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14. ABSTRACT
During this project, we demonstrated a temporal imaging system based on parametric mixing that allows simple triggering from an external clock by using a time-lens-based pump laser. We experimentally demonstrated wavelength-preserving spectral phase-conjugation for compensating chromatic dispersion and self-phase modulation in optical fibers. We extended the application of photonic systems beyond characterization and demonstrated an instrument that generates complex and rapidly updateable ultrafast optical waveforms. We

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Report Title

Final Technical Report

ABSTRACT

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Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received	Paper
2012/05/24 1· 7	Mark A. Foster, Reza Salem, Alexander L. Gaeta. Ultrahigh-Speed Optical Processing Using Space-Time Duality, Optics and Photonics News, (05 2011): 0. doi: 10.1364/OPN.22.5.000029
2012/05/24 1· 6	Mark A. Foster, Reza Salem, David F. Geraghty, Amy C. Turner-Foster, Michal Lipson, Alexander L. Gaeta. Silicon-chip-based ultrafast optical oscilloscope, Nature, (11 2008): 0. doi: 10.1038/nature07430
2012/05/24 1· 5	Reza Salem, Mark A. Foster, Amy C. Turner-Foster, David F. Geraghty, Michal Lipson, Alexander L. Gaeta. High-speed optical sampling using a silicon-chip temporal magnifier, Optics Express, (03 2009): 0. doi: 10.1364/OE.17.004324
2012/05/24 1· 4	Yoshitomo Okawachi, Reza Salem, Mark A. Foster, Amy C. Turner-Foster, Michal Lipson, Alexander L. Gaeta. High-resolution spectroscopy using a frequency magnifier, Optics Express, (03 2009): 0. doi: 10.1364/OE.17.005691
2012/05/24 1· 3	Mark A. Foster, Reza Salem, Yoshitomo Okawachi, Amy C. Turner-Foster, Michal Lipson, Alexander L. Gaeta. Ultrafast waveform compression using a time-domain telescope, Nature Photonics, (9 2009): 0. doi: 10.1038/nphoton.2009.169
2012/05/24 1· 2	Yoshitomo Okawachi, Onur Kuzucu, Reza Salem, Mark A. Foster, Amy C. Turner-Foster, Michal Lipson, Alexander L. Gaeta. Spectral phase conjugation via temporal imaging, Optics Express, (10 2009): 0. doi: 10.1364/OE.17.020605
2012/05/24 1· 1	Daniel H. Broaddus, Mark A. Foster, Onur Kuzucu, Amy C. Turner-Foster, Karl W. Koch, Michal Lipson, Alexander L. Gaeta. Temporal-imaging system with simple external-clock triggering, Optics Express, (06 2010): 0. doi: 10.1364/OE.18.014262

TOTAL: 7

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Paper

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Long Chen	0.12	
Jacob Levy	0.19	
FTE Equivalent:	**0.31**	
Total Number:	**2**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Pablo Londero	0.13
Jaime Cardenas Gonzalez	0.05
Amy Turner-Foster	0.02
Gustova Wiederhecker	0.01
FTE Equivalent:	**0.21**
Total Number:	**4**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Alexander L. Gaeta	0.03	No
Michal Lipson	0.05	No
FTE Equivalent:	**0.08**	
Total Number:	**2**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED	Discipline
Edgar Peralta	0.19	Engineering Physics
FTE Equivalent:	**0.19**	
Total Number:	**1**	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: ......

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:......

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:......

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale): ......

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering: ......

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense ......

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: ......

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME
Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
Carl Poitras	0.05
FTE Equivalent:	**0.05**
Total Number:	**1**

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Technology Transfer

Scientific Progress, "Ultrafast, Single-Shot Oscilloscope"

During this project, we accomplished the following:

We demonstrated a temporal imaging system based on parametric mixing that allows simple triggering from an external clock by using a time-lens-based pump laser. We integrated our temporal imaging system into a time-to-frequency measurement scheme and demonstrated the ability to perform characterization of temporal waveforms with 1.4-ps resolution and a 530-ps record length. We also integrated our system into a temporal-magnification scheme and demonstrated single-shot operation with a 113 x magnification factor, 1.5-ps resolution, and 220-ps record length.

We experimentally demonstrated wavelength-preserving spectral phase conjugation for compensating chromatic dispersion and self-phase modulation in optical fibers. Our implementation is based on a temporal imaging scheme that uses time lenses realized by broadband four-wave mixing in silicon waveguides. By constructing a temporal analog of a 4-f imaging system, we compensated for pulse distortions arising from second- and third-order dispersion and self-phase modulation in optical fibers.

Photonic systems provide access to extremely large bandwidths, which can approach a petahertz1. Unfortunately, full utilization of this bandwidth is not achievable using standard electro-optical technologies, and higher (>100 GHz) performance requires all-optical processing with nonlinear-optical elements. A solution to the implementation of these elements in robust, compact and efficient systems is emerging in photonic integrated circuits, as evidenced by their recent application in various ultrahigh-bandwidth instruments. These devices enable the characterization of extremely complex signals by linking the high-speed optical domain with slower speed electronics. We extended the application of these devices beyond characterization and demonstrated an instrument that generates complex and rapidly updateable ultrafast optical waveforms. We generated waveforms with 1.5-ps minimum features by compressing lower-bandwidth replicas created with a 10 GHz electro-optic modulator. In effect, our device allows for ultrahigh-speed direct 270 GHz modulation using relatively low speed devices and represents a new class of ultrafast waveform generators.

We experimentally demonstrated a spectral magnifier using an imaging system with two time-lenses based on four-wave mixing in a Si nanowaveguide. We achieved a magnification factor of 105 with a frequency resolution of 1 GHz. The system offers potential as a tool for single-shot, high resolution spectral measurements.

We demonstrated a single-shot technique for optical sampling based on temporal magnification using a silicon-chip time lens. We demonstrated the largest reported temporal magnification factor yet achieved (>500) and applied this technique to perform 1.3 TS/s single-shot sampling of ultrafast waveforms and to 80-Gb/s performance monitoring. This scheme offers the potential of developing a device that can transform GHz oscilloscopes into instruments capable of measuring signals with THz bandwidths.

With the realization of faster telecommunication data rates and an expanding interest in ultrafast chemical and physical phenomena, it has become important to develop techniques that enable simple measurements of optical waveforms with subpicosecond resolution. State-of-the-art oscilloscopes with high-speed photodetectors provide single-shot waveform measurement with 30-ps resolution. Although multiple-shot sampling techniques can achieve few-picosecond resolution, single-shot measurements are necessary to analyse events that are rapidly varying in time, asynchronous, or may occur only once. Further improvements in single-shot resolution are challenging, owing to microelectronic bandwidth limitations. To overcome these limitations, researchers have looked towards all-optical techniques because of the large processing bandwidths that photonics allow. This has generated an explosion of interest in the integration of photonics on standard electronics platforms, which has spawned the field of silicon photonics and promises to enable the next generation of computer processing units and advances in high-bandwidth communications. For the success of silicon photonics in these areas, on-chip optical signal-processing for optical performance monitoring will prove critical. Beyond next-generation communications, silicon-compatible ultrafast metrology would be of great utility to many fundamental research fields, as evident from the scientific impact that ultrafast measurement techniques continue to make. Using time-to-frequency conversion via the nonlinear process of four-wave mixing on a silicon chip, we demonstrated a waveform measurement technology within a silicon-photonic platform. We measured optical waveforms with 220-fs resolution over lengths greater than 100 ps, which represent the largest record-length-to-resolution ratio (>450) of any single-shot-capable picosecond waveform measurement technique. Our implementation allows for single-shot measurements and uses only highly developed electronic and optical materials of complementary metal-oxide-semiconductor (CMOS)-compatible silicon-on-insulator technology and single-mode optical fibre. The mature silicon-on-insulator platform and the ability to integrate electronics with these CMOS-compatible photonics offer great promise to extend this technology into commonplace bench-top and chip-scale instruments.

Temporal imaging systems enable the implementation of functional processing systems in robust guided-wave architectures. Powerful time lenses using ultrafast parametric nonlinear optical processes are yielding temporal imaging systems of increased functionality and intricacy, including multilens systems. Research has shown that these processing systems provide a practical approach for meeting the bandwidth demands of next-generation ultrahigh-speed technologies. We expect future work in this research area to continue to push the envelope of robust, ultrafast all-optical processing.