-0098
3167	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Twenty-First Monthly Report for the period 15 June — 15 July 1980 (August 1980).	EPRI RP1395-3
3168	Staff, "Acoustic Techniques for Measuring Stress Regions in Materials," Technical Report (September 1980.	EPRI RP609-1
3169	P. Panissod, D. Aliaga Guerra, A. Amamou, J. Durand, W.L. Johnson, W.L. Carter, and S.J. Poon, "Local Symmetry Around the Glass-Former sites in Amorphous Metallic Alloys Through Electric Quadrupole Effects," Reprint from Physical Review Letters, Vol. 44, No. 22, 1465-1468 (2 June 1980).	F49620-78-C-0009

G.L. No.	Report	Contract
3170	B. Couillaud, L.A. Bloomfield, J.E. Lawler, A. Siegel, and T.W. Hänsch, "Saturation Spectroscopy of Ultraviolet Transitions in Mercury with a Frequency-Doubled CW Ring Dye Laser," Preprint (September 1980). Also: Published in Optics Communications, Vol. 35, No. 3, 359-362 (December 1980).	N00014-78-C-0403 and NSF PHY80-10689
3171	B.A. Auld, F. Muennemann, and D.K. Winslow, "Surface Flaw Detection with Ferromagnetic Resonance Probes," Preprint (September 1980).	RISC BO-F01246-3
3172	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Twenty-Second Monthly Report for the period 15 July — 15 August 1980 (September 1980).	EPRI RP1395-3
3173	Staff, "Acoustic Microscopy for Non-destructive Evaluation of Materials," R & D Status Report covering the period 1 May — 31 July 1980 (September 1980).	F49620-78-C-0098
3174	Staff, "Acoustic Microscopy for Non-destructive Evaluation of Materials," Annual Report for the period 1 July 1979 — 30 June 1980 (August 1980).	F49620-79-C-0098
3175	C.F. Quate, "Microwaves, Acoustics and Scanning Microscopy," Preprint (September 1980). Published in Proceedings of Rank Prize International Symposium on Image Microscopy.	F49620-78-C-0098 and NIH
3176	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Summary Report (September 1980).	EPRI RP1395-3
3177	T.W. Hänsch and B. Couillaud, "Laser Frequency Stabilization by Polarization Spectroscopy of a Reflecting Reference Cavity," Preprint (October 1980). Also: Published in Optics Communications, Vol. 35, No. 3, 441-444 (December 1980).	N00014-78-C-0403

G.L. No.	Report	Contract
3178	R.C. Bray, J. Calhoun, R. Koch, and C.F. Quate, "Film Adhesion Studies with the Acoustic Microscope," Preprint (October 1980). Also: Published in Journal of Thin Solid Films, Vol. 74, 295-302 (1980).	F49620-78-C-0098
3179	Staff, "Studies on Lasers and Laser Devices," Semiannual Status Report for the period 1 April — 30 September 1980 (September 1980).	NASA NAG 2-44
3180	G. Giuliani, Y.K. Park, and R.L. Byer, "The Radial Birefringent Element and its Application to Laser Resonator Design," Preprint (October 1980). Also: Published in Optics Letters, Vol. 5, No. 11, 491-493 (November 1980).	AFOSR 80-0144
3181	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Twenty-third Monthly Report for the period 15 August — 15 September 1980 (October 1980).	EPRI RP1395-3
3182	R.D. Feldman, R.H. Hammond, and T.H. Geballe, "Epitaxial Growth of A15 Nb_3Si," Preprint (October 1980). Also: Published in IEEE Transactions on Magnetics, Vol. MAG-17, No. 1, 545-548 (January 1981).	F49620-78-C-0009
3183	T.P. Orlando, J.A. Alexander, S.J. Bending, J. Kwo, S.J. Poon, R.H. Hammond, M.R. Beasley, E.J. McNiff, Jr., and S. Foner, "The Role of Disorder in Maximizing the Upper Critical Field in the Nb-Sn System," Reprint from IEEE Transactions on Magnetics, Vol. MAG-17, No. 1, 368-369 (January 1981).	DOE DE-AT03-76ER71043

G.L. No.	Report	Contract
3184	Staff, "Acoustic Techniques for Measuring Stress Regions in Materials," Fiftieth Report for the period 1 August — 30 September 1980 (October 1980).	EPRI RP609-1
3185	B.T. Khuri-Yakub, "Nondestructive Evaluation of Structural Ceramics 420/00118," Preprint (September 1980). To appear in the Encyclopaedia of Science and Technology.	RISC BO-F01243-3 and N00014-78-C-0283
3186	J. Kwo and T.H. Geballe, "Superconducting Tunneling into the A15 Nb$_3$Al Thin Films," Preprint (October 1980). Also: Published in Physical Review B, Vol. 23, No. 7, 3230-3239 (1 April 1981).	F49620-78-C-0009
3187	J.E. Bowers, B.T. Khuri-Yakub, and G.S. Kino, "Monolithic Sezawa Wave Storage Correlators and Convolvers," Preprint (November 1980). Also: Published in 1980 Ultrasonics Symposium Proceedings 118-123 (November 1980).	N00014-76-C-0129
3188	B.A. Auld and S. Ayter, "Perturbation Method for Analyzing the Effect on Ultrasonic Echo Returns on Rough Surfaces in Material Cracks and Voids," Preprint (November 1980). Presented at the 1980 Ultrasonics Symposium.	RISC BO F01246-3
3189	W.A. Harrison, "Total Energies in Tight-Binding Theory," Preprint (October 1980). To appear in Phys. Rev. B.	NSF DMR77-21384
3190	M. Tan and B.A. Auld, "Normal Mode Variational Method for Two- and Three-Dimensional Acoustic Scattering in an Isotropic Plate," Preprint (October 1980). Presented at the 1980 Ultrasonics Symposium.	NSF ENG77-28541

G.L. No.	Report	Contract
3191	C.H. Chou, J.E. Bowers, A.R. Selfridge, B.T. Khuri-Yakub, and G.S. Kino, "The Design of Broadband and Efficient Acoustic Wave Transducers," Preprint (November 1980).	F49620-7.-C-0217, EPRI RP609-1, N00014-76-C-0129, RISC BO-F01246-3
	Also: Published in 1980 Ultrasonics Symposium Proceedings, pp. 984-988.	
3192	A.R. Selfridge, G.S. Kino, and B.T. Khuri-Yakub, "Fundamental Concepts in Acoustic Transducer Array Design," Preprint (November 1980). Presented at the 1980 Ultrasonics Symposium.	EPRI RP609-1 and F49620-79-C-0217
3193	B.T. Khuri-Yakub and J.G. Smits, "Reactive Magnetron Sputtering of ZnO," Preprint. Presented at the 1980 Ultrasonics Symposium (November 1980).	N00014-78-C-0129
3194	Staff, "Research Studies on Radiative Collisional Processes," Progress Report for the period 1 July — 30 September 1980 (November 1980).	F49620-80-C-0023
3195	K. Liang, B.T. Khuri-Yakub, C-H Chou, and G.S. Kino, "A Three-Dimensional Synthetic Focus System," Preprint (November 1980).	RISC BO-F01246-3
	Also: Published in 1980 Ultrasonics Symposium Proceedings, pp. 732-737.	
3196	G.S. Kino, D. Corl, S. Bennett, and K. Peterson, "Real Time Synthetic Aperture Imaging System," Preprint (November 1980).	F49620-79-C-0217
	Also: Published in 1980 Ultrasonics Symposium Proceedings, pp. 722-731.	
3197	R.L. Thornton and G.S. Kino, "Monolithic ZnO on Si Schottky Diode Storage Correlator," Preprint (November 1980. Presented at the 1980 Ultrasonics Symposium.	N00014-76-C-0129

G.L. No.	Report	Contract
3198	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Twenty-Fourth Monthly Report for the period 15 September — 15 October 1980 (November 1980).	EPRI RP1395-3
3199	Staff, "Elastic Domain Wall Waves in Ferroelectric Ceramics and Single Crystals," Progress Report (End-of-Year Letter) (November 1980).	N00014-79-C-0222
3200	R.D. Feldman and R.H. Hammond, "The Effects of Oxygen on Superconducting A15 NbSi," Preprint (November 1980). To appear in March 1981 Journal of Applied Physics.	F49620-78-C-0009
3201	R.L. Byer and M.D. Duncan, "A 100 μsec Reliable 10 Hz Pulsed Supersonic Molecular Beam Source," Preprint (November 1980). Also: Published in Journal of Chemical Physics, Vol. 74, No. 4, 2174-2179 (15 February 1981).	NSF CHE79-12673 and NASA NSG-2372
3202	M.D. Duncan, P. Österlin, and R.L. Byer, "Pulsed Supersonic Molecular Beam CARS Spectroscopy of C_2H_2," Preprint (November 1980). Also: Published in Optics Letters, Vol. 6, No. 2, 90-92 (February 1981).	NSF CHE79-12673 and NASA NSG-2372
3203	J.B. Green, G.S. Kino, and B.T. Khuri-Yakub, "Focused Surface Wave Transducers on Anisotropic Substrates: A Theory Developed for the Waveguided Storage Correlator," Preprint (November 1980).	N00014-75-C-0632
3204	J.E. Rothenberg, J.F. Young, and S.E. Harris, "High Resolution XUV Spectroscopy of Potassium Using Anti-Stokes Radiation," Preprint (November 1980). To appear in Optics Letters.	F49620-80-C-0023, N00014-78-C-0403, NASA NSG 2-44, N00014-75-C-0632

G.L. No.	Report	Contract
3205	Staff, "Research on Nondestructive Testing," Annual Scientific Report (November 1980).	F49620-79-C-0217
3206	Staff, "Acoustic Microscopy for Non-destructive Evaluation of Materials," R & D Status Report for the period 1 August — 31 October 1980 (November 1980).	F49620-78-C-0098
3207	D.J. Jackson, "Excited State Spectros-copy on Helium Using a Color Center Laser," Internal Memorandum and Special Research Report (December 1980).	NSF PHY80-10689
3208	Staff, "Research Studies on Radiative Collisional Processes," Final Report for the period 1 October 1979 — 30 September 1980 (December 1980).	F49620-80-C-0023
3209	Staff, "Tunable Optical Sources," Final Report for the period 1 September 1979 — 31 August 1980 (November 1980).	DAAG29-79-C-0181
3210	Staff, "Film Synthesis and New Super-conductors," Interim Technical Report for the period 1 October 1979 — 30 September 1980 (November 1980).	F49620-78-C-0009
3211	H.J. Shaw, D. Weinstein, L.T. Zitelli, C.W. Frank, R.C. DeMattei, and K. Fesler, "PVF_2 Transducers," Reprint from 1980 Ultrasonics Symposium Proceedings, pp. 927-940.	N00014-75-C-0582, AFOSR 77-3386, NSF-MRL (CMR), EPRI RP609-1
3212	R.A. Bergh, H.C. Lefevre, and H.J. Shaw, "All Single Mode Fiber Optic Gyroscope," Preprint (December 1980). Also: Published in Optics Letters, Vol. 6, No.4, pp. 198-200 (April 1981).	Anaconda Copper Company

G.L. No.	Report	Contract
3213	J.A. Hildebrand, D. Rugar, R.N. Johnston, and C.F. Quate, "Acoustic Microscopy of Living Cells," Preprint (December 1980). Also: Published in Proceedings of the National Academy of Sci, Vol. 78, No. 3, p. 1656 (1981).	NIH 1 RO1 GM25326-02
3214	Staff, "Acoustic Techniques for Measuring Stress Regions in Materials," Fifth-First Report for the period 1 October — 30 November 1980 (December 1980).	EPRI RP609-1
3215	Staff, "Measurement of Surface Defects in Ceramics," Year-End Report (November 1980).	N00014-78-C-0283
3216	A.E. Siegman, P.A. Belander, A. Hardy, "Optical Resonators Using Phase-Conjugate Mirrors," Technical Report (December 1980). Invited Chapter for a book on Optical Phase Conjugation (Academic Press).	AFOSR 80-0145
3217	A.J. Mendelsohn, R. Normandin, S.E. Harris, and J.F. Young, "A Microwave Pumped XeCl* Laser," Preprint (December 1980). Also: Published in Applied Physics Letters, Vol. 38, No. 8, 603-605 (15 April 1981).	F49620-80-C-0023
3218	Rick Trebino, "Second-Harmonic-Generation Rings in Uniaxial Crystals," Preprint (January 1981). Also: Published in Applied Optics, Vol. 20, No. 12, 2090-2096 (15 June 1981).	N00014-75-C-0632
3219	Staff, "Acoustically Scanned Optical Imaging Devices," Annual Technical Report (February 1981).	N00014-76-C-0129
3220	D.J. Jackson, H. Gerhardt, and T.W. Hänsch, "Doppler-Free Optogalvanic Spectroscopy Using an Infrared Color Center Laser," Preprint (January 198-). Also: Published in Optics Communications, Vol. 37, No. 1, 23-26 (1 April 1981).	NSF PHY80-10689 and N00014-78-C-0403

G.L. No.	Report	Contract
3221	S.J. Poon, R.H. Hammond, and T.H. Geballe, "Superconductivity in Electron-Beam Co-deposited A15 Mo-Nb-Si Alloys," Preprint (January 1981).	F49620-78-C-0009
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		6. PERFORMING ORG'N REPORT NO. G.L. Report No. 3315

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		8. CONTRACT OR GRANT NO.
		N00014-75-C-0632

9. PERFORMING ORG'N NAME AND ADDRESS Edward L. Ginzton Laboratory Stanford University Stanford, CA 94305		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Chairman, Joint Services Electronics Program [through] The Office of Naval Research 800 North Quincy Street Arlington, Virginia 22217		12. REPORT DATE April 1981
		13. NO. OF PAGES 103
14. MONITORING AGENCY NAME & ADDRESS(if different from 11. above)		15. SECURITY CLASS (of this report) Unclassified
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Acoustics	Weak-link Josephson junctions	Surface acoustic wave devices
Surface waves	Nonlinear optical studies	High speed signal processing
Optical imaging	Single mode optical fibers	Ferroic-acoustic resonators
Fiber optics	High T_c superconducting materials	Pulsed laser technology

20. ABSTRACT (Continue on reverse side if necessary and identify by Block no.)

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This report summarizes the research progress and activity on Joint Services Electronics Program Contract N00014-75-C-0632 for the period 1 April 1980 through 31 March 1981. Specific Projects are: (1) High T_c Superconducting Weak-Link Josephson Junctions and Circuits (M.R. Beasley); (2) Acoustic Surface Wave Scanning of Optical Images (G.S. Kino); (3) Research on Fiber Optic Interactions with Application to High Speed Signal Processing (H.J. Shaw); (4) Nonlinear Interactions of Acoustic Waves with Domains in Ferroic Materials (B.A. Auld); (5) Measurements of Ultrafast Physical Phenomena (A.E. Siegman); (A) Optical and Nonlinear Optical Studies of Single Crystal Fibers (R.L. Byer).

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