Thursday Morning, November 7, 2002

Photonic Materials Topical Conference
Room: C-111 - Session PH-ThM

Photonic Nanostructures
Moderator: G. P. Nordin, University of Alabama at Huntsville

8:20am **PH-ThM1 Enhanced Optical Properties Utilizing Photonic Crystal Technology**, ***L.A. Kolodziejski***, *G.S. Petrich, J.D. Joannopoulos, E.P. Ippen,* Massachusetts Institute of Technology, *S. Fan,* Stanford University **INVITED**

The optical performance of a number of photonic devices can be greatly enhanced by incorporating photonic crystal (PC) technology into the device design. One-dimensional (1D), two-dimensional (2D), and three-dimensional (3D) variations in the dielectric constant enable creation of photonic crystals; the operating wavelength is determined by the lattice constant with the size of the corresponding bandgap dictated by the contrast in dielectric constant and the structure's geometry. Due to the considerable difficulty in fabricating 3D semiconductor-based photonic crystals, 1D and 2D photonic crystal designs are being explored using GaAs-based high dielectric materials with large index contrast established by the use of oxidized AlAs (or Al_xO_y). As one example, the optical performance of a light-emitting diode (LED) is enhanced by utilizing a particular PC design. By etching a triangular array of holes into the top InGaP cladding layer of an InGaAs quantum well LED structure, the 980nm emission is resonantly extracted in the direction normal to the surface of the LED. Photoluminescence measurements indicate that a greater than 100-fold enhancement is obtained at the wavelengths corresponding to the resonant or leaky modes available for radiation; the data agree very well with three-dimensional simulations of the actual structure. Alternatively, by creating a PC with a greater volume ratio of air-to-dielectric, enhanced optical pumping can be achieved by improved coupling of the pump light into the high dielectric slab. As a second example,a 2D arrangement of dielectric rods offer opportunities for waveguiding and the creation of nanocavities. Unique differences exist in the case of guiding light within a 2D PC constructed of rods since the propagation of light now occurs in the lower effective dielectric constant material. Novel opportunities, as well as fabrication-related difficulties, will be discussed for photonic devices enhanced with PC technology.

9:00am **PH-ThM3 "Colloidal Self-Assembly, Multi-Beam Interference Lithography, and Photonic Crystals"**, ***P. Wiltzius***, University of Illinois at Urbana-Champaign **INVITED**

Photonic crystals are materials that allow us to manipulate light in new and unexpected ways. Semiconducting materials played a tremendous role in microelectronics and we expect photonic crystals to revolutionize the world of microphotonics in a similar way. Colloidal self-assembly and multi-beam interference lithography are great tools to build crystals with interesting optical properties. I will review some recent progress towards constructing photonic band-gap materials and switchable 3D Bragg gratings.

9:40am **PH-ThM5 The Fabrication and Properties of Silicon-based Three-dimensional Photonic Lattices**, ***J.G. Fleming***, *S.-Y. Lin*, Sandia National Laboratories **INVITED**

Three-dimensional photonic lattices are structurally complex elements with submicron minimum feature sizes when active in the infrared. While photonic lattices were proposed over 15 year ago and were demonstrated in the millimeter regime relatively quickly, progress towards infrared and lower wavelength structures has been slow due to fabrication challenges. However, such structures can now be readily fabricated using modifications of standard silicon processing techniques. The minimum feature sizes required to manipulate 1.5 micron radiation, 0.2 microns, are now well within the capabilities of current lithographic tools and planarity can be maintained using chemical mechanical polishing (CMP). This approach has numerous advantages, the required infrastructure is in place and is very well supported, there is a high level of control over individual feature sizes and positions and the final structures possess full three dimensional bandgaps. The ability to carefully control the position and size of structures is of critical importance to the creation of waveguides and cavities. The disadvantage of the approach is that, while the infrastructure is well established, the initial capital investment required is substantial. However, if a suitable "killer application" can be found it would be possible to quickly apply this infrastructure to the fabrication of such devices. In this presentation we will outline the range of structures that have been achieved, examples of process flows, and the properties of the structures obtained.

10:20am **PH-ThM7 Resonant Photoemission of the TiO_2/CuI Interface: Towards New Solid State Photovoltaic Cells**, *W.R. Flavell*, ***A.G. Thomas***, *A.R. Kumarasinghe, A.K. Mallick, D. Tsoutsou, G.C. Smith,* UMIST, UK, *R.L. Stockbauer,* Louisiana State University, *M. Grätzel, R. Hengerer*, Swiss Federal Institute of Technology

Currently, nanocrystalline metal oxide semiconductor films, notably anatase TiO_2, are the subject of intense discussion because of their potential application in a number of charge-separating devices such as dye sensitised liquid state and solid sta te solar photovoltaics, which are considered to be possible alternatives for Si based solar cells. In a recently proposed solid state device, p-type CuI is deposited onto n-type 'dye-sensitised' TiO_2 in order to form the pn junction central to the o peration of the cell.[1,2] In this work, resonant photoemission at the Daresbury SRS is used to investigate the electronic structure of the prototype junction formed by depositing CuI from a getter source onto both rutile and anatase single cryst al surfaces. Valence band resonant photoemission spectra at the Cu 3p-3d and Ti 3p-3d edges are monitored for a number of coverages and compared with data recorded for single crystal TiO_2 (rutile and anatase) and polycrystalline CuI. At the Cu 3 p t hreshold, a very strong and prolonged resonance is observed, consistent with earlier observations from the copper halides[3]. Shifts in the resonance energies between the 'junction' and its component layers are interpreted in terms of Cu-3d/Ti-3d hybridisation at the interface.

[1] K. Tennakone, G.R.R.A. Kumara, A.R. Kumarasinghe, K.G.U. Wijayantha, and P.M. Sirimanne, Semicond Sci Technol, 10, (1995), 1689.

[2] U. Bach, D. Lupo, P. Comte, J.E. Moser, F. Weissörtel, J. Salbeck, H. Spreitzert, and M. Grätzel, Nature, 395, (1998), 544

[3] T. Ishii, M. Taniguchi, A. Kakizaki, K. Naito, H. Sugawara, and I. Nagakura, Phys Rev B, 33, (1986), 5664. 1.

10:40am **PH-ThM8 Macroscopic and Microscopic Investigations of Dye Sensitization**, ***B.A. Parkinson***, Colorado State University, *N. Takeda*, Brookhaven National Laboratory, *C.B. France*, Colorado State University

Dye sensitization of large band gap semiconductors has been extensively studied both from a fundamental perspective and due to its practical importance. Electron injection from excited states of dyes into the conduction band of semiconductors is the principal processes of silver halide based photography and is also a key element of possible solar-to-electrical energy conversion devices. Photoelectrochemical methods have been used for many years to study the dye sensitization process but despite this a complete picture of the interfacial structure of the dye on the semiconductor surface is still lacking. We use a combination of scanning probe microscopies (AFM and STM), photocurrent spectroscopy and absorbance spectroscopy to obtain a more complete picture of the dye absorbance, sensitization efficiency and dye morphology on the semiconductor surface. Two semiconductors will be discussed, SnS_2 and TiO_2. SnS_2 has a bandgap of 2.2 eV is a useful model system for studying sensitization since atomically flat, reproducible surfaces can prepared. We have studied the morphology of several squaraine dyes on this material and were able to correlate it with the spectral response and the quantum yield for photocurrent generation. Quantum yield for electron collection per absorbed photon of 100% were observed with monolayer coverage of some dyes. The sensitization of titanium dioxide electrodes was also studied using both a ruthenium based sensitizer and a series of carbocyanine dyes with two pendant carboxylate groups to bind to the oxide surface. Rutile, anatase and brookite crystals were all investigated and the face dependence of the sensitized photocurrents was measured. The face dependence of photocurrent yield and the adsorption and desorption kinetics for a particular dye were explained by the ability of the carboxylate groups to both attach to binding sites on a given TiO_2 face.

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