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Dielectric Properties of Ordered and Disordered Particulates in Semiconductor Matrices

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Michael R. Melloch
School of Electrical and Computer Engineering
Purdue University
West Lafayette, IN 47907-1285

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Dr Michael R. Melloch

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Purdue Research Foundation
1063 Hovde Hall
West Lafayette, IN 47907-1063

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We have demonstrated a very unique application of LTG-GaAs for nanometer scale ohmic contacts to GaAs. We coat an LTG-GaAs layer with a self-assembled monolayer of xylyl diol, which serves as a metal/semiconductor interface layer. The xylyl diol molecules are 1.8 nm long and have a thiol group at each end to provide chemical bonding to the GaAs and to the gold clusters. The IV data of the contact shows good ohmic behavior with repeatability between various clusters distributed across the surface. We have achieved a specific contact resistivity of 1×10^{-6} ohm cm^2. Current densities above 1×10^{6} A/cm^2 have also been observed.

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Accomplishments/New Findings:

- We formed a tunnel diode from GaAs containing excess arsenic. The excess arsenic was incorporated by molecular beam epitaxy at reduced substrate temperatures. The incorporation of the excess arsenic during growth results in a more efficient incorporation of silicon on donor sites and beryllium on acceptor sites. The better dopant incorporation, along with trap assisted tunneling through deep levels associated with the excess arsenic, results in a tunnel junction with record peak current density of 1800 A/cm^2, zero-bias resistance of under $1x10^{-4}$ Ω-cm, and room-temperature peak-to-valley current ratio of 28. High-quality tunnel junctions, such as the new one we have demonstrated, have a number of applications including series connections between tandem solar cells, non-alloyed ohmic contacts, digital logic, and high-frequency oscillators.

- We demonstrated a velocimeter or vibrameter based on a low-temperature grown, multiple-quantum well (LTG-MQW) structure. The LTG-MQW is used to store a hologram of the target with a voltage strobe using the photorefractive effect that we previously demonstrated in these LTG-MQWs. The stored hologram contains the phase distortion the target causes on the reflected laser beam. If the target is moving, or vibrating, the laser beam reflected off the target will mix with the reference laser beam and impose a moving grating on the stored hologram in the LTG-MQW. Because the hologram is spatially fixed, this moving grating will result in an oscillatory output whose frequency is the same as the Doppler shift induced on the reflected laser beam by the target. The result is that this LTG-MQW functions as a velocimeter or vibrameter. This technology has many potential applications including monitoring in production.

- Reduced temperature growth of GaAs by molecular beam epitaxy (MBE) incorporates excess arsenic into the crystal. With anneal this excess arsenic precipitates. The resulting arsenic precipitates and residual defects reduce the carrier lifetime. Low temperature grown (LTG) GaAs, which has about 1% excess arsenic, has a carrier lifetime of about 1 ps. Controlling the growth temperature, and hence controlling the excess arsenic concentration, the carrier lifetime can be controlled. We have used this control of the carrier lifetime to tailor material for applications as metal-semiconductor-metal (MSM) photodetectors (PDs). Using intermediate temperature growth (ITG), the lifetime can be controlled so that it is a little longer than the transit time between electrodes. This removes the slow tail response typical of the impulse response of MSMs, yet does not significantly reduce the responsivity. Since the MSM photodetector has a lower capacitance per unit area than a PiN photodetector, larger-area high-speed photodetectors are possible. The samples in this study consist of a 1 μm thick ITG-GaAs light absorption layer grown at 400 °C by MBE, which contains about 0.02% excess arsenic. On top of this a 30 nm thick layer of $Al_{0.3}Ga_{0.7}As$ was grown to improve the surface mobility and the structure was capped with an $Al_{0.5}Ga_{0.5}As$ layer. The samples were then annealed at a temperature of 800 °C. MSM-PDs with finger spacing varying from 2 μm to 6 μm were then fabricated by depositing 1 μm wide Ti-Au fingers using standard photolithography and lift-off techniques. The light absorption region of the device has a square geometry with an area of 400 μm X 400 μm. The devices were contacted using a ground-signal-ground pad arrangement. The 6 μm spacing MSM had a FWHM of 86 ps (4 GHz Bandwidth) and a fall time of 112 ps for its temporal response. The devices studied also had dark current densities in the range of 4.2 fA/μm^2 and responsivities in the range of 0.12 to 0.22 A/W. Both the temporal response and dark currents demonstrate dramatic improvement for large-area detectors. The reduced lifetime of the ITG-GaAs light-absorption region and the reduced device capacitance of the MSM structure have improved the temporal response of the device. Thus, we have shown that ITG-GaAs is an excellent material for fabricating large-area MSM-PDs.

- The real part of the permittivity of annealed low temperature grown gallium arsenide (LTG-GaAs) has been measured via capacitance measurements taken on p-i-n devices. The intrinsic region of the devices contained LTG-GaAs annealed at 700 °C, 800 °C, and 900 °C for 30 sec. The capacitance trends as a function of frequency for the annealed LTG-GaAs samples were compared to that of GaAs grown at a standard substrate temperature. An increased screening of the electric field was observed for the LTG samples as the test frequency was lowered. The capacitance measurements were taken at various test temperatures, enabling the computation of an activation energy of the electric field screening in the annealed LTG-GaAs from Arrhenius plots.

- As semiconductor devices are downscaled, the demand on ohmic contacts will become more stringent. In particular, suitable contacts must provide low contact resistance in nanometer scale contact areas, and must be spatially uniform at the nanoscale. We have demonstrated a very unique application of LTG-GaAs for nanometer scale ohmic contacts to GaAs. We coat an LTG-GaAs layer with a self-assembled monolayer of xylyl diol, which serves as a metal/semiconductor interface layer. Controlled size nanometer scale contact areas were defined by sparsely depositing gold clusters with diameters of 4 nm. The xylyl diol molecules are 1.8 nm long and have a thiol group at each end to provide chemical bonding to the GaAs and to the gold clusters. The nature of the contact to the GaAs by the Au clusters was investigated with scanning tunneling microscopy (STM). The IV data of the contact shows good ohmic behavior with repeatability between various clusters distributed across the surface. We have achieved a specific contact resistivity of $1x10^{-6}$ ohm cm^2. Current densities above $1x10^6$ A/ cm^2 have also been observed.

- We have investigated the effects of post-growth annealing on Al-Ga interdiffusion and arsenic precipitate coarsening in AlAs/GaAs superlattices grown by molecular beam epitaxy at low temperatures. High-resolution x-ray diffraction spectra show a significant decrease in the number and intensity of satellite peaks for the *ex situ* annealed compared with the as-grown superlattices, a feature that is often attributed to a reduction in interface abruptness. However, our cross-sectional scanning tunneling microscopy images show significant variation in the apparent superlattice period of the *ex situ* annealed compared with the as-grown superlattices. For the as-grown superlattices, preferential arsenic precipitation on the GaAs side of AlAs/GaAs interfaces is evident. In the *ex situ* annealed superlattices, a preference for arsenic precipitates at the GaAs on AlAs interface is apparent, although the arsenic precipitates are no longer restricted to the interface region. Thus, the apparent change in superlattice period is likely due to variations in arsenic precipitate density, which may be influenced by AlAs-GaAs alloying at the AlAs/GaAs interfaces.

Personnel Supported:
Faculty: Michael R. Melloch
Research Scientist: Marian Hargis
Post-doctoral Student: Eric S. Harmon
Support Engineer: David Lubelski
Graduate Students: Kirk Yap, Pranav Kalavade, Shibly Ahmed, Sumiya Imam, Vijay Krishnamurthy and Mubin Ahmed

List of Awards
M.R. Melloch was elected Fellow of the Institute of Electrical and Electronic Engineers January 1999, elected Fellow of the American Vacuum Society June 1999, and elected Fellow of the Optical Society of America February 2000.

List of Publications Acknowledging Support:

1. I. Lahiri, R.M. Brubaker, D.D. Nolte, and M.R. Melloch, "Two-Wave Mixing in Stark-Geometry Photorefractive Quantum Wells Using Moving Gratings," Appl. Phys. Lett. 69, 3414(1996).
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Interactions/Transitions:
Presentations/Presentations at Conferences:

1. J. Ye, J.C.P. Chang, D.T. McInturff, M.R. Melloch, and J.M. Woodall, "Precipitation in Fe-doped GaAs or Ag-Implanted $Al_{0.3}Ga_{0.7}As$," 39th Electronic Materials Conference, Fort Collins, CO, June 25–27, 1997.
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