Spectroscopic Ellipsometry
Room 209 F W - Session EL1-TuA

Spectroscopic Ellipsometry Material Applications

Moderators: David Aspnes, North Carolina State University, **James Hilfiker**, J. A. Woollam Co., Inc.

2:15pm **EL1-TuA-1 Optical Properties of Chromogenic Thiazolothiazole-embedded Polymers**, *Nuren Shuchi, Dustin Louisos, Glenn D. Boreman, Tyler Adams, Michael G. Walter,* University of North Carolina at Charlotte*; **Tino Hofmann**,* New Jersey Institute of Technology **INVITED**

The growing demand for advanced optical technologies capable of dynamic manipulation of spectral properties through external stimuli has spurred significant interest in chromogenic materials with tunable optical properties. Chromogenic materials that exhibit reversible changes in their optical properties in response to optical stimuli are called photochromic materials [1,2].These materials have been demonstrated to play a significant role in facilitating the development of tunable infrared metasurfaces by leveraging their light-induced changes in optical properties [3]. The development of photochromic materials that exhibit strong and reversible changes in their optical properties in the infrared and visible spectral regions could offer an alternative approach to achieving tunable ir/vis metasurfaces, potentially with advantages in terms of cost, fabrication, or power consumption.Viologens represent an important class of photochromic materials [4]. Their properties can be enhanced by incorporating a thiazolo[5,4-d]thiazole (TTz) fused, conjugated bridge, an approach that has gained growing interest due to its strong fluorescence, solution-processability, and reversible photochromic transitions. Notably, dipyridinium thiazolo[5,4-d]thiazole viologens exhibit high-contrast, rapid, and reversible photochromic changes when integrated into a polymer matrix. Upon exposure to radiation with energy exceeding 2.8 eV, they undergo a color transition from light yellow (TTz^{2+}) to purple (TT^{+}) and then to blue (TTz^{0}) due to two distinct photoinduced single-electron reductions [5]. In this presentation, we report on a parameterized dielectric function of photochromic dipyridinium thiazolo[5,4-d]thiazole embedded in polymer obtained from a quantitative analysis of the polarization-sensitive optical response in the visible and infrared spectral ranges. In addition to discussing the photochromically-induced changes to the optical response we will report on recent results on the infrared imaging contrast obtained for this material as well as interesting temporal responses observed upon photoexcitation. **References:** [1] J. Crano and R.J. Guglielmetti, Organic Photochromic and Thermochromic Compounds Vol. 1 (New York, NY: Kluwer Academic Publishers., 1999). [2] H. Konaka, *et al.*, Inorg. Chem. **42**, 1928-1934 (2003). [3] S. Bang, *et al.*, Micromachines **9**, 560 (2018). [4] Z. Guo, *et al.* , Adv. Opt. Mater. **12**, 2401791 (2024). [5] T.J. Adams, *et al.*, ACS Appl. Opt. Mater. **2**, 704-713 (2024).

2:45pm **EL1-TuA-3 Dielectric Function of Atomic Layer Deposition Grown VO_2 Determined by Spectroscopic Ellipsometry**, ***Dustin Louisos***, *Nuren Shuchi, Glenn Boreman,* University of North Carolina at Charlotte*; Tino Hofmann,* New Jersey Institute of Technology

VO_2 is a transition metal oxide that experiences a temperature driven metal insulator transition at 68 ˚C [1,2], which makes it a promising material for tunable optical and electronic devices [3,4]. Accurate knowledge of its optical constants is critical for design and modeling of devices, however, reported optical constants vary widely depending on deposition method, annealing recipe, and film quality. In this work, the optical properties of VO_2 thin films grown by atomic later deposition are investigated using spectroscopic ellipsometry in the visible and infrared spectral range.

VO_2 films with a nominal thickness of 35 nm were grown on c-plane sapphire substrates using atomic layer deposition [5]. Atomic layer deposition was followed by a post-deposition thermal annealing step for 30 minutes at 400 ˚C. Spectroscopic ellipsometry measurements were performed from 0.045 to 5.9 eV using the J.A. Woollam IR-VASE and RC2. Spectroscopic ellipsometry measurements were taken on the as-deposited amorphous VO_x, annealed VO_2 at room temperature, and annealed VO_2 at 100 ˚C.

A single-model dielectric function was developed to describe the dielectric function over the entire spectral range. The oscillator model for the as-deposited sample is a sum of four Gaussian oscillators [6] and one Tauc-Lorentz oscillator [7]. The oscillator model for the as-deposited VO_x sample was used to determine the oxygen content, x, using a technique given by [8]. The oxygen content was found to be approximately 2, which has the proper stoichiometry needed to anneal to VO_2. For the annealed sample, the model uses a sum of Lorentz and two Tauc-Lorentz with a Drude term [9] added for the metallic state. For the sample measured in this work, we find a resistivity of 5.71 10^{-4} Ohm·cm which is significantly lower than the resistivity found for films deposited by magnetron sputtering [10] and other atomic layer deposition approaches [11] reported recently.

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3:00pm **EL1-TuA-4 Temporal Properties of Photochromic Thiazolothiazole-Embedded Polymer Films**, ***Nuren Shuchi***, *Tyler Adams, Naz Tumpa, Dustin Louisos, Glenn Boreman, Michael Walter,* University of North Carolina at Charlotte*; Tino Hofmann,* New Jersey Institute of Technology

Organic photochromic polymers, whose photo-chemical and optical properties can be altered through optical stimulation, are found in diverse applications ranging from tinted lenses and smart windows to memory devices, actuators, tunable filters, and holographic gratings [1-4]. Recently, extended viologens containing the thiazolo[5,4-d]thiazole (TTz) backbone are increasingly attracting interest due to their strong fluorescence, solution-processability and reversible photochromic transition [5]. Especially, dipyridinium thiazolo[5,4-d]thiazole viologen exhibits high-contrast, fast, and reversible photochromic changes. When exposed to radiation with an energy larger than 3.1 eV, it transitions from light yellow (TTz^{2+}) to purple (TTz^{+}) to blue (TTz^{0}) state due to two distinct, photo-induced single electron reductions [5]. The complex dielectric function of a non-photochromic TTz derivative and a photochromic TTz-embedded polymer has been determined previously in the visible and near-infrared spectral range using spectroscopic ellipsometry [6-7].

In this presentation, we will discuss the dynamic optical properties of photochromic thiazolothiazole-embedded polymer films. Attenuated total reflectance ellipsometry was used in order to isolate surfaces exposed to oxygen-rich and oxygen-deficient environments. This facilitates the spatial separation of surface regions based on oxygen exposure and the distinction between surface and bulk contributions to the overall optical response.

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3:15pm **EL1-TuA-5 Determination of optical properties of ultrathin silane films coated on Silicon substrate by means of Immersion Ellipsometry**, ***Samira Jafari***, Brigham Young University*; Blaine Johs,* Film Sense LLC*; Matthew Linford,* Brigham Young University

This study investigates the optical properties of ultrathin silane films deposited on silicon substrates using Immersion Ellipsometry (IE). IE is a very sensitive optical technique and can determine the refractive index (n) of very thin films (< 5 nm) by analyzing ellipsometric data acquired in both air and liquid ambients (water, n=1). The immersion approach enhances the accuracy of very thin film characterization, by decorrelating the film thickness and optical constants. A series of silanes, including chloro octadecyl silane, chloro decyl silane, (heptadecafluoro-1,1,2,2-tetrahydrodecyl) silane, and other silanes were studied, revealing distinct optical characteristics attributable to their varying chemical compositions. Notably, a correlation between refractive index and electronegativity was observed, where lower electronegativity resulted in a lower refractive index, given the film thickness approximation to the molecular length. This demonstrates SIE's ability to decouple optical constants from film thickness

in ultrathin films, enabling accurate determination of optical parameters. To complement the optical analysis, X-ray photoelectron spectroscopy (XPS) was used to characterize the chemical composition and bonding states of the deposited silanes, while contact angle goniometry provided insights into the films' surface wettability. This comprehensive approach highlights IE's efficacy in characterizing transparent ultrathin films and underscores its potential for improving control over silane-based coatings in microelectronics, biomedical devices, and optical applications.

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