Wednesday Afternoon, September 20, 2023

Novel Materials

Room Ballroom A - Session NM-WeA

Low Dimensional and Topological Materials

Moderator: Prof. Dr. Joshua Zide, University of Delaware

12:15pm **NM-WeA-1 Piezo- and Flexoelectricity Arising from Extreme Strain Gradients in Bent GaAs Nanowires**, *F. Marin, O. Brandt,* ***Lutz Geelhaar***, Paul-Drude-Institut für Festkörperelektronik Leibniz-Institut im Forschungsverbund Berlin, Germany

Strain induced by lattice mismatch can be employed to engineer the electronic properties of semiconductors and enhance device performance. Conventionally, only homogeneous strain is considered, but in nanostructures strain gradients can be relevant. In particular, our group has demonstrated for freestanding GaAs nanowires (NWs) controlled bending resulting in extreme strain gradients [1]. Here, we analyze the effect of such gradients on charge carrier recombination.

GaAs NWs are grown under Ga droplets by molecular beam epitaxy on pre-patterned Si substrates under conditions that lead to an exceptionally low degree of polytypism so that their low-temperature photoluminescence spectra exhibit only two transitions characteristic for zincblende GaAs [2]. Spectra with multiple transitions as observed in typical GaAs NWs would prohibit the subsequent analysis. Bending is induced by the growth of a lattice-mismatched asymmetric (Al,In)As stressor shell on only one NW side.

Even moderate bending induces a substantial red-shift of the free-exciton transition that cannot be explained by the change in band gap due to strain alone but indicates the presence of internal electric fields. These fields arise from both piezo- and flexoelectricity. We emphasize that flexoelectricity is an effect occurring in all dielectric materials under strain gradients but whose influence on the electronic transitions of semiconductors has not been studied experimentally.

For further analysis, systematic variations in NW diameter and bending curvature are needed. The former is modified by symmetric (Al,Ga)As shell growth or thinning by thermal evaporation. The latter is affected by the diameter and stressor shell thickness. We can predict the resulting experimental curvature variations by analytical strain calculations following linear elasticity.

In bent NWs with the same diameter, the free-exciton transition red-shifts with increasing curvature. For NWs with similar curvature but different diameter, we systematically observe a stronger red-shift with larger diameter. Since, for a given curvature, the strength of the piezoelectric field depends on the diameter but the flexoelectric one does not, these experimental data allow to disentangle the piezo- and flexoelectric effect on the electronic transitions of inhomogeneously strained GaAs.

More generally, our study has the potential to elevate the concept of strain engineering in semiconductors to a new level, exploiting spatially inhomogeneous instead of homogeneous strain.

[1] Lewis et al., Nano Lett. 18, 2343 (2018).

[2] Oliva et al., arXiv:2211.17167 (2022).

12:30pm **NM-WeA-2 InAs Quantum Dot Nucleation on Finite Surface for Scalable Quantum Light Sources**, ***Chen Shang***, *Y. Pang, M. Kennedy,* University of California Santa Barbara*; G. Moody, J. Bowers,* University of California at Santa Barbara

The development of quantum photonic technologies will fuel a paradigm shift in data processing and communication protocols. A controlled generation of non-classical states of light is a challenging task at the heart of such technologies. Epitaxially grown self-assembled semiconductor quantum dots (QDs) offer the advantages of deterministic generation of single photons and prospects of device integration. Even though self-assembled QDs on planar substrates have demonstrated superior single deterministic single photon emission, the random distribution of the QDs limits the scalability of the emitters. In this work, we realize site-controlled nucleation of InAs QDs in SiO_2 pockets patterned on unetched GaAs substrates. Pockets with various dimensions aligned to the <1 1 0> directions of the III-V crystal were fabricated with the anticipation that the QD nucleation process would depend on the dimensions of the finite nucleation surface.

The initial 1.5 µm SiO_2 was deposited on GaAs with PECVD. To protect the surface of epi-ready GaAs substrate, the oxide pockets were formed by ICP dry etching for the first 1.3 µm oxide followed by BHF dip for the remaining oxide. After calibrating the growth temperature offset induced by the oxide patterns, InAs QDs were deposited in the pockets with both buried dots and exposed surface dots for photoluminescent (PL) and AFM characterizations, respectively. The reference QD structures grown on planar GaAs substrate have an areal density of 5×10^{10} cm^{-2}, a typical dot height of 8 to 9 nm, and an emission wavelength of 1292 nm. However, a blue shift of the emission wavelength and a significant reduction of density have been observed for QDs nucleated in the pockets on finite surfaces. The smaller the pocket dimensions, the fewer and bluer the dots, with no observable dots in pockets smaller than certain dimensions. Compared to the dots grown in rectangular pockets, dots grown in square pockets with the same width are generally bluer and sparser. This is attributed to indium adatom diffusion onto the edge of the finite surfaces and adatom evaporation at the corners. Square pockets provide an additional diffusion path to the surface edge. At the same time, the surviving indium adatoms would diffuse onto the fewer nucleation centers in smaller, yet not too small, pockets resulting in larger dot sizes. Thus, in combination with the growth conditions, one could control the location and the structure of the dots by simply adjusting the pocket dimensions without etching the substrate. Such QD nanoparticles could potentially function as scalable on-chip quantum light sources for on demand single photon streams.

12:45pm **NM-WeA-3 Epitaxial Cd_3As_2 Heterostructures for Vertical Device Architectures**, ***Anthony Rice***, *J. Nelson, A. Norman, K. Alberi,* National Renewable Energy Laboratory

Dirac semimetals provide exciting opportunities in a number of applications, owing to their gapless band structures, high electron mobilities, broadband light absorption, and fast carrier dynamics. Cd_3As_2 is a particularly promising example due to it's similarity to a number of existing III-V and II-VI technologies. A significant limiting factor to date has been its high vapor pressure, leading to growth temperatures as low as 115 °C, also significantly limiting the ability to grow epitaxial layers on top. While there have been successful reports of device structures incorporating, among others, Al_2O_3, pentacene, and metallic layers, more sophisticated devices taking advantage of band structure engineering would require higher quality, epitaxial layers.

Here, we present the first demonstration of a fully epitaxial vertical heterostructure containing Cd_3As_2 layers. Starting from existing growth approaches to high quality Cd_3As_2 (112) growth on II-VI/GaAs(111)B structures [1], CdTe capping layers were nucleated at Cd_3As_2 growth temperatures. While underlaying Cd_3As_2 layers survived temperatures much higher than possible without a capping layer, the low energy Cd_3As_2(112) surface results in visible pinholes and makes conformal layers <50nm thick impossible. Combining previously mentioned growth approaches, and demonstration of growth on GaSb(001), Cd3As2(001) is grown on GaAs(001). By moving to a higher energy (001) surface, smooth CdTe capping layers as thin as 5nm are achieved, while preserving Cd_3As_2 film quality, with electron mobilities >10,000 cm^2/V-s. Subsequent deposition of a p-type Zn_3As_2 layer creates in a p-b-n structure, as measured with C-V and I-V measurements [2]. Photodiode behavior is demonstrated up to 1000 nm. This work sets the foundation of future epitaxial devices containing Dirac semimetals.

This work was performed by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding was provided by the U.S. Department of Energy, Office of Science, Basic Energy Sciences, Division of Materials Sciences and Engineering, Physical Behavior of Materials Program under the Disorder in Topological Semimetals project.

[1] A. D. Rice, K. Park, E. T. Hughes, K. Mukherjee, K. Alberi. *Phys. Rev. Mat*. **3**, 121201(R) (2019)

[2] A.D. Rice et al. *Adv. Funct. Mater.*2022, 32, 2111470.

1:00pm **NM-WeA-4 Closing Remarks and Thank Yous**,

Author Index

Bold page numbers indicate presenter