OFFICE OF NAVAL RESEARCH

PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT

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Epitaxial Growth and Electro-Optical Properties
of Metal GaAs Superlattices

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(a.) Papers Submitted to Referred Journals (and not yet published)

L. Hsu. L. W. Zhou. F. L. A. Machado, W. G. Clark, and R. S. Williams: "Electrical resistivity, magnetic susceptibility, and thermoelectric power of $PtGa_2$," Phys. Rev. B (in press).

Y. K. Kim, D. K. Shuh, R. S. Williams, L. P. Sadwick, and K. L. Wang: "Electronic structure study of Pt-Ga intermetallic compounds using X-ray photoemission spectroscopy," Phys. Rev. B (under review).

T. C. Kuo, T. W. Kang, and K. L. Wang: "RHEED studies of epitaxial growth of CoGa on GaAs by MBE–Determination of epitaxial phases and orientations," J. Crystal Growth (in press).

R. Arghavani, R. G. P. Karunasiri, T. C. Kuo, and K. L. Wang: "Internal photoemission in CoGa/GaAs Schottky barriers, possible injection of electrons into L valleys," J. Vac. Sci. Technol. (in press).

D. A. Baugh and R. S. Williams: "Chemistry of metal/compound semiconductor interfaces," to be published as a feature article in the Journal of Physical Chemistry.

D. A. Baugh, A. A. Talin, R. S. Williams, T. C. Kuo, and K. L. Wang: "Phase stability versus the lattice mismatch of (100)$Co_{1-x}Ga_x$ thin films on (100)GaAs," J. Vac. Sci. Technol. (in press).

T. C. Kuo and K. L. Wang: "Electrical resistivity of ultrathin, epitaxial CoGa on GaAs," Appl. Phys. Lett. (submitted to).

D. A. Baugh, Y. K. Kim, and R. S. Williams: "Growth and annealing of $Co_{1-x}Ga_x$ thin films on (100)GaAs," J. Mats. Res. (submitted to).

(b.) Published Papers in Referred Journals

R. A. Fiscer, H. D. Kaesz, S. I. Khan, and H. -J. Muller: "Synthesis and structural characterization of [cis-$(Cy_2PCH_2CH_2PCy_2)$(neo-Pe)PtGa(neo-Pe)$_2$](Cy=C-C_6H_{11}; neo-Pe=$CH_2C(CH_3)_3$)," Inorg. Chem. 29, 1601-1602 (1990).

H. D. Kaesz, R. S. Williams, R. F. Hicks, J. I. Zink, Y, -J. Chen, J. -J. Muller, Z. Xue, D. K. Shuh, and Y. K. Kim: "Deposition of transition-metal and mixed-metal thin films from organometallic precursors," New J. Chem. 14, 527-534 (1990).

Y. K. Kim, D. Baugh, D. K. Shuh, R. S. Williams, L. P. Sadwick, and K. L. Wang: "Structural and chemical stability of Pt-Ga intermetallic thin films on GaAs(001)," J. Mats. Res. 5, 2139-2151 (1990).

(c.) Books and (sections thereof) Submitted for Publication

None

(d.) Books and (sections thereof) Published

None

(e.) Patents Filed

None

(f.) Patents Granted

None

(g.) Invited Presentations to Topical or Scientific/Technical Society Conferences

D. A. Baugh, A. A. Talin, T. Ngo, and R. S. Williams: "The most stable epitaxial metallization of a III-V semiconductor: (100)CoGa on (100)GaAs," Material Research Society Spring Meeting, Symp. C, Anaheim, Ca, April 29-May 3, 1991.

(h.) Contributed Presentations at Topical or Scientific/Technical Society Conferences

D. Baugh and R. S. Williams: "Selective growth of (100) and/or (110)CoGa films on (100)GaAs," European-Materials Research Society Meeting, Strasbourg, France, May 29-June 1, 1990.

D. Baugh, A. Talin, and R. S. Williams: "Reaction and phase stability of epitaxial (100)CoGa thin films on (100)GaAs," Chemistry of Surfaces Meeting, Irving, CA, Oct. 21-24, 1990.

T. C. Kuo, T. W. Kang, and K. L. Wang: "RHEED studies of epitaxial growth of CoGa on GaAs by MBE," 6Th International Conference on Molecular Beam Epitaxy, San Diego, CA, Aug. 27-31, 1990.

R. Arghavani, K. L. Wang, and R. G. P. Karunasiri: "Internal photoemission in CoGa/GaAs Schottky barriers, possible injection of electrons into X and L valleys," American Vacuum Society 37th Annual Symposium, Oct. 8-12, 1990, Toronto, Canada.

D. A. Baugh, A. A. Talin, R. S. Williams, T. C. Kuo and K. L. Wang: "Phase stability versus the lattice mismatch of (100)$Co_{1-x}Ga_x$ thin films on (100)GaAs," Physics and Chemistry of Semiconductor Interfaces (PCSI 18), Long Beach, CA, Jan. 29-Feb. 1, 1991.

(i.) Honors/Awards/Prizes

Dr. Delroy A. Baugh (postdoctoral fellow), U. C. President's fellowship.

Title	Epitaxial Growth and Electro-Optical Properties of Metal GaAs superlattices
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High quality single phase CoGa epitaxial films have been grown on GaAs by MBE. CoGa offers the advantages of providing a perfectly lattice matched and thermodynamically stable contact to GaAs and other possible substrates. Two different epitaxial orientations, (100) and (110)CoGa, were obtained, and the control of the growth orientation was achieved by controlling the surface stoichiometry of the GaAs substrate before the CoGa deposition. The good crystalline quality of the metallic CoGa films was verified by *in situ* RHEED, RBS and X-ray rocking curves.

The thermodynamic stability of the CoGa/GaAs system was also demonstrated to depend on the stoichiometry of the CoGa. For the Co rich condition, the film was not stable at 500 °C annealing and the CoGa reacted with the GaAs substrate. However, for 61% Ga rich samples, the films were stable up to 800 °C annealing.

The fundamental electric properties of these CoGa films were investigated. First, the size effect of the transport electric resistivity was studied for the first time. The CoGa films were found to be continuous down to 10Å, with a streaky RHEED pattern indicating a 3D growth mode. The temperature dependence of the resistivity was performed for layer thickness from 10Å to 700Å, and the results were analyzed with Markowitz's model. Second, the Schottky barrier heights were obtained from I-V, C-V, activation energy, and internal photoemission measurements. Furthermore, the barrier heights at different temperatures were also studied by these different methods. The Fermi level was found to pin relatively to the GaAs conduction band minimum. This result sheds new light on the enigmatic Schottky barrier pinning problem. The understanding of these basic properties enabled us to continue our research into the fabrication of quantum devices.

Electrical Resistivity, Magnetic Susceptibility and Thermoelectric Power of $PtGa_2$

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The electrical resistivity (ρ), magnetic susceptibility (χ) and thermoelectric power (S) of $PtGa_2$ were measured as a function of temperature (T). This compound is metallic at high temperatures, as shown from the room-temperature resistivity value ($19\mu\Omega$-cm) and the linear dependence of the S vs. T curve at temperatures above the Debye temperature (θ_D). It undergoes a superconducting phase transition with a critical temperature (T_c) at zero magnetic field of 2.13K. The density of states (DOS) at the Fermi energy (E_F) at high temperatures obtained from χ and S data are 22% and 15% higher, respectively, than the value obtained previously from a semi-empirical band structure calculation.

Electronic structure study of the Pt-Ga intermetallic thin films on GaAs (100) using X-ray photoemission spectroscopy

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Single-phase films of Pt-Ga intermetallic compounds with different stoichiometric compositions were grown using molecular beam epitaxy (MBE) and investigated with X-ray photoemission spectroscopy (XPS). For decreasing Pt concentration in the intermetallic compounds, the Pt d-band centroid moved to higher binding energy (BE) and the density of states (DOS) at the Fermi level (E_f) decreased. The Pt d-band width narrowed considerably and Pt 4f core level spectra shifted to higher BE as the the Pt 4f core level line shape became more symmetric.

RHEED Studies of Epitaxial Growth of CoGa on GaAs by MBE—Determination of epitaxial phases and orientations

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ABSTRACT

Epitaxial growth of single crystal CoGa is investigated in-situ using reflection high energy electron diffraction (RHEED). The formation of different phases of CoGa (different stoichiometric compounds and epitaxial orientations) due to various initial growth conditions has been probed with X-ray diffraction and correlated with the RHEED patterns. The growth of (100)CoGa or (110)CoGa is found strongly dependent on the termination of the GaAs surface, with either Co or Ga, before the epitaxial deposition of CoGa. When the flux ratio is deviated from the proper stoichiometric range, additional Co-Ga-As compounds are found in the X-ray diffraction measurement. It is concluded that the CoGa phases and orientations can be determined by pre-deposition of Co or Ga with a control of stoichiometry in the proper range. The high quality epitaxial CoGa has potential applications in thermodynamically stable contacts, and more importantly for fabrication of GaAs/metal/GaAs quantum well structures.

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Internal Photoemission in CoGa/GaAs Schottky Barriers, Possible Injection of Electrons into the L Valley

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ABSTRACT

Internal photoemission in epitaxially grown films of CoGa/GaAs Schottky barriers by back illumination is used to study the injection of electrons into L and X valleys of the conduction bands of n-type GaAs. The general theory of Fowler predicts that the photocurrent per absorbed photon should vary as the square of the photon energy $h\nu$ for $[(h\nu - \Phi_b)/kT] \geq 0$, where Φ_b is the difference between the Fermi level and Γ point in the GaAs conduction band. Unlike the case for Au/GaAs Schottky barriers, we observe two thresholds in the photocurrent measurements of uniform epitaxial CoGa/GaAs contacts. The second threshold formed at $\approx$0.3 eV higher than the first threshold (Γ point) is interpreted as the injection of carriers into the L valley of the GaAs from the metal side. A third threshold at $\approx$0.5 eV above the Γ point requires a photon energy greater than the energy gap of GaAs (1.4 eV) and hence cannot be observed in the back illumination mode.

Chemistry of Metal/Compound-Semiconductor Interfaces

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Abstract

The key to understanding chemical reactions that occur at the interface between a metal and a semiconductor is to first understand the bulk thermodynamic properties of the system. Phase diagrams are required to know under what conditions two materials will react with each other and what the stable products will be. Phase diagrams can also be used to intentionally design interfaces that are stable with respect to a chemical reaction between two solids joined at an interface. These principles are illustrated by describing why the noble metal Au reacts readily with compound semiconductors such as GaAs and InP, whereas selected intermetallic compounds such as $PtGa_2$ and CoGa are stable with respect to GaAs up to the temperature where the semiconductor alone begins to thermally decompose. In addition, interfaces can gain kinetic stability if the overlayer that is deposited on a single crystal substrate is epitaxial, that is if the film is itself a single crystal. These issues are important in modern microelectronics and provide stimulating challenges for solid state chemistry.

Phase Stability Versus The Lattice Mismatch of (100)$Co_{1-x}Ga_x$ Thin Films on (100)GaAs

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ABSTRACT

Thin films of the intermetallic compound $Co_{1-x}Ga_x$, which has a broad homogeneity range and a continuously variable lattice constant, were grown on the (100)GaAs surface by molecular beam epitaxy (MBE). The stoichiometry of the films and the cleanliness of the substrates were determined *in-situ* by Auger electron spectroscopy (AES). The identity and orientation of the phases present in the films were determined *ex-situ* by X-ray diffraction (XRD). The films were annealed to various temperatures in N_2 and reexamined by XRD to detect any chemical interactions between the $Co_{1-x}Ga_x$ and GaAs. Films of $Co_{1-x}Ga_x$ deposited with a 2% lattice mismatch (x=0.5) reacted with the substrate to produce $CoGa_3$ at 600°C, whereas films with no detectable mismatch (x=0.61) did not react until they had been heated to 800°C.

Electrical resistivity of ultrathin, epitaxial CoGa on GaAs

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ABSTRACT

In this letter, the successful growth of ultrathin CoGa on GaAs by MBE is demonstrated. The crystalline quality of the films is verified by *in-situ* RHEED, RBS and X-ray rocking curve. Transport studies are performed in the temperature range of 4 to 300 °K for layer thickness from 10 Å to 730 Å, and all the films are found to be electrically continuous. The Markowitz's model of the electrical resistivity is applied to analyze the measured data. Finally, the specularly scattering probability of these thin films is studied using Fuchs' theory.

Growth and Annealing of $Co_{1-x}Ga_x$ Thin Films on GaAs (100)

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Abstract

Films of the B2-structure intermetallic compound $Co_{1-x}Ga_x$ have been grown on GaAs (100) surfaces using molecular beam epitaxy. The stoichiometry of the films was varied from x=0.39 to 0.74. For x<0.5, the films reacted with the GaAs substrate after annealing to only 300°C. Films with 0.62<x<0.74 grew with the B2 structure, even though the bulk Co-Ga phase diagram predicts that a mixture of $Co_{1-x}Ga_x$ and $CoGa_3$ phases should have formed. After heating to 500°C, these films disproportionated to form the expected mixture of phases. Films with 0.5<x<0.6 were especially stable, with no products forming until the samples were annealed to above 500°C.

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