SYMPOSIUM D

Materials, Integration, and Technology for Monolithic Instruments

March 29 - 30, 2005

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Proceedings to be published online
(see *ONLINE PUBLICATIONS* at www.mrs.org)
as volume 869E
of the Materials Research Society
Symposium Proceedings Series.
This volume may be published in print format after the meeting.

* Invited paper

SESSION D1: Performance Imager and Detector Arrays
Chair: Markus Boehm
Tuesday Morning, March 29, 2005
Room 2008 (Moscone West)

8:30 AM *D1.1
Vertical Integration of Hydrogenated Amorphous Silicon on CMOS Circuits. Nicolas Wyrsch[1], C. Miazza[1], C. Baliff[1], A. Shah[1], N. Blanc[2], R. Kaufmann[2] and P. Jarron[3]; [1]IMT, University of Neuchatel, Neuchatel, Switzerland; [2]CSEM SA, Zurich, Switzerland; [3]CERN Meyrin, CERN, Geneva, Switzerland.

Active pixel sensors (APS) in CMOS technology have recently gained a lot of interest. However, the fact that the pixel readout-electronics shares the die area with the sensor element is an important factor limiting the sensitivity and leads also to "dead areas" which are unacceptable for certain applications. The implementation of additional functionalities (at the pixel level) and the introduction of more advanced technologies (with smaller feature sizes) renders the problem more acute. Vertical integration of hydrogenated amorphous silicon (a Si:H) sensors on top of the readout electronics is a promising solution to this problem. It has been introduced successfully for several applications, especially for vision sensors with high sensitivity [1] or high dynamic [2], infrared light vision [3] and for particle detection [4]. a Si:H offers two significant advantages: (a) low deposition temperature ($\approx$200°C) posing, thus, no problem for the direct deposition on CMOS chips, and (b) a larger band gap (larger than that of crystalline silicon), a fact that has beneficial aspects for the applications mentioned above. This paper will review some of the main examples of this thin-film on ASIC (TFA) technology (also called thin-film on CMOS (TFC) technology). The integration of the a Si:H sensors on the CMOS chip will be discussed in detail and especially the issues regarding the a Si:H design and the influence of the CMOS chip design (i.e. its surface morphology) on the a Si:H sensor performance. [1] S. Benthien et al., IEEE Journal of Solid State Circuits, vol. 35, No. 7, pp. 939-945, 2000. [2] B. Schneider et al.,in B. Jahne, H. Haussecker, P. Geissler, Handbook on Computer Vision and Applications, Academic Press, Boston, pp. 237-270, 1999. [3] A.J. Syllaios et al., MRS Proc. Vol. 609 (2001) A14.4.1.1 [4] N. Wyrsch et al., MRS Proc. Vol. 808 (2004) in print.

9:00 AM D1.2
Influence of Design Parameters on Dark Current of Vertically Integrated a-Si:H Diodes. Clement Miazza[1], Nicolas Wyrsch[1], Gregory Choong[1], Sylvain Dunand[1], Arvind Shah[1], Christophe Ballif[1], Rolf Kaufmann[2], Nicolas Blanc[2], Mathieu Despeisse[3] and Pierre Jarron[3]; [1]Insititute of Microtechnology, University of Neuchatel, Neuchatel, Switzerland; [2]Photonics Division, CSEM SA, Zurich, Switzerland; [3]EP Division, CERN, Geneva, Switzerland.

The development of image and particle sensors based on thin-film on CMOS (TFC) technology, where the a-Si:H detectors are vertically integrated on top of a CMOS chip, has led to promising preliminary performances [1]. A high sensitivity (50 to 195 V/(μJ/cm^2)) was proven [2]. However difficulties in reaching very low dark currents (Idark$<10^{-10}$A/cm^2) on these TFC sensors were encountered [2]. Therefore, to understand the correlation between the diode architecture and the substrate topology with the observed behaviour of the dark current, some special test structures were developed and fabricated both, on glass by photolithography and on a dedicated CMOS chip designed by CERN. Thanks to these structures we could gain in testing flexibility compared to the conventional TFC sensors and investigate the influence of various design parameters on dark current. In the present paper the results of this study will be presented and the crucial parameters influencing the dark current will be evidenced and discussed in detail. This will lead to a better understanding of dark current mechanisms and give design rules together with alternative solutions to improve dark current. The final goal will be to transfer and apply this new knowledge to the fabrication of high performance/optimized TFC sensors. [1] N. Wyrsch, et al., MRS, San Francisco, Vol. 762, 2003, p. 205. [2] C. Miazza, et al., MRS, San Francisco, Vol. 808, 2004, in print.

9:15 AM D1.3
Reduction of Residual Transient Photocurrents in a Si:H Elevated Photodiode Array Based CMOS Image Sensors. Jeremy Theil, Lumileds, LLC, San Jose, California.

While a-Si:H based elevated photodiode arrays hold the promise of superior performance and lower cost CMOS-based image sensors relative to those based upon crystalline silicon photodiodes, one area where a-Si:H based sensor performance has not been as good is in image lag. This problem is only exacerbated by Staebler-Wronski Effect induced junction degradation. Image lag is caused by residual charge from photocurrents trapped within the junction once the light source is removed and can be measured for several seconds, even under continuous applied reverse bias. It is seen both in constant and variable bias pixel architectures. However, by carefully controlling a-Si:H junction bias conditions, it is possible to significantly reduce these transient photocurrents. This article will describe how the photocurrent decay time constants can be reduce by almost an order of magnitude. Finally the physical causes behind image lag in a-Si:H based photodiode arrays will be discussed.

9:30 AM *D1.4
Thin Film on ASIC (TFA) - A Technology for Ambitious Image Sensor Applications. Juergen Sterzel, Jena-Optronik GmbH, Jena, Germany.

Thin Film on ASIC (TFA) sensors are a further development of CMOS image sensors. They combine the electro optical advantages of amorphous silicon in the visual spectral range with electrical advantages of a crystalline ASIC. Additionally, because of the three-dimensional integration, compact image sensors are possible. For example, complex pixel electronics do not decrease the important image sensor parameter fill factor. In recent years, many applications have been presented, showing the potential of this technology. However, low light levels, where the signal is in the range of the detection limit, need a more fundamental analysis of image sensor parameters like noise and dark current. This talk presents work performed by the author at the University of Siegen. The progresses in the development of TFA image sensors for low light level detection (photo current <1fA) are presented. The influence of the capacitances on the sensitivity, on the dynamic behavior, and on the linearity of the transfer behavior is described. Especially the comparison of charge transimpedance amplifiers shows the sensitivity behavior of different pixel circuit input stages. Further the leakage currents of the amorphous and of the crystalline electronic parts are documented. These currents, which result in the image sensor dark current, are expressed as a function of the temperature. Expanded SPICE models consider this leakage current to describe the pixel behavior. Additionally a SPICE model will be presented, which expresses the temporal noise of the amorphous silicon. The noise of the complete pixel electronics can be evaluated with this model. Low noise behavior and a high sensitivity can be conflicting goals. This will be demonstrated with the presented model. A concept to evaluate the gain fixed pattern noise shows the photo response non-uniformity depending on the component geometry and for different pixel circuit input stages. It is important to supplement the SPICE simulation tool used so far to estimate image sensor parameters. If the pixel circuit shall be changed for new applications, the presented results are helpful, too.

10:30 AM *D1.5
Issues and Progress in Monolithic Imaging Systems. E. R. Fossum, S. Ay[1] and I. Takayanagi[2]; [1]Micron Imaging, Pasadena, California; [2]Micron Imaging, Tokyo, Japan.

Advancement in integrated circuit technology has enabled concomitant advancement in monolithic sensor technology. Perhaps the most successful example of this is in imaging where a convergence of integrated circuit technology maturity, concepts borrowed from charge-coupled devices, and some new concepts enabled the CMOS active pixel sensor camera-on-a-chip. This technology is now in widespread use most notably in camera-phones, but also in webcams, entertainment, automotive applications, biomedical applications and digital still cameras, and represents a billion-dollar-per-year-plus growing industry. This paper will begin with a discussion of the issues in implementing high performance imaging systems in a monolithic silicon chip. The issues include optical and opto-electronic performance, circuit calibration, uniformity, fundamental noise, and substrate noise coupling. Two specific examples of monolithic imaging systems will be presented. The first is a 16.85 Mpixel CMOS image sensor with 18 um pixels. This "chip" at 76x77 mm may well be the world's largest CMOS integrated circuit ever fabricated, with one chip per six-inch wafer. It is also believed to be the world's largest CMOS image sensor in both area and pixel count. The specific issues in building such a large sensor, including high full-well capacity, will be discussed. The second example is a cryogenic charged-particle imager for 2-D SIMS imaging. This 345kpixel image sensor with 20 um pixel size achieves a noise floor less than 3 ions and a dark current less than 16 electrons per *hour* at 100K. The issues associated with achieving low noise and such low dark current will be discussed.

11:00 AM D1.6
Thin Film Color Sensor Arrays. Dietmar Knipp[2,1], Robert A. Street[2], Helmut Stiebig[3], Mathias Krause[3,4], Jeng P. Lu[2], Steve Ready[2] and Jackson Ho[2]; [1]Science and Engineering, International University Bremen, Bremen, Germany; [2]Electronic Materials Laboratory, Palo Alto Research Center, Palo Alto, California; [3]Institute of Photovoltaics, Research Center Juelich, Juelich, Germany; [4]Infineon Technologies, Dresden, Germany.

The first all amorphous silicon three color thin film sensor array was

realized. Conventional color imagers using color filter arrays to separate the three fundamental components of the visible light. This approach leads to color aliasing or color moiré effects. In order to overcome these limitations color sensor arrays were realized using vertically integrated thin film sensors. The complete color information can be detected at the same spatial position of the sensor array without optical filters. The color separation is realized by two terminal nipiin structures prepared by a low temperature CVD process. The spectral sensitivity of the sensors can be controlled by the optical and optoelectronic properties of the materials on one hand and the design of the devices on the other hand. Blue light is absorbed in the top diode, whereas green and red light is absorbed in the bottom diode. By changing the applied voltage from +2V to -4V the spectral sensitivity can be changed from blue to green and red. The sensors were fabricated on top of a 512 x 512 pixel active matrix readout electronic with a pixel pitch of 100μm. Amorphous silicon TFTs were used as pixel switches. The operating principle of the all amorphous silicon three color imager will be presented. The influence of the illumination conditions and the applied bias voltages on to color separation, the lines spread function and modulation transfer function will be discussed. The p-layer of the nipiin sensor is unpatterned so that the top diode is more sensitive to crosstalk.

11:15 AM D1.7
Integration of Zinc Oxide Thin Films and Nanostructures in Polymer-Based Devices. Masashi Matsumura[1], Zvonimir Z. Bandic[2] and Renato P. Camata[1]; [1]Dept. of Physics, Univ. of Alabama at Birmingham, Birmingham, Alabama; [2]Hitachi San Jose Research Center, San Jose, California.

Zinc oxide (ZnO) exhibits a suite of properties that are desirable for monolithic integration. Its wide direct band gap (3.37 eV) and large exciton binding energy (59 meV) at 300K make it an attractive compound for UV light emitting diodes, lasers, and sensors. ZnO nanostructures with high aspect ratios that have been recently demonstrated display strong piezoelectricity and potential applications in biosensors and nanoactuators. ZnO is biologically safe and good quality polycrystalline films with moderate Hall mobilities (>1 cm^2/Vs) that can be grown at room temperature are compatible with polymeric materials. Because it is transparent in the visible, ZnO-based thin film transistors may also be used in drivers for displays and, through doping, as magnetic storage medium. If integrated into polymer-based systems, these ZnO functionalities could enable new devices with intelligent semiconductor films featuring multiple embedded sensors, data processing arrays, and distributed memory elements. In this study we have targeted the integration of ZnO thin films onto free-standing flexible polyimide films and on polyimide/Au/SiO_2 substrates with various device topologies. ZnO layers with thickness between 100 nm and several microns were deposited by pulsed laser deposition (PLD) while structural and optical properties were evaluated with x-ray diffraction and photoluminescence (PL). Room temperature PL of ZnO films deposited between 100°C and 300°C using a laser energy density of 3.0-6.2 J/cm^2 exhibit a broad spectral feature centered at 370 nm from excitonic emission in ZnO. Broader PL bands are observed between 400 nm and 500 nm due to bound exciton/complex recombinations. This PL behavior is indistinguishable from that observed for ZnO films on traditional substrates (e.g., sapphire, silicon) showing that the essential optical properties of these films are not affected by their integration into polymer-based devices. In this work we also address the challenge of spatially resolved device incorporation of nanocrystals and nanostructures. For this purpose we used a novel PLD-based technique known as Nanoparticle Beam Pulsed Laser Deposition to produce ZnO nanocrystals that are delivered in the form of a nanoparticle beam to the polyimide substrate. This method achieves the decoupling of the deposition of nanoparticles and gas phase constituents that are often present simultaneously in conventional PLD. These processes are manipulated independently by operating two separate PLD-based sources, such that one source predominantly generates nanoparticles while the other is configured for the production of a gas-phase dominated plume. We will describe how we are exploring the focused nanoparticle beam capability of this method to deposit ZnO nanocrystals of specific sizes at selected locations on our polyimide surfaces. This approach may allow the integration of new functionalities to polymer-based devices with lateral spatial resolution of tens of microns.

11:30 AM D1.8
Infra-Red Photo-Detectors Monolithically Integrated with Silicon-based Photonic Circuits. J. D. Bradley, P. E. Jessop and Andy Peter Knights; Engineering Physics, McMaster University, Hamilton, Ontario, Canada.

The development of monolithic silicon photonic systems has been the subject of intense research over the last decade. In addition to passive waveguiding structures suitable for DWDM applications, integration of electrical and optical functionality has yielded devices with the ability to dynamically attenuate, switch and modulate optical signals. Despite this significant progress, much higher levels of integration and increased functionality are required if silicon is to dominate as a substrate for photonic circuit fabrication as it does in the microelectronic industry. In particular, there exists a requirement for efficient silicon-based optical sources and detectors which are compatible with wavelengths of 1.3 and 1.5μm. While a great deal of work has focussed on the development of silicon-based optical sources, there has been less concentrated effort on the development of a simple, easily integrated detector technology. We describe here the design, fabrication and characterization of a wholly monolithic silicon waveguide optical detector, utilizing an integrated p-i-n diode, which has significant response to optical signals at the communication wavelength of 1.54μm. Measurable infra-red response is induced via the controlled introduction of mid-gap electronic levels within the rib waveguide. This approach will be shown to be completely compatible with ULSI fabrication. The requirement for the detectors to be integrated with a rib waveguide and hence the guarantee of a long optical signal-device interaction, results in electrical signals of several μAs, even for deep-levels with a small optical absorption cross-section. Further, the rise and fall time of the detectors is compatible with current monolithic, silicon device based, optical switching and modulation. We also demonstrate that these detectors can be easily integrated with on-chip amplifiers. Our results suggest that these detectors offer a cost-effective route to signal monitoring in integrated photonic circuits.

11:45 AM D1.9
Direct Growth of Ge on Si by Molecular Beam Epitaxy for CMOS Integrated Long Wavelength Optical Devices. Yu-Hsuan Kuo[1], Xiaojun Yu[1], Junxian Fu[1], Theodore I. Kamins[2], Glenn S. Solomon[1] and James S. Harris[1]; [1]Solid State and Photonics Lab, Stanford University, Stanford, California; [2]Hewlett-Packard Laboratories, Palo Alto, California.

The delay and power consumption of metal wires have become a bottleneck in the inter- and intra-chip communications of future high speed ICs. One approach to this problem is optical interconnections for high-speed signaling and clock distribution with low attenuation and crosstalk. Germanium is not only useful for near infrared (NIR) photodetection but also compatible with silicon fabrication. Ge grown on silicon will enable the low-cost monolithic integration of optical sensing and electronic processing components into the same chip. The main issue in the growth of Ge on Si is the 4% lattice mismatch, causing severe problems, like 3-D islanding and dislocations. In this presentation a two-stage growth by solid source molecular beam epitaxy (MBE) is used. First, a thin Ge layer is grown at a temperature just above the amorphous region to form a flat and relaxed buffer. A second Ge layer is then grown at a relative high temperature. Growth is studied at different temperatures, especially below 400 degree C for backend compatibility with silicon processing. As compared with other vapor growth techniques, like thick graded SiGe buffer, surfactant-meditated growth, or two-stage growth with cyclic annealing, MBE dissociates the dependence of growth rate on the substrate temperature and is useful for the investigation of growth mechanism in the low temperature region. The growth is monitored by in-situ reflection high-electron energy diffraction (RHEED), which shows streaky pattern and the line only broadens during the deposition of the first Ge layer. TEM images show that misfit dislocations are mainly confined to the Si/Ge interface, including cell-like crystal structures in some samples. X-ray diffraction (XRD) indicates the Ge film is fully relaxed, and atomic force microscope (AFM) shows a highly flat surface morphology with the best RMS roughness below 0.2 nm. The Hall mobility and absorption spectrum of Ge on Si are similar to that of bulk Ge substrates. The measured absorption coefficient is 5300 cm-1 at 1.5μm.

SESSION D2: Fabrication for 3D Devices
Chairs: Travis Blalock and Nicolas Wyrsch
Tuesday Afternoon, March 29, 2005
Room 2008 (Moscone West)

1:30 PM *D2.1
A CMOS Medium Density DNA Microarray with Electronic Readout. Roland Thewes[1], C. Paulus[1], M. Schienle[1], F. Hofmann[1], A. Frey[1], P. Schindler-Bauer[1], M. Atzesberger[1], B. Holzapfl[1], G. Beer[2], T. Haneder[1] and H.-C. Hanke[1]; [1]Infineon Technologies AG, Munich, Germany; [2]Infineon Technologies AG, Regensburg, Germany.

In a wide-spread area of biotech and medical applications tools are required for the parallel detection of presence or quantitative amount of specific DNA sequences in a given sample. Commercially available state-of-the art DNA microarray chip systems use optical detection techniques for that purpose. By avoiding the relatively expensive and complicated optical set-ups, electronic readout techniques in principle

allow more robust and easier operation, but their status of development is lower. Medium and high density (approx. > 50 resp. > 10000 sites) electronic chips require on-chip circuitry. Standard CMOS extended by the requested transducer materials allows signal amplification, signal processing, and multiplexing directly beneath the sensors. This feature translates into superior signal integrity, optimum robustness against cross talk related signal distortions, and consequently highest possible signal-to-noise ratio and dynamic range. In [1-4], the development of fully-electronic medium-density CMOS sensor arrays is reported. A redox-cycling based electrochemical sensor principle is used. A single sensor consists of interdigitated gold electrodes (width = spacing = 1 μm, diameter = 100 ... 250 μm). After immobilization of single-stranded DNA probe molecules on the Au surface, a sample containing target molecules is applied to the whole chip. Hybridization of matching DNA strands translates into increasing sensor currents [5]. The required Au sensor electrodes are provided in a post CMOS extra process. A Ti/Pt/Au stack is deposited and structured using a lift-off process. The basic CMOS technology is a 0.5 μm, 5 V, 6", n-well standard process. To allow operation of these chips within a wide field of application scenarios, the specified electronic dynamic range per sensor equals 10^{-12} A ... 10^{-7} A. Specifically adapted ADCs are operated within each sensor site, using a sawtooth generator concept where an integrating capacitor is charged by the sensor current, and reset again by a switch transistor when the switching level of a comparator is reached. The number of reset pulses is counted by a digital counter whose output provides a digital word representing the sensor signal. Based on this sensor site circuit approach, a user-friendly prototype array is derived with 8 x 16 positions , peripheral blocks such as bandgap reference, auto-calibration circuit, and serial digital electronic interface with a total amount of 6 pins for power supply and data transmission. [1] R. Thewes et al., Tech. Dig. ISSCC, p. 350, 2002 [2] F. Hofmann et al., Tech. Dig. IEDM, p. 488, 2002 [3] M. Schienle et al., accepted for publication in IEEE JSSC, 2004 [4] A. Frey et al, submitted for publication at ISCAS 2005 [5] R. Hintsche et al., in 'Frontiers in Biosensorics I', F. Scheller et al. ed., Birkhauser Verlag Basel/Switzerland, 1997.

2:00 PM D2.2
Blue Phosphorescent Cyclometalated Iridium Complexes derived from Phenylpyrazole Derivatives: Synthesis, Density Functional Theory (DFT) Calculations and Organic Light-Emitting Diodes Study. Tae-Hyuk Kwon[1], Myoung-Chul Um[1], Myoung Ki Kim[1], Hyo Soon Cho[1], Su-youn Choi[1], Kwan Hee Lee[2], Su Jin Park[2] and Jong-In Hong[1]; [1]School of Chemistry, Seoul National University, Seoul, South Korea; [2]Corporate R&D Center, Samsung SDI, Seoul, South Korea.

There have been increasing interest and research activity in organic light-emitting diodes (OLEDs), and enormous progress has been made in the improvement of color index, luminance efficiency, and device reliability. In OLED displays, blue phosphorescent materials still remain elusive because their color index and efficiency have not been fully optimized. This study shows how color tuning and emission intensity control can be possible through the modification of the main ligand on iridium (III) complexes. Herein, we report on the design, synthesis, spectroscopic study and EL data of new blue phosphorescent cyclometalated iridium complexes derived from phenylpyrazole derivatives. Our initial approach was to calculate the theoretical energy band gap of cyclometalated iridium complexes derived from phenylpyrazole derivatives via Density Functional Theory (DFT) calculations. Phenylpyrazole derivatives with substituents at appropriate positions were designed using DFT calculations and synthesized in order to give rise to λmax emission values in the blue region. Detailed solution (77 K and 298 K), film photoluminescence (PL), and EL data will be presented.

2:15 PM D2.3
Application of Magnetic Ferrite Electrodeposition and Copper Chemical Mechanical Planarization for On-Chip RF Circuitry. Santosh K. Kurinec[1], Cody Washburn[1], Daniel Brown[2], Jay Cabacungan[1] and Jayanti Venkataraman[2]; [1]Microelectronic Engineering, RIT, Rochester, New York; [2]Electrical Engineering, RIT, Rochester, New York.

Inductors are important components of radio frequency (RF) designs, from matching circuitry to passive filters. In this study, the application of electrophorectically deposited nano-ferrite material has been investigated as a technique to increase the inductance of integrated copper planar inductors fabricated using copper plating and chemical mechanical planarization. Sintered Mn-Zn ferrite particles are suspended in a medium of isopropyl alcohol with magnesium nitrate and lanthanum nitrate salts. The transportation of the particles to the substrate surface is assisted by applied electric field and particles adhere to the substrate surface by a glycerol based surfactant. Electrophorectic deposition process forms a self aligned polymeric thin film on the surface of a p-type silicon substrate selectively with respect to copper. This ferrite deposition method yields high selectivity to the inductor coils and patterned silicon substrates compatible with standard silicon technology. Measured values of inductance have been compared with simulated values obtained using a High Frequency Structure Simulator (HFSS) and analytical modeling.

2:30 PM D2.4
RF Hollow Cathode Plasma Jet Deposition of $Ba_xSr_{1-x}TiO_3$. Natale J. Ianno[1], Rodney Joseph Soukup[1], Noel Lauer[1] and Zdenek Hubicka[2]; [1]Electrical Engineering, University of Nebraska, Lincoln, Nebraska; [2]Division of Optics, Academy of Sciences of the Czech Republic, Prague, Czech Republic.

Tunable and affordable high-frequency microwave devices are the key components for the next generation of communication and radar systems. Recent advancements in the compositional development and processing science of ferroelectric BST based thin films suggest them to be among the most promising candidates for phase shifters in these systems. Since most electronic systems are built as integrated circuits on Si substrates linked via metal interconnects, it is of significant interest to integrate these BST-based thin films with Si substrates. This Si-integration technology is driven by the affordability and large size availability of Si wafers and the widespread industrial/commercial use of Si-based processing technology. Suitable low loss, passive buffer layers can be sandwiched between the Si substrate and the active BST based thin film. This materials design is fully compatible with both the coplanar and varactor phase shifter device designs. We have developed a hollow cathode deposition process that can be scaled to large areas and is capable of depositing device quality amorphous semiconducting material. In this work we present the initial results of the deposition of $Ba_xSr_{1-x}TiO_3$ thin films via this deposition technique. The films were deposited in a uhv plasma jet system from a single composite $BaTiO_3/SrTiO_3$ nozzle, and from separate $BaTiO_3$and $SrTiO_3$ nozzles. These nozzles work as rf hollow cathodes and sputter very rapidly in an Ar and O_2 gas flow. A plasma jet was created at the outlet of the nozzles and interacted with the substrate. The $Ba_xSr_{1-x}TiO_3$ thin films were deposited in this manner. Films were deposited onto silicon substrates which were coated with platinum/TiO_2/SiO_2 and on bare Si. The magnitude of the rf power was varied in the range of 50 to 150 W. Chemical composition of the films was measured by electron probe analysis. The stoichiometric ratio of the Ba and Sr was correlated with the deposition parameters of rf power, gas flow rate, and nozzle composition. We will show that in the single hybrid nozzle system, the film composition can be controlled by adjusting the ratio of $BaTiO_3/SrTiO_3$ in the nozzle, while in the dual nozzle system the film composition can be controlled by adjusting the power supplied to each nozzle. Post deposition annealing in oxygen at temperatures in the range of 650 to 750 C is necessary to form homogeneous $Ba_xSr_{1-x}TiO_3$ thin films.

2:45 PM D2.5
Optimization of the Metal/Silicon Ratio on Nickel Assisted Crystallization of Amorphous Silicon. Luis Pereira, Francisco Braz Fernandes, Elvira Fortunato and Rodrigo Martins; Materials Science Department, CENIMAT/CEMOP, Caparica, Portugal.

The aim of this work is to optimize the metal/silicon ratio on nickel metal induced crystallization of silicon layers. For this purpose amorphous silicon layers with 90, 135 and 180 nm were used on the top of which Ni layers with 0.5 nm were deposited and annealed the required time to crystallize the a-Si with different thicknesses. The data show that the a-Si layer with 90 nm reaches a 79% crystalline fraction (as detected by spectroscopic ellipsometry) after only a 2 hours annealing. No significant structural improvement is detected by ellipsometry neither by XRD when annealing for longer times. However, on samples with 135 nm after annealing for 2 hours the crystalline fraction is only 47% reaching a similar value to the one with 90 nm only after 5h, with a crystalline fraction of 82%. Here again no significant improvements were achieved by using longer annealing times. Finally, the a-Si sample 180 nm thick does not show any significant crystallization after 10h of annealing. Indeed, only after 20 h was possible to detect some crystalline fraction, that do not overcomes 52%. However when using 5 nm of Ni the a-Si was crystallized after 5h. These data clear suggest that the crystallization of thicker a-Si layers requires thicker Ni films to be effective for short annealing times.

3:15 PM *D2.6
Integrated Optical Sensing for Biological Analysis. Evan Thrush[1,2], Ofer Levi[2], Jonathan Ziebarth[2], James S. Harris[2], Stephen J. Smith[3] and Mike McGehee[4]; [1]Agilent Technologies, Palo Alto, California; [2]Department of Electrical Engineering, Stanford University, Stanford, California; [3]Department of Molecular and Cellular Physiology, Stanford University, Stanford, California; [4]Department of Material Science, Stanford University, Stanford, California.

Optical sensing remains one of the most widely used methods to study and analyze biological systems. Integrated optical systems hold much potential for portable diagnostics, high throughput experimentation and medical implants. The realization of integrated optical sensors is now possible due to development in optoelectronics over the past several decades. The focus of this research has been the development of integrated fluorescence sensors. Vertical cavity surface emitting lasers (VCSELs), PIN photodetectors and optical emission filters have been monolithically integrated to form a fluorescence sensor. The advantages of this approach are drastically reduced costs, increased parallelism and near-infrared (NIR) sensing. A theoretical limit of detection of 40 nM of IRDye 800 has been achieved on a microfluidic format. Large increases in sensitivity are possible through the systematic reduction of laser background. Another area of research has been the development of implantable optical systems within the body. Researchers at Stanford have particularly focused on imaging systems to study brain activity in-vivo. A novel imaging modality has been invented that capitalizes on organic-LED technology combined with micro-optics. This approach allows for wide-field imaging while reducing the dimension along the optical axis, creating a relatively flat system for implantable systems.

3:45 PM D2.7
Co-Firing of Low- and High- Permittivity Dielectric Tapes for Multifunctional Low-Temperature Co-Fired Ceramics.
Jae-Hwan Park, Young-Jin Choi and Jae-Gwan Park; Korea Institute of Science and Technology, Seoul, South Korea.

Based on a same glass composition, the compatibilities in cofiring between low-K and high-K hybrid LTCC material systems were studied. By designing a lithium borosilicate glass frit system carefully, we developed an optimum glass frit system for both low-K and high-K dielectric fillers. The effects of glass addition on the densification and electrical properties in low-K and high-K dielectric materials were examined. By adjusting glass compositions and contents, we tried to match low-K and high-K tapes physically and chemically.

4:00 PM D2.8
Making Wafer Bonding viable for Mass Production.
Cher-Ming Tan[1], Weibo Yu[1] and Jun Wei[2]; [1]School of EEE, Nanyang Technological University, Singapore, Singapore; [2]Singapore Institute of Manufacturing Technology, Singapore, Singapore.

Wafer bonding is an attractive wafer fabrication technology for SoC, SIP, MEMS, SOI devices etc. However, traditional wafer bonding requires high temperature annealing above 800oC, and the time required for complete bonding is usually more than 100 hours. Recently, we have developed a medium vacuum wafer bonding (MVWB) for Si-SiO2. High bonding strength (larger than 20 MPa) is achieveable at the bonding temperature of only 400oC, and the annealing time for complete bonding is only several hours (less than 5 hours). Table 1 shows the comparison of the bonding strength in MPa between traditional air wafer bonding and MVWB. The bonding efficiency (percentage of the bonded area over entire wafer area) of the MVWB is also compared with the traditional wafer bonding. It is found that at 400C and 2 hours annealing, the bonding efficiency of MVWB is 99.4% whilst for traditional wafer bonding under the same condition, it is only 91.5%. One can see that the bonding efficiency is improved by MVWB. Qualitative description of the mechanism of MVWB is proposed in present work: Medium vacuum can enhance the out-diffusion of the water molecules and other trapped impurities at the initial porous interface, hence speed up the following reaction and the formation of Si-O-Si, Si-OH+HO-Si $\leftrightarrow$ Si-O-Si+HOH and thus more bonding sites can be achieved before the interface close-up. This results in an increase in bonding strength and bonding efficiency as well as the bonding speed. Based on this, mathematical model for the MVWB has been derived, and the predicted bonding strength with time from the model agrees well with the experimental results. With the high bonding strength achievable in short time and low temperature, and that the required vacuum level is only 10-4 mbar, the cost of wafer bonding production is becoming feasible at an economical scale.

4:15 PM D2.9
Low Temperature Deposition of Indium Tin Oxide(ITO) Films on Plastic Substrates. Vandana Singh, B. Saswat and Satyendra Kumar; SCDT, IIT Kanpur, IIT Kanpur, Kanpur, Uttar Pradesh, India.

Organic light emitting diodes (OLED) require a transparent conducting electrode for injection of charge carriers and the emitted light to come out. Indium tin oxide (ITO) is a popular electrode material. The requirement of ITO is similar for solar cells and electronic papers. In order to exploit the full flexibility of organic semiconductor based large area electronic devices, the deposition of transparent conducting oxides on plastic substrates is essential. Further, processing of organic devices on plastics prohibits high temperature processing. Therefore, low temperature deposition of ITO films is very important for flat panel displays and solar cells. In this work, we have carried out a systematic study of ITO deposition on polycarbonate substrates using rf magnetron deposition. For the optimization of structure, electrical conductivity and optical transparency of ITO coated films a variety of characterization tools such as X ray diffractometer transmission measurements, sheet resistance, atomic force microscopy and spectroscopic ellipsometry were employed. The structural, electrical and optical properties of these films were investigated as a function of substrate temperature, deposition times, rf powers and different gas pressures. From these experiments, we obtained a reasonably low sheet resistance (14 W / ?) and high transmittance (75%) in the visible region on plastic substrates. The uncoated plastic substrates had a transparency of ~85%. These properties were obtained at a substrate temperature below 100°C. These experiments used Argon gas and low temperature vacuum annealing during the deposition. It is also observed that these films are not much affected by atmosphere and does not degrade with time. These films shows good conductivity even after long time ageing (two to three months). From the observations it is clear that sheet resistance decreases with increase in deposition time at the same temperature. The ITO film thickness increases as expected. If deposition temperature is increased transmission of ITO coated plastic improves. We also observe that ITO film is amorphous in nature at the temperature up to 100 ?C. AFM shows low surface roughness. Finally we have employed these ITO coated substrate in polymer LED structures using PPV. We conclude that these ITO coated substrates can be used successfully for the fabrication of organic light emitting displays.

4:30 PM D2.10
In-situ Spectroscopic Impedance of Different Transparent Conductive Oxides Before and After Sustaining Hydrogen Plasma. I. Ferreira, L. Raniero, R. Igreja, A. Pimentel, A. Goncalves, E. Fortunato and R. Martins; Department of Materials Science, New University of Lisbon and CEMOP-UNINOVA, Caparica, Portugal.

In this work we studied the properties of transparent conductive oxides - TCOs (ZnO:Ga, ITO and ZnO:In) after being exposed to different hydrogen plasma conditions. The in-situ impedance spectroscopy was used to evaluate the effect of hydrogen plasma or heat treatment in vacuum conditions on the electrical properties of the TCOs. The eventual modification of the optical transmittance was determined by UV-VIS-NIR after exposing the TCOs to the initial steps of the solar cell process. The overall results indicate the pre-heat treatment in vacuum, enhances the TCOs resistivity. Nevertheless the hydrogen plasma conditions have a great and distinct influence on the transmittance and resistivity of the different TCOs studied. The ZnO:Ga is supporting extreme plasma condition without significant degradation, while the electrical an optical transmittance of ITO and ZnO:In are reduced in more than 50%. This result is consistent with the electrical characteristics of the solar cell produced using different TCOs where the ones produced with a ZnO:Ga TCO have the lowest series resistance.

4:45 PM D2.11
Preparation of ITO Thin Films for OLED Application with O2 Gas by FTS (Facing Targets Sputtering) System.
HyunWoong Kim, GeonHi Kim, MinJong Keum and KyungHwan Kim; Kyungwon Univ., KyungGi-Do, South Korea.

In this work the ITO thin films were prepared by FTS (Facing Targets Sputtering) system under different sputtering conditions which were varying O2 gas, input current and working gas pressure at room temperature. As a function of sputtering conditions, electrical and optical properties of prepared ITO thin films were measured. The FTS system consists of facing the two targets and the substrate located apart from the center of facing the two targets. Also the energetic particles are restricted by magnetic force within plasma. Therefore the FTS system contributes to suppression of high energy particles bombardment to the substrate. In the results the FTS system can deposit high quality thin films at low temperature. In the result, as increasing O2 gas 0[sccm] to 0.2[sccm], resitivity of ITO thin film was rapidly decreased with increasing the carrier mobility. Over O2 gas 0.2[sccm], resitivity of ITO thin film was increased with a little decreasing carrier concentration, in this section, O2 gas over 0.2[sccm] the carrier mobility have a similarly value. Transmittance of prepared ITO thin film was improved about 40% to 70% at increasing O2 gas 0[sccm] to 0.1[sccm]. And at O2 gas over 0.2[sccm], transmittance of prepared ITO thin films were over 80%.

SESSION D3: Chemical Detection and Manipulation Systems
Chairs: Mark Brongersma and Jeremy Theil
Wednesday Morning, March 30, 2005
Room 2008 (Moscone West)

8:30 AM *D3.1
Integration of Fluidic and Photonic Functional Elements for More Versatile Lab-On-A-Chip Systems. Jorg P. Kutter, Klaus B. Mogensen, Detlef Snakenborg, Fredrik Eriksson, Omar Gustafsson, Thorbjorn Anderson and Henning Klank; MIC - Dept. of Micro and Nanotechnology, Technical University of Denmark, Lyngby, Denmark.

Miniaturization and integration of all elements necessary for, e.g., a chemical analysis or a biochemical assay, is at the heart of the idea of micro-Total Analysis Systems (μ-TAS) or Lab-on-a-Chip systems. However, while fluidic handling and chemical reactions in microchannel networks have come a long way, many of the detection systems necessary to monitor processes on the devices are still off-chip. This is in particular true for optical detection, where bulk optics can compromise some of the advantages of miniaturized chemical devices, such as compactness, ruggedness and portability. In our lab, we work on the integration of optical elements to improve the performance and enhance the versatility of lab-on-a-chip systems. We have used silica-on-silicon technology to realize waveguides, which can be employed for UV absorbance detection in connection with, e.g., separation techniques. A typical waveguide sandwich consists of three layers (buffer, core and cladding). The doping of the core material ensures a higher refractive index, which is a prerequisite for waveguiding. The nature of the core dopant determines the optical transmission properties. We have successfully worked with a nitrogen doping realizing UV transparent waveguides. In an effort to constantly improve the performance of waveguides, the latest generation features pure silica waveguides, which have a better transparency in the lower wavelengths and less propagation losses. Furthermore, we have fabricated arrays of up to 128 waveguides. Such waveguide arrays can be used to illuminate a channel at regularly spaced locations. Ensembles of beads or cells passing by will give off flashes of fluorescent or scattered light, which can be registered by a detector. The frequency associated with this flashing is related to the velocity of the particles. Mathematical data treatment allows the determination of particle velocities even though many hundreds of cells can be in the detection area at the same time, and it is also possible to get information about velocities changing over time. A number of applications for bead-based biochemical assays can be envisioned. While silica-on silicon technology gives excellent results, it is typically also costly and time-consuming. We have also investigated to integrate waveguides with fluidic channels using cheaper materials and simpler fabrication approaches, e.g., for a microdevice, where all functional elements (channels, waveguides and fiber couplers) are defined in SU-8. Only a single mask step is necessary and turnaround times for device production are around two days. Of course, the optical properties of SU-8 waveguides are quite different than those of glass waveguides. Finally, silicon-based on-chip photodiodes and SU-8-based fluidic dye lasers (developed by our colleagues at MIC), waveguides and fluidic channels were integrated to arrive at a higher functionality microdevice for biochemical applications.

9:00 AM D3.2
Macroporous Silicon Sensor Arrays for Chemical and Biological Detection. Karl D. Hirschman[1], Vimalan Rajalingam[1], Jeffrey Clarkson[1], Wei Sun[2] and Philippe M. Fauchet[2]; [1]Microelectronic Engineering, Rochester Intsitute of Technology, Rochester, New York; [2]Electrical and Computer Engineering, University of Rochester, Rochester, New York.

A new class of silicon-based chemical and biological sensors that offer an electrical response to a variety of substances is described. The devices utilize silicon flow-through sensing membranes with deep trench structures formed to depths up to 100um, fabricated by electrochemical etching which transforms the silicon into macroporous silicon (M-PSi). The sensors have demonstrated the ability to detect the presence of certain chemical and biological materials. Although the principle of operation of the devices is fairly complex, the transduction mechanisms can be compared to chemiresistors and chemically sensitive field-effect transistors (chemFETs). The electrical responses that have shown the most sensitivity are AC conductance and capacitance. Previous work has demonstrated that upon exposure to organic solvents (i.e. ethanol, acetone, benzene) the devices exhibit a characteristic impedance signature. The devices have also shown the ability to detect the hybridization of complementary DNA. The incorporation of other materials that have demonstrated sensitivity to low ambient levels of contaminants is also under investigation. The sensors have been designed and fabricated in linear array configurations; a microfluidic transport chip/package co-design is currently in progress. A configurable network interface has been developed to accommodate the use of the sensors for a variety of applications. Further size reduction and future integration with microelectronics will mark significant steps toward the realization of a lab-on-a-chip microsystem.

9:15 AM *D3.3
Monolithic Liquid Chemical Sensing Systems.
Steven M. Martin[1], Timothy D. Strong[2] and Richard B. Brown[3]; [1]Electrical Engineering, University of Michigan, Ann Arbor, Michigan; [2]Sensicore, Ann Arbor, Michigan; [3]Electrical Engineering, University of Utah, Salt Lake City, Utah.

The miniaturization of electrochemical transducers is crucial for the development of implantable biosensors, wearable microdetectors, and remote sensing networks due to the small dimensions required in these applications. Additionally, improvements in detection limit, reliability, use-life, and cost can be realized through sensor scaling. As sensors scale, however, the quality of their analytical response can degrade due to parasitics and noise. These deficiencies can be reduced or eliminated by creating integrated sensors which include the active sensing element(s) and the necessary instrumentation on a monolithic substrate. This work details the development of CMOS-integrated liquid chemical sensors. The sensors are cost-effectively post-processed on top of foundry-fabricated CMOS electronics using thin-film techniques. The five-mask post-process consists of three metal depositions (Ti/TiN/Ti/Pt, Ti/Au, and Ti/Ag), a passivation deposition (400C PECVD silicon nitride), a contact etch using reactive ion etching, and the photo-patterning of a permanent SU-8 layer. The devices are sealed with epoxy, the Ag is chloridized, and polymer membranes are cast over some sensors to form ion-selective electrodes. Further details of the process including metal corrosion, metal incompatibility, process-induced damage, and chemical inertness will be discussed in the full manuscript. MOSFET extracted parameters were measured versus post-processing step and showed no significant cumulative shift. The same parameters were extracted versus soaktime in a 100mM NaCl test solution and varied by less the 2% over a 35day timespan. Using electrochemical impedance spectroscopy, the leakage current through the passivation layer measured less than 5pA per sensor over a 30day timespan. The CMOS-integrated voltammetric sensors were characterized in solutions of ferricyanide, dopamine, and lead. The active sensors had a detection limit of 0.8ppb lead on two 3e-6cm2 gold electrodes. This represents a 13x improvement in detection limit/electrode area trade-off versus current, state-of-the-art systems. The integrated electronics also afforded low power consumption as the device demonstrated a 58x improvement in detection limit/power consumption trade-off versus previously published results. The CMOS-integrated ion-selective electrodes were characterized in solutions of potassium. The active sensors demonstrated a 50x improvement in lifetime and a 200x improvement in response time versus passive sensors. The performance of microsensors can be greatly enhanced by the integration of the necessary electronics. We have developed a fabrication technique for the cost-effective implementation of CMOS-integrated electrochemical sensors and verified their functionality for several different analytes. These smart sensors can be used in a wide range of applications and can additionally serve as enabling technologies for more complex, chip-scale microsystems.

9:45 AM D3.4
Study of Sputtered Hafniumoxide-Films for Sensor Applications. Christian Kunath[1], Heinrich Grueger[1], Eberhard Kurth[1], Stephan Sorge[1], Wolfram Pufe[1] and Torsten Pechstein[2]; [1]Fraunhofer IPMS, Dresden, Germany; [2]E+H Conducta, Waldheim, Germany.

Transition metal oxides apply to a variety of purposes, such as surface enhancement or as dielectric layer in semiconductor applications. Some of the metal oxide properties for instance high dielectric permittivities, temperature stability, mechanical and chemical strength make them suitable for ion concentration or gas detection sensors. As the layer thicknesses may vary widely the deposition methods need to be adopted. Atomic layer chemical vapour deposition (ALCVD) and metal organic chemical vapour deposition (MOCVD) are used for thin layers whereas physical vapour deposition (PVD) is used for thicker layers. In this paper hafnium dioxide is considered that has been deposited using r.f. sputtering of a HfO2 target in a argon/oxygen plasma on 150mm silicon wafers. The target impurity meets 30 ppm and is sufficient for the electrical and chemical layer properties for the application in mind. During layer deposition the equipment constitution has large influence on the final layer parameters. The influence of the main parameters plasma power, pressure, gas flow and gas mix was studied. During deposition the wafer and target were kept at room temperature. According to the development focus on sensor applications layer thicknesses in a range from 30 to 150nm were achieved. Layers formed in a single step and layers obtained from multiple deposition steps are compared. Rapid thermal processing (RTP) with temperature ramps of about 50K/s has been used as well as oven processing with temperatur slopes of about 3K/min to form the final state of the layer properties. Special research interest was focused on the comparision between annealing in inert and oxidizing athmospheres. Especially the absolut gas pressure and oxygen partial pressure during sputter deposition determine the final mechanical and sensor quality. Also the chemical inertness increases

with higher annealing temperature. Using X-ray diffraction the layers cristallinity has been studied. Using AFM and SEM the surface condition and grain boundaries have been characterized. Layers as deposited show generally amorphous state with only small amounts of cristallytes below 20nm in size. The crystallographic appearance can be controlled by the annealing processing. Stress measurements by laser deflection of the wafer bow revealed, that annealing convertes the original pressure layer stress into tensile stress. In order to investigate the impact on electrical properties in electronic devices dot structures and field effect transistors from this layers have been prepared and CV-characteristics and transistor functions recorded. So transfer and drain characteristics, hysteresis and dielectric properties under various environments has been obtained.

10:30 AM *D3.5
An Electronic Nose from Arrays of Polymer Composite Vapor Sensors. Nathan S. Lewis, Division of Chemistry and Chemical Engineering, California Institute of Technology, Pasadena, California.

A method is described for generating a variety of chemically diverse, broadly responsive, low power vapor sensors. A key to our ability to fabricate chemically diverse sensing elements is the preparation of processable, air stable films of electrically conducting organic composites. An array of such sensing elements produces a chemically reversible, diagnostic pattern of electrical resistance changes upon exposure to different odorants. Such conducting composite elements are simply prepared and are readily modified chemically to respond to a broad range of analytes. In addition, these sensors yield a fairly rapid, low power, dc electrical signal in response to the vapor of interest, and their signals are readily integrated with software or hardware-based neural networks for purposes of analyte identification. Principle component analysis has demonstrated that such sensors can identify and quantify different airborne organic solvents, and can yield information on the components of gas mixtures.

11:00 AM D3.6
External Coupling of Molecular Dye Emission to High-Q Microdisk Resonators. David R. Rink[1], Michael H. Bartl[4,2], Lidong Zhang[4], Galen D. Stucky[2] and Evelyn L. Hu[1,3,4]; [1]Electrical and Computer Engineering, UC Santa Barbara, Santa Barbara, California; [2]Chemistry and Biochemistry, UC Santa Barbara, Santa Barbara, California; [3]Materials, UC Santa Barbara, Santa Barbara, California; [4]California NanoSystems Institute, UC Santa Barbara, Santa Barbara, California.

Semiconductor microdisk resonators have proven to be excellent high-Q microcavities with the ability to efficiently modify emission from embedded self-assembled semiconductor quantum dots. For emerging applications in, for example ultralow threshold lasing, quantum computing, and bio-sensing, however, it would be desirable to separate emitter/resonator fabrication and incorporation. This would not only greatly expand the choice of the emitting species including colloidal nanocrystal quantum dots, organo-metallic complexes and organic dyes, but would also allow individual fine-tuning and optimization of both emitter and microresonator. It would be desirable to independently fabricate the emitter and resonator such that the emitter is not incorporated within the microdisk but rests on the surface. In order to couple to a mode of the microdisk, an emitter must coincide in frequency and spatially overlap the mode. Theoretical simulations show that the mode leaks out tens of nanometers in the vertical direction of the disk. We demonstrate here the proof-of-principle coupling of external emission from dye molecules to the cavity modes provided by a microdisk resonator. Coupling is achieved by bringing the dye molecules - embedded in a low refractive index SBA-15 type nanostructured hybrid silica matrix - in close proximity to the microdisk utilizing a fast and simple fabrication method that combines semiconductor microprocessing with sol-gel supramolecular self-assembly chemistry. We found that emission from dye molecules located at the rim of the microdisk is strongly modified, exhibiting several well-defined high-Q modes. In contrast, much poorer coupling was observed to emission of dye molecules in the center of the microdisk, and no mode structure was observed in the emission of dye molecules distant from the microdisk. We will discuss the external coupling behavior and efficiency in terms of spatial position of the emitter, properties of the silica host matrix, and microdisk dimensions.

11:15 AM *D3.7
Some Recent Applications Colorimetric Sensor Arrays. Ken Suslick, Michael Janzen, Jennifer B. Wilson and Chen Zhang; Chemistry, University of Illinois, Urbana, Illinois.

Array based vapor sensing has emerged as a powerful approach toward the detection of chemically diverse analytes. We have developed a unique chemical detection technology [1-4] in which colorimetric changes in an array of dyes constitute a signal much like that generated by the mammalian olfaction system; each dye is a cross-responsive sensor. This technology uses a disposable two-dimensional array of chemoresponsive dyes as the primary sensor elements, making it particularly suitable for detecting many of the most odiferous compounds. Striking visual identification of a wide range of VOC's are easily made at parts per billion (ppb) levels, for example to amines, carboxylic acids, and thiols (i.e., sensitivities comparable to GC-MS detection). Nearly all prior sensors rely exclusively on van der Waals interactions (e.g., physical adsorption on to surfaces, absorption into polymers) between the analytes and the sensors. Unfortunately, vdW interactions are the weakest and least selective of all intermolecular interactions and are a poor choice for any process involving molecular recognition. In contrast, our design of colorimetric sensor arrays is based chemo-responsive dyes that must contain a center to interact strongly with analytes, through reversible bond formation, strong acid-base interactions, or strong dipolar interactions. The consequent dye classes from these requirements are (1) Lewis acid dyes (i.e., metal ion containing dyes), (2) Brønsted acidic or basic dyes, and (3) dyes with large permanent dipoles (solvatochromic dyes). By using hydrophobic dyes on a hydrophobic substrate, we have avoided essentially any response to changes in humidity, which is a very serious problem for other electronic nose technology. A variety of recent applications will be discussed. [1] Rakow, N. A.; Suslick, K. S. "A Colorimetric Sensor Array for Odor Visualization" *Nature*, **2000**, 406, 710-714. [2] Suslick, K. S.; Rakow, N. A. "Colorimetric Artificial Nose Having an Array of Dyes & Method for Artificial Olfaction" *U.S.Patent6, 368, 558*; April 9, 2002.; Suslick, K. S.; Rakow, N. A.; Sen, A. "Colorimetric Artificial Nose Having an Array of Dyes and Method for Artificial Olfaction: Shape Selective Sensors" *U.S.Patent6, 495, 102*; Dec. 17, 2002. [3] Suslick, K.S.; Rakow, N.A.; Kosal, M.E.; McNamara III, W.B.; Sen, A. "Chemsensing: A Colorimetric Array Detector" *Proc.ISOEN02* (ed. A. D'Amico and C. DiNatale; IEEE: Baltimore, 2003), pp. 46-52. [4] Suslick, K. S. "An Optoelectronic Nose: Colorimetric Sensor Arrays" *MRSBulletin*, **2004**, 29, 720-725. Suslick, K. S.; Rakow, N. A.; Sen, A. "Colorimetric Sensor Arrays For Molecular Recognition" *Tetrahedron* **2004**, in press;

11:45 AM D3.8
A Novel Technology to Create Monolithic Instruments for Micro Total Analysis Systems. Konstantin Seibel, Lars Schoeler, Marcus Walder, Heiko Schaefer, Dietmar Ehrhardt and Markus Boehm; Institute for Microsystem Technology, University of Siegen, Siegen, Germany.

For micro total analysis systems methods for micropatterning, sealing, and manufacturability, as well as techniques for connecting the microstructures to the macroworld are of particular significance. Monolithic instruments consist of an assembly of three-dimensional integrated modules (e.g. fluidic networks, electrical and optical sensors, microelectronic circuits) to support the advantage of efficient interconnections. To demonstrate the feasibility of an application specific lab-on-microchip, results on a fabricated micro flow cytometer with monolithically integrated optical detectors based on amorphous silicon, an electroosmotic micropump without moving parts and a mass flow sensor using the thermal anemometric principle are reported. Further developments and potential applications for microanalysis are outlined. The fluidic channel network is built into a polymer layer (SU-8) which is sandwiched between two plates (e.g. glass-glass, ASIC wafer-glass). In case of the cytometer the excitation light, λ_{ex}=380nm, enters through the glass plate and irradiates the chromophore in the channel. Lab-on-microchip test results with anthracenyl-oxazoline (Ox) demonstrate a significant difference in the normalized intensity spectrum of Ox and Ox-H^+ according to 260fmol amount of substance. Experimental test parameters are bias voltage V_{bias}=-2.5V, detection volume $\Delta V \sim 26$nl, fluid concentration c=10^{-5}M, diode area A_{Dct}=0.1225mm^2 and a constant flow of 1μl/min. The micropump consist of several stages of narrow channel structures (channel cross section 4μm x 15μm) to enhance electroosmotic flow. The pump operates at voltages around 4-6V. It is capable of pumping against the hydrostatic pressure that arises from differences in the liquid level of the reservoirs. Typical pumping speeds are on the order of 100μm/sec corresponding to the flow rate of 5nl/min. The present pump design uses a PDMS cover to allow electrolysis gases to escape the pumping channels. The mass flow sensor consists of a heater sandwiched between two temperature sensors, all made of platinum and placed on the substrate on the channel's bottom. The flow rate measurements for DI water were performed using a syringe pump. The sensitivity is about 1μV/(nl/min) at the amplifier input for flow rates ranging from 10nl/min to 2μl/min. It can be improved by thermal isolation of the sensor elements from the substrate.

SESSION D4: Photonic Systems
Chair: Don Gardner
Wednesday Afternoon, March 30, 2005
Room 2008 (Moscone West)

1:30 PM D4.1
Integration of Polymer Pillar Optical Interconnects with Group IV MSM Photodetectors. Ali K. Okyay[1], Chi On Chui[1], Muhannad S. Bakir[2], James D. Meindl[2] and Krishna C. Saraswat[1]; [1]Electrical Engineering, Stanford University, Stanford, California; [2]Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, Georgia.

As the degree of integration in ICs continue to increase, electrical interconnects are facing severe limitations such as speed, power dissipation, and cross-talk. On-chip optical interconnects are promising to eliminate many problems associated with large multi-GHz Si ICs particularly in global signaling and clocking. In such applications, monolithic integration of photodetectors (PD) with the advanced Si CMOS is essential to accommodate a high density of detectors on the chip in a cost-effective way. MSM-PDs are attractive for their integration simplicity for low-cost realization of Si-based optoelectronics. Efficient distribution of optical signal to PDs is of utmost interest. Amongst optical transmission media, polymer waveguides play a key role in optical systems due to their ease of integration. Moreover, being mechanically compliant, polymer waveguides can tolerate thermal expansion mismatches and maintain optical alignment. In this work, Si MSM-PDs are integrated with Sea of Polymer Pillars, interconnection technology that enables high density and mechanically compliant electrical and optical I/O interconnects at the wafer level. Interdigitated Si-MSMs were fabricated by liftoff of 15nm Ti and 35nm Au. A thin ($<1\mu$m) SiO_2 layer for adhesion was then deposited at 150^{o}C on the prefabricated MSM-PDs. Avatrel 2000P polymer was spin-coated followed by UV irradiation, hard bake, and spray development. Finally, wafers were cured for 1 hour at 200^{o}C. Pillars with different geometry, size and aspect ratio were fabricated on identical MSM-PDs. Some pillars were intentionally removed to asses the effects of polymer processing on detector performance. Current-voltage (I-V) characteristics for PDs with different pillars were measured under dark conditions. A reduction in leakage, primarily attributed to the SiO_2 passivation, was observed. I-V of PDs with no polymer processing was also measured as reference. Similar responsivity values around 0.45A/W over different species were obtained using a λ ~790nm and 1mW laser. Photo-to-dark current ratio normalized to input optical power (NPDR) metric was used to evaluate overall device performance. NPDR was higher for PDs with better surface passivation coverage because of lower I_{dark}. Finally, we also studied the effect of processing with different thermal budgets. I_{dark} of MSM-PDs increased only slightly after an additional hour of cure; possibly attributed to an enhanced metal-silicon interaction or intermixing. Efficient light coupling into photodetectors is achieved without significantly degrading device performance with polymer processing. Such an integrated optoelectronic device would envision many applications in future on-chip optical interconnects and telecommunications.

1:45 PM *D4.2
Liquid Crystal on Silicon Devices. Mark A. Handschy[1] and Timothy J. Drabik[2]; [1]Displaytech, Inc., Longmont, Colorado; [2]Page Mill Technology Corp., Palo Alto, California.

The concept of using liquid-crystal light modulators to read out the state of underlying electrodes on an integrated circuit had its origins in the 1970's and 80's when experimental active-matrix displays were constructed on 2-3 inch-diameter silicon wafers. The same concept was also used a tool to diagnose defective integrated circuits by allowing signal propagation to be visualized. The intersection in the late 1980's of interest in optical computing with the ready availability of custom wafers from silicon foundries spurred research into liquid-crystal-on-silicon (LCOS) spatial light modulators (SLMs). Ferroelectric liquid crystals (FLCs), with their fast switching speeds, provided SLMs with 10 kHz frame rates. In addition to light modulators, LCOS SLMs can integrate micro-optical elements (such as lenslet arrays), photodetector arrays, intra- and inter-pixel analog and digital signal processing circuitry, and interface and control logic into a single silicon die. The few-fJ/μm^2 switching energies of FLC materials match the favorable power-delay product of silicon CMOS technology, which does not degrade at the comparatively low rates corresponding to liquid crystal switching times. Consequently, silicon/FLC technology suits applications having massive parallelism and requiring low power operation at moderate speeds, such as front-end image processing systems. The adoption by silicon foundries of chemical-mechanical planarization (CMP) enabled LCOS devices with high-quality pixel mirrors, leading to improved liquid crystal alignment and higher optical reflectivity and setting the stage for utilization of LCOS devices as *microdisplays*. LCOS microdisplays are currently finding commercial application as electronic viewfinders for camcorders and digital still cameras, and are being developed as image generators for projection televisions. Future applications for LCOS devices might include write-heads for holographic optical data storage drives and optical beam steering and adaptive conditioning elements. This talk reviews the history of LCOS devices and their applications, provides an overview of current LCOS device fabrication practice, and speculates on future directions.

2:15 PM D4.3
Surface Acoustic Wave-Induced Electroluminescence Intensity Oscillation in Planar Light-Emitting Devices. Marco Cecchini[1], Vincenzo Piazza[1], Fabio Beltram[1], Martin Ward[2], Andrew Shields[2], Harvey Beere[3] and David Ritchie[3]; [1]Scuola Normale Superiore and NEST-INFM, Pisa, Italy; [2]Toshiba Research Europe Limited, Cambridge, United Kingdom; [3]Cavendish Laboratory, Cambridge, United Kingdom.

Surface acoustic waves (SAWs) are attracting much interest in semiconductor community in view of the exploitation of their interaction properties with two-dimensional-electron-gases (2DEGs) embedded in semiconductor heterostructures[Phys. Rev. Lett. 56, 2104 (1986); Phys. Rev. Lett. 71, 3846 (1993)]. SAWs propagating through mesas containing high-quality 2DEGs indeed drive modifications on the 2DEG equilibrium state. Acoustic waves propagating along piezo-electric substrates are accompanied by potential waves which can trap electrons in their minima and induce dc currents or voltages (the so-called acoustoelectric effect)[Surf. Sci.305, 83 (1994); Solid State Commun. 84, 939 (1992); Solid State Commun. 84, 735 (1992)]. Moreover, this same interaction induces changes in SAW velocity and amplitude that can be used to probe the transport properties of two-dimensional systems[Phys. Rev. Lett. 56, 2104 (1986); Phys. Rev. Lett. 71, 3846 (1993); Phys. Rev. B 45, 11342 (1992); Phys. Rev. B 54, 13878 (1996)]. Many devices were proposed and realized exploiting the acoustoelectric effect but very few SAW based optoelectronic devices were reported. We recently introduced an original technique for fabricating high-performance planar light-emitting devices (pLEDs) with a geometry which is fully compatible with SAW propagation. pn lateral junctions were obtained by standard semiconductor processing techniques within a single GaAs quantum well embedded in a p-type modulation doped AlGaAs/GaAs heterostructure[Appl. Phys. Lett. 82, 636 (2003)]. We have integrated these junctions with interdigital transducers and studied the effect of SAWs on device optical and transport properties. From a fundamental physics point of view such devices extend the acoustoelectric effects to planar systems where both electrons and holes are present and allow detailed studies of the effects of the acoustic modulation in light-emitting devices. We demonstrated the possibility of controlling the electroluminescence emission by means of SAWs[Appl. Phys. Lett. in press]. Devices were systematically characterized by current-voltage, light-voltage, photoluminescence and lifetime measurements at cryogenic temperature. The traveling electric field associated with SAWs was found to drive electrons into the p-side of the junction when the junction was biased below the conduction threshold. It was thus possible to turn on transport and light emission by acoustic perturbations. We also studied SAW-induced electroluminescence signal by time-resolved measurements. We found that the intensity of the SAW-induced electroluminescence is modulated at the SAW frequency (~1 GHz), demonstrating electron injection into the p-type region synchronous with the SAW wavefronts.

2:30 PM D4.4
Efficient Focusing with an Ultra-Low Effective-Index Lens Based on Photonic Crystals. Eugen Foca[1], V. V. Sergentu[2], Helmut Foell[1], Juergen Carstensen[1], Frank Daschner[1], Reinhard Knoechel[1] and I. M. Tiginyanu[2]; [1]Chair for General Materials Science, Faculty of Engineering, Christian-Albrechts-University of Kiel, Kaiserstr. 2, 24143 Kiel, Germany; [2]Institute of Applied Physics, Technical University of Moldova, 2004 Chisinau, Moldova.

Photonic Crystals (PC) are meta materials that allow to manipulate the propagation of electromagnetic radiation in hitherto unknown ways. Treating a PC as quasi-homogeneous meta material for suitable wavelength regions, it can be assigned an effective refractive index n_{eff} under certain circumstances that will be outlined, and this n_{eff} can be quite different from some average index obtained from the refractive indices of the material constituents of the PC; in particular it might be close to, or even smaller than zero. While these "negative index" or "left-handed" meta-materials have received considerable interest in recent years, quantitative experiments with these materials are still rather scarce. Based on a modified multiple scattering technique, the properties of a PC consisting of Al_2O_3 rods ($n \cong 3$ in the GHz regime) and having a sufficiently well-defined n_{eff} were calculated for wavelengths in the microwave regions; the corresponding frequencies are 6 GHz - 12 GHz. Based on these calculations, an optical element resembling a concave lens with an expected ultra-low n_{eff} was constructed from 112 Al_2O_3 rods and extensively characterized with microwave radiation in an anechoic chamber. The measurements mapped the intensity distribution behind the lens at high spatial resolution for a large range of frequencies in the TM and the TE mode. The results were analyzed with respect to the frequency dependence of n_{eff}, the focusing quality of the lens, and the transmission coefficient, and compared to predictions of

theoretical simulations. The results obtained demonstrate effective indices in a range from n_{eff} = 0.004 to 0.6, good to very good focusing properties, and sufficient transmission of the lens. For example, at 7.59 GHz and for the TM mode, n_{eff} = 0.0042, increasing to 0.53 if the frequency is increased to 12 GHz. The maximum intensity in the focus spot increases from 3 to 40 (in terms of a transmission coefficient) under these conditions. If the TE mode is chosen, an effective index cannot be defined and the lens behaves as kind of efficient beam splitter. The experimental results compare favourably, or even quite well with theoretical predictions, albeit some topics need to be addressed in more detail. The lens also exhibits interesting additional properties such as multiple focusing points, or beam splitting; depending on the frequency and the mode chosen. Moreover, the lens properties are quite robust; in particular they are not sensitive to sizeable deviations of the rods from the crystal lattice position. We believe that this is the first time that an optical device with an ultra-low effective index of refraction has been used for efficient focusing of radiation. The device is easily scaled to other frequency bands and may find uses not only in the microwave regime, but also in the THz and optical part of the spectrum.

2:45 PM D4.5
MBE Growth of High Quality GaAs on Si through Direct Ge Buffers. Xiaojun Yu, Yu-Hsuan Kuo, Junxian Fu and James S. Harris; Solid State and Photonics Laboratory, Stanford University, Stanford, California.

The realization of low defect density GaAs on Si heteroepitaxy would enable monolithic integration of III-V materials and devices with conventional Si integrated-circuit (IC) technology. However, GaAs/Si heteroepitaxy has been a difficult challenge with only minor success for two decades due to its two growth characteristics: large lattice mismatch (4%) and polar-on-nonpolar growth. This paper presents the growth result of low defect density GaAs on Si using a Ge buffer. The usage of high quality Ge buffer layers separates these two growth issues. First, a high quality and fully relaxed Ge buffer layers is directly deposited on Si by solid source MBE through a two-step growth method. Then, single phase GaAs is grown on the lattice-matched Ge buffers. This growth approach needs only a thin Ge buffer layer (less than 1um), and consumes much less material compared with published GaAs growth on Si via SixGe1-x buffers where the thickness of SixGe1-x is close to 10um. Single phase of GaAs is achieved by using vicinal Si substrates, and by controlling the growth temperature and prelayers. Comparison was made for the growth on nominal (001) substrate and on 4 degree off (001) towards [110] Si substrates. The GaAs layers grown on (001) substrate contained mixed phases, but anti-phase free GaAs was grown on off-axis substrates, at 500 degree C, using As2 prelayers. The growth is monitored by in-situ reflective high-electron energy diffraction (RHEED), which shows a 4x4 pattern for the GaAs growth on nominal (001) substrates and a 2x4 streaky pattern for the growth on off-axis substrates. The cross-sectional TEM shows a low threading dislocation density in the GaAs layer. The threading dislocations mostly originate from the Si/Ge interface and propagate into GaAs, instead of starting from GaAs/Ge interface. The anti-phase domains are negligible which are mainly confined near the GaAs/Ge interface. Photoluminescence (PL) of GaAs grown on off-axis substrates shows the characteristic peak of GaAs, but no GaAs peak is observed for the GaAs grown on nominal (001) substrates.

3:30 PM D4.6
Luminescent Si Nanocrystals Formed Within Silicon Rich Silicon Oxide Thin Films. Tyler Roschuk[1,2], Michael Flynn[1,2], Jacek Wojcik[1,2], Othman Zalloum[1,2], Edward Irving[1,2] and Peter Mascher[1,2]; [1]Engineering Physics, McMaster University, Hamilton, Ontario, Canada; [2]Centre for Electrophotonic Materials and Devices, McMaster University, Hamilton, Ontario, Canada.

Silicon nanocrystals have been the subject of many research projects in the past few years. Quantum confinement effects resulting from their small size cause these nanocrystals to exhibit luminescence. This has brought hope in the search for a silicon based emission device, something that is typically disregarded in photonics due to the indirect bandgap of silicon, which makes emission from Si an inefficient process. In this paper we present our research into the formation of silicon nanocrystals in silicon rich silicon oxide (SiO_x) thin films, with compositions from 36% to 50% Si, deposited by electron cyclotron resonance plasma enhanced chemical vapor deposition and subjected to thermal annealing at temperatures up to 1200 ^{O}C in an Ar ambient. The resulting phase separation and nanocrystal nucleation have been analyzed as a function of the initial composition and annealing conditions through the use of transmission electron microscopy (TEM), x-ray diffraction, and Fourier transform infrared spectroscopy experiments. TEM has also been used to examine the nanocrystal size and distribution within the films. Photoluminescence experiments for these films have been conducted using a HeCd laser emitting at 325 nm. Through these experiments compositional and annealing limits for the observation of luminescence have been determined. Refractive indices of these films have been analyzed using spectroscopic ellipsometry and correlated with the structural analysis. The potential for electronic transport within the films has been analyzed through C-V measurements. Additionally, we have examined the effects of varying the substrate temperature during the deposition process on nanocrystal formation as well as the luminescent and optical properties of the films. Finally, we discuss the potential applications for these films in integrated Si-based photonics, including use as waveguides and emitters. This work is being supported by Ontario Centres of Excellence (OCE) Inc. and the Ontario Photonics Consortium (OPC).

3:45 PM *D4.7
Towards CMOS Compatible Nanophotonics. Mark Brongersma, Rashid Zia, Anuranjita Tewary, Anu Chandran, Ragip Pala, John Liu, John Schuler, Alex Guichard, Rohan D. Kekatpure, Andrew Carlson, Benjamin Reddy, David N. Barsic, Peter B. Catrysse and Mark D. Selker; Geballe Laboratory for Advanced Materials, Stanford University, Stanford, California.

The enormous growth of the communication industry has increased the demand for new photonic functionality at a low cost. For this purpose, it would be highly desirable to have light sources, waveguides, amplifiers, and detectors that are monolithically fabricated on Si with CMOS technology. The materials used in current CMOS integrated circuit technologies are chosen to optimize electronic performance. However, upon closer examination these materials are also suitable for generating, manipulating, and detecting optical signals. The unique properties of Si nanostructures such as nanoparticles and nanowires can be exploited to fabricate Si-based light sources and detectors. Si and SiO_2 can be used to fabricate ultra-high quality factor micro-disc resonators for light modulation and generation. Metallic interconnects can serve as plasmonic waveguides that guide and manipulate electromagnetic waves at optical frequency ("light") below the diffraction limit. To evaluate the use of deep submicron CMOS technology as a fabrication platform for integrated nanophotonic and plasmonic devices, our group is developing a laboratory-on-a-chip environment. Optical techniques, including photon scanning tunneling microscopy, are used to investigate the unique properties of these devices and study the fundamentals of light-matter interactions at the nanoscale.

4:15 PM D4.8
Characterization of Undoped ZnO Thin Films Prepared by O_3 Assisted Pulsed Laser Deposition. Tamiko Ohshima[1], Shouta Nakashima[1], Yuji Matsunaga[1], Hiroharu Kawasaki[1], Yoshiaki Suda[1] and Kenji Ebihara[2]; [1]Sasebo National College of Technology, Sasebo, Japan; [2]Kumamoto University, Kumamoto, Japan.

Zinc oxide (ZnO) is a II-VI wide direct band gap semiconductor and is an important material in various fields of applications such as transparent conductive electrodes, surface acoustic wave devices and optoelectronic devices. ZnO is suitable for an ultraviolet light-emitting devices due to its wide direct band gap (3.37 eV) with a large exciton binding energy of 60 meV at room temperature. Because spontaneously grown ZnO thin films form donor defects such as oxygen vacancies or zinc vacancies or interstitial zinc, they have n-type conductivity. Many researches about the synthesis of p-type ZnO thin films by impurity doping or co-doping techniques have been performed. In this research, we have attempted to synthesize undoped ZnO thin films with p-type electrical conductivity by pulsed laser deposition (PLD) method using a second harmonic Nd:YAG laser. High oxidation ozone (O_3) gas was used in order to compensate oxygen vacancies and suppress interstitial zinc. Undoped ZnO thin films deposited on the corning glass and silicon substrates at various conditions were characterized by measuring structural, optical and electrical properties. The structural properties of the films were analyzed by X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS). Photoluminescence (PL) measurement and UV-visible spectrometer were used to study the optical properties. The electrical properties such as conduction type (p-type or n-type), carrier density, resistivity and mobility were investigated by Hall measurement. Undoped ZnO thin films were deposited at the substrate temperature of room temperature and the O_3+O_2 gas pressure of 1.3 Pa. The post-annealed ZnO thin films showed c-axis orientation having a sharp (002) diffraction peak. The ZnO thin films prepared in the O_3 concentration region of 3,000-5,000 ppm showed p-type conduction.

4:30 PM D4.9
Improved Luminescent Efficiency of PDP Blue Phosphor by Microwave Irradiation. Shu-Ping Lee, Chin-Ching Lin, Kuan-Ting Kuo and San-Yuan Chen; Materials Science and Engineering, National Chiao-Tung University, Hsinchu, Taiwan.

BaMgAl10O17:Eu2+ phosphor is useful and commercial blue

phosphor for plasma display panel and lamp. For the enhancement of phosphor efficiency , it is necessary to be advanced in the particle size and morphology of the phosphor materials. Highly luminescent efficiency blue-light phosphors have been successfully produced by microwave irradiation treatment. The SEM images and XRD analysis reveal that the surface morphology of the blue-light phosphors can be notably modified by microwave irradiation to become more spherical shapes and exhibit with better crystalline property .In addition, the surface of the phosphor is formed cleaner with a few surface defects, which acts as a quenching site consuming photoexcited electrons. The vacuum ultraviolet (VUV) PL spectra show that the microwave irradiation treatment can effectively enhance the luminescent efficiency by a factor of 2.5 times for intensity in comparison with that phosphor without microwave treatment. The improvement in all visible emission can be related to the modified surface morphology to induce the large internal quantum efficiency and increased crystalline properties of the blue-light phosphors. The commercial phosphors make re-treatment to reach highly luminescence by microwave irradiation. These results demonstrate that such a simple approach can provide for the fabrication of highly luminescent efficiency phosphors for the optoelectronic devices.

4:45 PM D4.10
Tungsten Oxide Nanoribbons Fabricated in Moisturized Environment. Yiu WingChing[1,2], Hong HunQuan[1,2], Wu HuaSheng[1,2], Xie MaoHai[1,2], Wei ZhiFeng[1] and Xu ShiJie[1]; [1]Department of Physics, The University of Hong Kong, Hong Kong, China; [2]CAS and HKU Joint Laboratory on New Materials, Hong Kong, China.

Tungsten oxide is a very potential material for photonic and superconducting applications due to its wide bandgap and superconducting behavior. However, due to the lack of preparation methods, the reported nanostructures for this material so far are limited to nanowires and nanorods. We report in this paper the first successful synthesis of tungsten oxide nanoribbons using a novel thermal oxidation method. Also the morphologies and optical properties relationship of tungsten oxide nanoribbons, as well as that of nanowires and nanorods were investigated. By oxidizing tungsten plate under a moisturized condition at 650 C, and using Potassium iodide as catalyst, tungsten oxide nanoribbons were obtained on a large scale; while under a dry synthesis environment, only nanowires and nanorods were realized. The morphologies and optical properties relationship of the nanostructures were examined using scanning electron microscopy (SEM), transmission electron microscopy (TEM), and low temperature photoluminescence (PL). As-grown nanoribbons, with 30nm thick and length up to 300nm, exhibit similar photoluminescence spectra with the value reported for a tungsten oxide film, whereas nanowires and nanorods have different photoluminescence spectra. Therefore, it can be concluded that the appearance of tungsten oxide nanoribbons is strongly dependent on the moisturized fabrication conditions, and that the photoluminescence properties are related to the morphologies of the nanostructures. Acknowledgement: This work is supported by the HKUGC grant HKU7034/03P.