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13. ABSTRACT *(Maximum 200 words)*

The objective of this research project was to fabricate, characterize and understand resonant-tunneling diodes based on semi-metallic quantum wells of ErAs, and self-organized rare-earth-arsenide/semiconductor nano-composites. Three terminal resonant tunneling transistors with rare-earth arsenide semi-metal quantum wells have been fabricated. Dispersion of the resonant channel, with quantum well thickness, reveals that electrons tunnel through quantized hole states in the semimetal quantum well. The resonant channel exhibits a giant splitting in a magnetic field due to exchange interacction with the magnetic moment on the Er 3+ ion. The exchange coupling depends on the quantum well thickness in agreement with recent theory. Self organized nano-composites of rare-earth arsenide islands in GaAlAs heterostructures have been grown by MBE. Island size can be controlled by growth temperature and/or high temperature anneal. Superlattices comprises of layers of ErAs islands have been grown. Picosecond near infrared photo-response has been measured in these semi-metal - semiconductor nanostructures.

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Progress Report: 1 August 1995-31 July 1996

PI: S.James Allen,
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F49620-93-0329, "Resonant tunneling and hot electron spectroscopy in buried rare-earth arsenide/semiconductor heterostructures"

ASSERT - F49620-93-0440, "Non-linear terahertz electronics with self organized rare-earth arsenide semi-metal/semiconductor composites" also known as "Rare-earth arsenide/semiconductor heterostructures: Internal photoemission from semi-metal quantum wells"

Objectives:

Magnetic, semi-metal quantum wells.

Grow rare earth arsenide / III-V semiconductor heterostructures for quantum transport devices.

Fabricate resonant tunneling diodes and resonant tunneling transistors based on semi-metal quantum wells.

Measure document and understand resonant tunneling in magnetic semi-metal quantum wells.

Rare-earth arsenide / III-V nano-composites.

Grow self - organized rare-earth arsenide semi-metal / semi-conductor nano-composites.

Measure document and understand the transport and optical propoerties of these nano-composites.

- Measure terahertz non-linearities of self-organized Schottky diode arrays.and relate to material composition and structure.
- Determine the near-infrared photo-response due to internal photo-emission in rare-earth arsenide / III-V semiconductor nano-composites.

Assess the importance of magnetic, rare-earth arsenide III-V semiconductor heterostructures and nanocomposites for new high speed electronics and opto-electronics.

Status of Effort:

Three terminal resonant tunneling transistors with rare-earth arsenide semi-metal quantum wells have been fabricated. Dispersion of the resonant channel, with quantum well thickness, reveals that electrons tunnel through quantized hole states in the semimetal quantum well. The resonant channel exhibits a giant splitting in a magnetic field due to exchange interaction with the magnetic moment on the Er^{3+} ion. The exchange coupling depends on the quantum well thickness in agreement with recent theory.

Self organized nano-composites of rare-earth arsenide islands in GaAlAs heterostructures have been grown by MBE. Island size (~10 to ~200 nm) can be controlled by growth temperature and/or high temperature anneal. Superlattices comprised of layers of ErAs islands have been grown. Picosecond near infrared photo-response has been measured in these semi-metal - semiconductor nanostructures.

Rare-earth arsenide "cluster to cluster" transport exhibits giant magneto-resistance at low temperatures as the nano-clusters are polarized in an applied magnetic field. Immersed in a δ-doped layer, ErAs nano-clusters control 2-dimensional electron transport. At percolation a self organized Schottky diode array is formed, that is potentially important for terahertz harmonic generation.

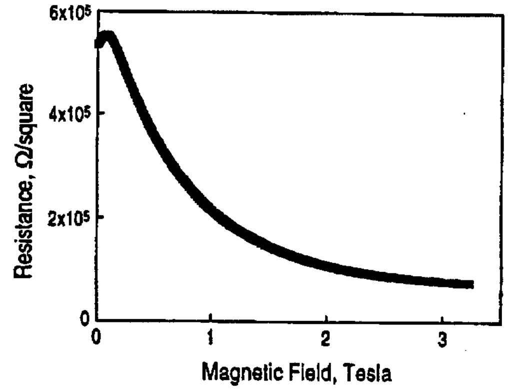

Fig.1 Negative magneto-resistance of ErAs cluster arrays.

Accomplishments/New Findings:

Giant negative magneto-resistance in ErAs semi-metal/semiconductor nano-composites is found at low temperatures. (Fig.1.) This suggests that cluster to cluster hopping transport is a strong function of the relative magnetization of the clusters. While these measurements are performed at low temperature, they indicate that transition metal pnictide nano-composites, magnetized at room temperature, may support large magneto-resistance and be important for information storage and magnetic sensors.

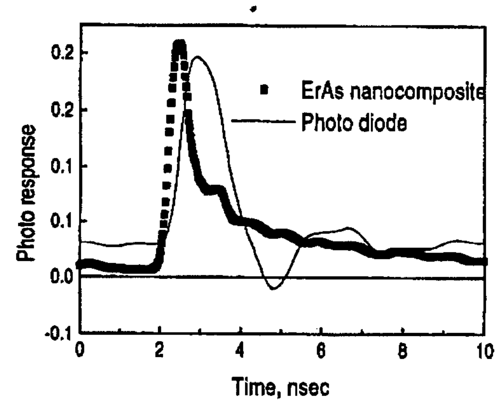

Fig. 2. Photo response of a metal/nano-composite/metal photo detector to 1 psec pulse of NIR radiation.

Fig. 3. A 2-dimensional array of ErAs islands in GaAs.

Self organized semi-metal / semiconductor nano-composites (ErAs islands in undoped GaAs) exhibit fast near infrared photo-response. (Fig. 2.) The ability to control the island size, the 2-dimensional semi-metal island density and the number of layers and spacing will make possible optimization of photo-response and speed.

By controlling the density of ErAs islands (Figs. 3), immersed in a δ-doped layer, and the δ-doping concentration we can control the "connectivity" or "percolation" of a two-dimensional electron gas. Theory indicates that the non-linear response should be enhanced at percolation. The ability to grow an arbitrarily large number of layers permits optimizing both the non-linear response of a single layer and the coupling to the radiation field to the macroscopic material. These self-organized Schottky diode arrays are potentially important for terahertz harmonic generation.

Personnel Supported:

Faculty - S.J. Allen (UCSB), C. Palmstrøm (U. Minnesota).

Post-doctoral researchers - F. Hegmann (UCSB), Mickey Yu (U. Minnesota)

Graduate student researchers - D. Brehmer, D. Schmidt, K. McCormick, (James Ibbettson, participated without support.)

Undergraduate student researchers - S.-P. Chau

Publications:

"Experimental determination of the Fermi surface of thin Sc1-xErxAs epitaxial layers in pulsed magnetic fields." Bogaerts, R., Herlach, F., De Keyser, A., Peeters, F.M., Brehmer, D, Allen, S.J. et al., Physical Review B (Condensed Matter), **53**,15951 (1996).

"Resonant tunneling through rare earth arsenide, semimetal quantum wells." Brehmer, D.E., Kai Zhang, Schwarz, Ch.J., Chau, S.-P., et al., Solid-State Electronics, **40**, 241 (1996).

"Quantum oscillations in the Hall effect of thin Sc/sub 1-x/Er/sub x/As epitaxial layers buried in GaAs." Bogaerts, R., De Keyser, A., Herlach, F., Peeters, F.M., Brehmer, D, Allen, S.J., et al. Proceedings of Conference on High Magnetic Fields in Semiconductor Physics, Edited by: Heiman, D. Singapore: World Scientific, 1995. p. 706-9.

Interactions/Transitions:

International Conference on Semiconductor Microstructures and Microdevices, Cincinatti, OH August 1995

Modulated Semiconductor Structures, Madrid July 1995

International Conference on Semiconductor Heteroepitaxy, Montpelier, France, July 1995

New discoveries, inventions, or patent disclosures.

None.

Honors/Awards:

Humboldt Science Award, 1995

Fellow of the American Physical Society, 1985

Distinguished Member of Technical Staff, 1983