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.

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

Optical Lightguides
Moderator: S. Shankar, Intel

2:00pm **PH-ThA1 Tunable Microfluidic Optical Systems**, ***J.A. Rogers***, Bell Laboratories, Lucent Technologies **INVITED**

This talk describes some of our recent work on pumped microfluidic networks for new classes of dynamically tunable fiber and integrated optical components. It presents two different types of devices. The first combines microstructured, or "holey", silica fiber with microfluidic plugs that can be tuned and pumped back and forth in the fiber using thermal pumps formed directly on the fiber surface.[1] We present two examples of devices that use this microfluidic optical fiber design. One relies on dual-fluid plugs and long period fiber gratings; this component provides variable, wavelength-tunable attenuation for dynamic gain equalization in wavelength division multiplexed optical networks. The other uses fiber tapers; it provides a broadband variable attenuator that can be useful at add/drop nodes. The second class of system combines electrowetting pumps and recirculating planar microfluidic channels with fiber and integrated optical structures. We describe the fluidic and optical physics of these devices, and we demonstrate the performance of several different components that use this design.[2]

[1] P. Mach, C. Kerbage, M. Dolinski, K.W. Baldwin, R.S. Windeler, B.J. Eggleton, J.A. Rogers, "Tunable Microfluidic Optical Fiber," Applied Physics Letters, in press.

[2] P. Mach, T. Krupenkin, S. Yang, J.A. Rogers, "Dynamic Tuning of Optical Waveguides with Electrowetting Pumps and Recirculating Fluid Channels," Applied Physics Letters, submitted.

3:00pm **PH-ThA4 A New Generation of Plastic Optical Fiber**, ***W.R. White***, *L.L. Blyler, R. Ratnagiri*, OFS Laboratories **INVITED**

During the last few years, there have been revolutionary advances in plastic optical fiber (POF) technology as a result of fibers based on perfluorinated polymers, especially poly(perfluorobutenylvinylether), commercially known as CYTOP.[1,2] Due to these new materials, the attenuation obtainable in POF has plummeted from 160 dB/km to less than 20 dB/km, and wide transmission windows have been opened in the commercially desirable wavelength range between 850 and 1300 nm. Moreover, graded-index POF(GI-POF) has been shown[3,4] to have unexpectedly large bandwidths, due to subtle interplay between low material dispersion,[4,5] high mode coupling,[4,5] and differential mode attenuation.[6] How can the remarkable properties of perfluorinated GI-POF be harnessed to deliver an extremely simple, longer reach, high bandwidth medium? To meet this goal, perfluorinated GI-POF must offer aspects of both older POF technologies and silica fiber technologies. From the POF tradition, it is important to retain simplicity of fiber termination and connector attachment. From the silica fiber tradition, we must replicate not only low attenuation and high bandwidths, but also low loss connectors and sophisticated cable designs. In this talk, I will discuss some highlights of our work to develop practical technologies for fabricating, cabling, terminating, and connectorizing perfluorinated GI-POF.

[1] Y. Koike, Proceedings of ECOC '96, v.1 p.141 (1996).

[2] K. Koganezawa and T. Onishi, Proceedings of POF Conference 2000, p.19 (2000).

[3] G. Giaretta, W.R. White, M. Wegmuller, and T. Onishi, IEEE Photonics Tech. Lett., v.12, p.347 (2000).

[4] G. Giaretta, et al, Proceedings of ECOC '99 (1999)

[5] W. R. White, M. Dueser, W. A. Reed, and T. Onishi, IEEE Photonics Tech. Lett., v.11 p.997 (1999).

[6] T. Ishigure and Y. Koike, Proceedings of POF Conference 2000, p.14 (2000).

4:20pm **PH-ThA8 Influence of Ge Content and Process Parameters on the Optical Quality of Low Temperature PECVD Deposited Silica Waveguides**, ***M. Dainese***, *L. Wosinski, H. Fernando, X. Cao*, Royal Institute of Technology, Sweden

Silica-on-Silicon technology for Planar Lightwave Circuits, based on Plasma-CVD, is a candidate for monolithic optoelectronic integration due to its potential compatibility with VLSI technology. But the standard fabrication process, that includes a final high temperature (≥1000°) consolidation step, is not compatible with this purpose. We propose a modified, full low temperature, PECVD-based process that has been optimized to obtain an as-deposited material with high optical quality. Using a capacitively coupled reactor, with 380kHz RF power supply and platen temperatures between 250° and 300°, we have investigated the properties of the as-deposited material, with emphasis on germanium doped silica glass, which forms the light guiding layer. The set of characterisation techniques includes: prism coupler, wet etch rate, FTIR, XPS, ERDA. The results show that, for pure silica, stoichiometry is controlled by the N_2O/SiH_4 flow ratio, whereas RF power affects the material structure and homogeneity, together with by-products release during surface processes. For a given SiH_4 flow and flow ratio, there is an optimum value for the deposition pressure which maximise the deposition rate (here 1750Å/min). In case of germanium doping (up to 6.5at%), the high reactivity and low surface mobility of germane radicals make the deposition more sensitive to platen temperature and produce films with higher porosity and co-ordination disorder, compared to pure silica. We demonstrate that increasing the flow ratio is not enough anymore to obtain correct stoichiometry and RF power becomes a critical variable with respect to this. The final result is a material with low optical losses (0.3dB/cm at 1.55µm), with no absorption due to higher order harmonics of either Si-H or N-H bond vibrations. Examples of photonic devices will be presented.

4:40pm **PH-ThA9 High Density Plasma Enhanced Chemical Vapor Deposition of SiOxNy for Optical Applications: Influence of Process Parameters**, ***P. Bulkin***, *D. Daineka, G. Girard, J.-E. Bourée, B. Drévillon*, CNRS, Ecole Polytechnique, France

Rapid development of integrated optics made necessary the development of the technology for fast deposition of high quality optical films that can be used as a base for waveguide fabrication. Such process shall not only produce silica films with low scattering and absorption in the communication window (1.3-1.6 microns) but also allow doping of the silica in order to create graded refractive index profiles and, maybe even convert it to active media. High-density plasma sources for PECVD, such as ECR, helicons and inductively coupled sources, are prime candidates considered for those applications. However, a process window for high density PECVD needs to be optimised for the deposition of films with thickness of several tens of microns. The deposition systems should also incorporate self-cleaning capabilities. We report in this work on extensive studies of a recently developed matrix distributed electron cyclotron resonance (MDECR) concept for the deposition of silica and silicon oxynitride films. We investigated influence of substrate temperature, microwave power, position and type of gas injection, gas composition and bias on the properties of material grown in such deposition system. Self cleaning by C2F6/O2 plasma was also studied. We show that the MDECR concept can be a technology of choice for the deposition of waveguide structures for integrated optical components.

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