Spectroscopic Ellipsometry Focus Topic
Room On Demand - Session EL-Contributed On Demand

Spectroscopic Ellipsometry Contributed On Demand Session

EL-Contributed On Demand-1 One-Pot Microwaved Synthesized Luminescent Carbon Quantum Dots From Various Citrus Fruit*, T. Gunawansa, **Sangram Pradhan**, M. Bahoura,* Norfolk State University

Green synthesized carbon quantum dots have been competitive alternatives to conventional heavily precursor dependent quantum dots due to their high biocompatibility, enhanced luminescent properties, simplicity, less toxicity, and repeatability all while being immensely cost-effective. Additionally, quantum dots are time-consuming to fabricate through standard wet chemical route. However, the utilization of a one-pot microwave allowed for the creation of more amount of size dependent luminescent carbon dots in short span by varying the cook time and fine controlled temperature. We have successfully synthesized carbon quantum dots from a variety of citrus fruits by fine-tuning the time, temperature, and pressure of the microwave. Furthermore, this comparative study highlighted the effects of the diverse fruit juices. After synthesis, the carbon quantum dots were characterized by transmission electron microscopy to determine nanostructure, Fourier transform infrared spectroscopy to analyze chemical bonding, ultraviolet-visible spectrophotometry, and photoluminescent spectrophotometry to evaluate absorption spectra and, emission/quantum yield of the materials respectively. These green synthesized one-pot microwaved carbon quantum dots have ample potential in enhancing optoelectronic, biosensing, and bioimaging applications.

EL-Contributed On Demand-4 Sub-Surface Imaging of Atomically-Thin Semiconductors Beneath Dielectrics Based on Optical Standing Wave Using Photoelectron Emission Microscopy With Deep-Ultraviolet Photoexcitation*, **Taisuke Ohta**, M. Berg,* Sandia National Laboratories*; F. Liu,* Los Alamos National Laboratory*; S. Smith, G. Copeland, C. Chan,* Sandia National Laboratories*; A. Mohite,* Rice University*; T. Beechem,* Sandia National Laboratories

Deep ultraviolet light sources provide new (and renewed) perspectives to photoemission experiments. In this talk, we will present an unconventional imaging approach using photoelectron emission microscopy to visualize two-dimensional materials sandwiched between amorphous thin-film dielectrics. Non-destructive imaging of fabricated nano-structures or nano-materials covered by dielectrics is highly sought after for diagnostics of optoelectronics devices. Exploiting the optical standing wave formation in the dielectrics cavity, we show imaging of atomically-thin MoS2 flakes buried beneath HfO2 overlayers up to 120 nm in thickness. The presence of MoS2 flakes modifies the optical response of the dielectric stack locally. Accordingly, the cavity resonance condition varies between the sample locations over buried MoS2 and surrounding areas, resulting in image contrast with submicron lateral resolution. This sub-surface sensitivity underscores the role of optical effects in photoelectron imaging with low-energy photons. Utilizing the optical effects and the overarching photoexcitation wavelengths in photoemission experiments presents possibilities to expand the materials and the phenomena of interests that can be pursued.

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EL-Contributed On Demand-7 A Comparison of Mueller Matrix Spectroscopic Ellipsometry Based Scatterometry With Cd-Small Angle X-Ray Scattering for Measurement of Feature Size, Shape and Dimension for Nanowire Fet Test Structures*, **Alain Diebold**, M. Korde,* SUNY Polytechnic Institute*; R. Kline ,* National Institue of Standards and Technology*; D. Sunday,* National Institute of Standards and Technology (NIST)*; N. Keller, A. Antonelli,* ONTO Innovation

The first volume manufacturing of field effect transistors (FETs) based on vertically stacked, horizontal nanosheets and nanowires is expected by early 2021.Although leading edge manufacturing is now possible, routine non-destructive measurement of feature shape and dimension remains a significant and unmet challenge.In this presentation, we compare the measurement capability of Mueller Matrix Spectroscopic Ellipsometry based Scatterometry (MMSE-Scatterometry)[1] with synchrotron based CD-Small Angle X-ray scattering (CDSAXS)[2] for measurement of Feature Size, Shape and Dimension for Nanowire FET Test Structure (NWTS).[1] The NWTS is composed of a periodic array of contact hole structures etched into $Si_{(1-x)}Ge_x$/Si/ $Si_{(1-x)}Ge_x$/Si/$Si_{(1-x)}Ge_x$/Si multilayers. The measurement challenge is determination of the amount of selective etching of the subsurface $Si_{(1-x)}Ge_x$ layers. This is also known as the cavity etch. Our research shows that MMSE-scatterometry provides a rapid means of determining the average amount of etch and is sensitive to anisotropic changes in the contact hole.Our initial results show that CDSAXS may be sensitive to differences in the amount of etch of the individual $Si_{(1-x)}Ge_x$ layers.

1. Non-destructive characterization of nanoscale sub-surface features during selective etching of multi-layered Nanowire Test Structures using Mueller Matrix Spectroscopic Ellipsometry based scatterometry, M. Korde, S. Kal, C. Alix, N. Keller, G.A. Antonelli, A. Mosden, A.C. Diebold, J. Vac. Sci. Technol. B, 38, (2020), 024007.
2. Characterization of nanoscale sub-surface features during selective etching of multi-layered Nanowire Test Structures using Critical Dimension – Small Angle X-Ray Scattering, M. Korde, S. Kal, C. Alix, , A. Mosden, R.J. Kline, D. Sunday, and A.C. Diebold in preparation.

EL-Contributed On Demand-10 Optical Constants of GaSbBi as a Function of Bi Content and Temperature*, **John H. McElearney**, K. Grossklaus, S. Lenney, M. Stevens, T. Vandervelde,* Tufts University

III-V-Bi semiconductor alloys, such as $GaSb_{1-x}Bi_x$, have garnered increased interest in recent years for their potential use in infrared optoelectronics. The Bi impurity state interacts with the host valence band edge to significantly reduce the film's bandgap [1]. In the case of $GaSb_{1-x}Bi_x$, reductions of up to 35 meV/% Bi have been reported for dilute concentrations [2]. Previous work also predicts a reduced temperature dependence of the bandgap [3,4], as well as suppressed Auger recombination with increasing Bi fraction [5]. As such, GaSbBi is a prime candidate for use in mid- to far-infrared devices, such as thermophotovoltaics, multi-junction solar cells, or IR photodetectors. To properly design these devices, however, requires a precise understanding of how the presence of Bi affects the material's optical properties.

In this work, we examine the optical constants of GaSbBi as functions of wavelength, Bi fraction and temperature by variable angle spectroscopic ellipsometry (VASE). Specifically, we determine the absorbance band edge energy, E_g, the refractive index, n, and the extinction coefficient, k, as functions of wavelength and Bi fraction for temperatures ranging from 80^o to 295^o -K. Optical data was collected using a J.A. Woolam VASE over a wavelength range of 300 nm to 3.2 µm. Samples were grown via molecular beam epitaxy (MBE) in a Veeco GenXPLOR system. Film composition was measured by x-ray diffraction and confirmed with bandgap measurements [5]. Surface morphology was examined via differential interference optical and atomic force microscopy. The results of this work will be crucial for accurate modeling of efficient mid- to long-infrared optoelectronic devices.

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[3] H. Asahi, in *Springer Handbook of Electronic and Photonic Materials,* edited by S. Kasap and P. Capper, Springer International (2017), pp. 543-555.

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EL-Contributed On Demand-13 A Machine Learning Approach to Thickness Prediction from in Situ Spectroscopic Ellipsometry Data for Atomic Layer Deposition Processes*, **S. Novia Berriel**,* University of Central Florida*; A. Arunachalam,* University of Texas at Dallas*; C. Feit, U. Kumar, S. Seal,* University of Central Florida*; K. Basu,* University of Texas at Dallas*; P. Banerjee,* University of Central Florida

Spectroscopic ellipsometery (SE) is a powerful technique that can be used in situ for the purpose of monitoring atomic layer deposition (ALD) processes. Traditionally, raw data representing the change in polarization is captured and then fit to a physics-based model via software provided by the manufacturers of the SE equipment. The model allows for the determination of optical constants (n, k) and thickness of the film. We propose an alternate approach that makes use of a machine learning (ML) algorithm trained on existing optical models. It is then possible for the algorithm to directly extract thickness without the need for optical modeling thus, reducing data requirements and computational overhead costs.

We have trained multiple ML algorithms using optically modeled in situ ZnO ALD SE to predict thickness of a given set of polarization data (i.e., Y and D) from a ZnO film. The in situ data was obtained on a J.A. Woollam® M2000 ellipsometer attached to a FIJI Gen2 VEECO® ALD system. The wavelength window of the SE data varied from 271 to 1688 nm. The thickness of the ZnO film varied from 0 – 44.08 nm, obtained during the course of 51.17 minutes of the ALD process. The five major algorithms tested were Logistic Regression (LR), Support Vector Machines (SVM), Decision Tree (DT), Random Forest (RF), and k- Nearest Neighbors (kNN). Out of these, the kNN based approach performed the best, as it effectively predicted the thickness of the ALD ZnO films to within ± 1.5 nm with over 87 % accuracy. Further, this algorithm performed remarkably well, maintaining its accuracy even when SE data was downsampled by over 50 %. The prediction accuracy of the kNN algorithm was also sensitive to the spectral bandwidth in the SE data. The kNN improved its prediction accuracy to 88 % when analysis was restricted to a narrow spectral window spanning 271 – 745 nm. Taken together, these results highlight the effective use of ML-based algorithms in predicting optical thickness in thin films, and in showcasing the redundancy in SE data, once ML algorithms are adequately trained.

EL-Contributed On Demand-16 Photonic Crystals with a Narrow-Band Defect for the Infrared Spectral Range*, **V. Paige Stinson**, S. Park, M. McLamb,* University of North Carolina at Charlotte*; D. Childers,* US Conec, Ltd.*; T. Hofmann,* University of North Carolina at Charlotte

The fabrication of micro-scale, optically sensitive, structures using additive manufacturing techniques like two photon polymerization, for instance, has attracted significant attention in recent years. In two photon polymerization, sub-wavelength scale resolution is achieved in a non-linear process; thereby enabling the fabrication of a photonic crystal for the mid-infrared spectral range. It has been observed that the performance of photonic crystals fabricated using two photon polymerization is often impaired by layer thickness non-uniformity. We report on the design and analysis of one-dimensional photonic crystals with intentional defects to allow the quantification of thickness non-uniformities within one-dimensional photonic crystals in mid-infrared spectral range. The capability of photonic crystals to provide, tunable, narrow band transmission by the introduction of a defect has been demonstrated. The optical sensitivity of such a transmission peak to layer non-uniformity is explored here. Experimental demonstration, using FTIR microscopy, corroborates a strong correlation between stratified optical layer model calculations in which the expected impact of layer non-idealities is considered. These structures can provide an exceptionally efficient alternative to determining the layer non-uniformity of complex structures compared to conventional methods. We envision the use of FTIR microscopy-based characterization of infrared photonic crystals with defects for the process parameter optimization used for two photon polymerization fabrication.

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