Selected Topics in Photonics/Optoelectronics Research at the University of Cincinnati

The purpose of this article is to provide an overview of the research activities in photonics and optoelectronics being carried out at the University of Cincinnati (UC). The article presents brief summaries of several topics covering research in optical sensors, near-field optical microscopy, optical displays, optical memory, visible and infrared light emitters. The summaries are certainly not comprehensive, nor does this article capture the totality of photonics-related research at UC. It is only intended to provide a window on our activities through which we encourage the readers to learn more by contacting us. Faculty with interest in photonics and optoelectronics at UC span a variety of disciplines including Electrical Engineering, Materials Science, Physics, Medicine, etc.

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Optically Interrogated MEMS Pressure Sensors for Propulsion Applications

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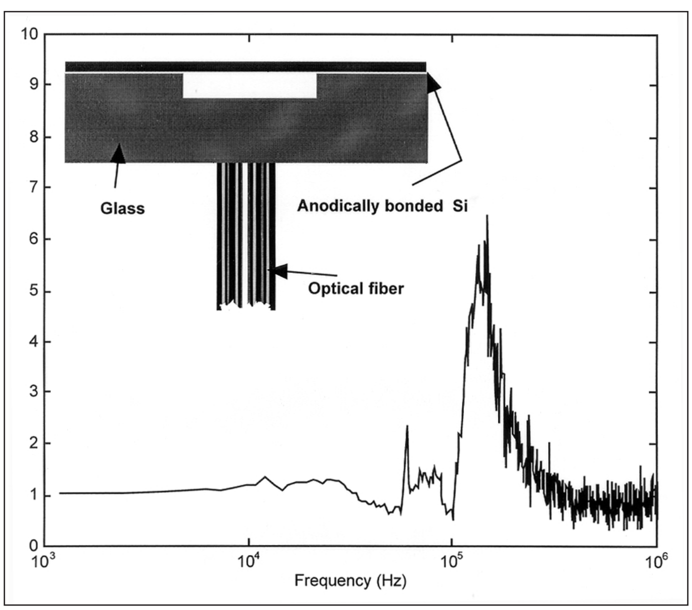
Pressure sensors utilizing microelectromechanical systems (MEMS) technology for fabrication of the sensing element and interrogation by fiber optics are being investigated.[1] Optically interrogated MEMS devices are more rugged than electrically interrogated MEMS devices so with sturdy packaging these optical devices are thus suitable for many propulsion applications involving harsh environments.[2] The configuration of the individual MEMS/optical fiber pressure sensor is shown in the insert of Fig. 1. It consists of a glass plate with a shallow cylindrical cavity etched into one surface with the cavity covered by a thin silicon diaphragm which has been electrostatically bonded to the patterned glass wafer. The position of the diaphragm deflects in response to pressure. A hole from the bottom of the plate to the cavity can be included depending on whether an absolute or relative pressure sensor is needed. Light is introduced into the cavity from an optical fiber through the glass and propagates perpendicular to the diaphragm-cavity interface. The silicon diaphragm-cavity interface reflects most of the light and the cavity-glass interface acts as the second reflector, thus forming a Fabry-Perot interferometer. Pressure causes the thin Si diaphragm to move and thus changes the separation between reflectors. This change results in a different amount of light reflected; thus measurement of this change of reflected light is related to pressure. The key design parameters of diaphragm thickness, initial cavity depth, and cavity diameter can be varied to provide linear response over various pressure ranges. Our design software allows us to select the pressure range and frequency response appropriate for several applications.



▼ *Figure 1. The transfer function of the pressure sensor as a function of frequency.*

We designed pressure sensors to respond over the pressure range 0 – 30 psi, to operate at a wavelength of 850 nm, and chose the radius of the circular diaphragm to be 300 μm as a size compatible with testing and fabrication. For this maximum pressure and diaphragm radius, the diaphragm thickness of about 25 μm will provide the desired response. We thus fabricated diaphragms having thickness close to this value. The glass-diaphragm structure and an optical fiber are mounted in a sturdy Lexan package which has been designed and constructed to be able to maintain their proximity to each other in the presence of harsh external environments. The packaged sensors were then placed onto a mounting assembly suitable for static and dynamic testing.

Detailed static calibration runs of the sensor unit were carried out over a pressure range of 0.5 psi to 30 psi. A LED source was utilized and reflected light monitored by photodetectors. A linear variation of signal output as a function of pressure was observed and a sensor sensitivity of 1.77 mV/psi is measured, a value within a factor of 2 of what is estimated based on the design and the input LED power utilized. Similar data was accumulated over several cycles to ensure no drift occurred in the readings. Scatter in the data was less than 0.25%.

The dynamic response of the pressure sensor was characterized with shock tube testing. The shock tube facility at Wright State University, a facility designed for dynamic calibration of pressure transducers for turbomachinery applications, was used. The shock tube generated a total pressure rise at the

[1] J. Zhou, S. Dasgupta, H. Kobayashi, J. M. Wolff, H. E. Jackson and J. T. Boyd, submitted for publication.
[2] G. N. De Brabander, G. Beheim, and J. T. Boyd, Applied Optics, Vol. 37, p. 3264, May 1998.

sensor of about 10 psi. Typical time traces of the response of the detector due to the shock wave sampled at a 5 MHz rate show sharp response to the shock wave pressure rise. The sensor shows some overshoot before reaching a constant output. The pressure step magnitude is about 10 psi as expected from the theoretical calculation.

A frequency response analysis is performed by taking 4096 points of data with a frequency resolution increment 1.22 kHz. Multiple time traces were individually analyzed, and then averaged in the frequency domain. The transfer function as a function of frequency is shown in the attached figure. An important result of these dynamic calibration tests is the usable frequency of the fabricated sensor. The flat response of the sensor extends up to 30 kHz. Therefore, it has an adequate unsteady pressure measurement capability for high speed propulsion applications, such as for gas turbines. Others participating in this research include Adjunct Research Assistant Professor S. Dasgupta, J. M. Wolf, Assistant Professor at Wright State University and graduate student J. Zhou. This work has been supported in part by a joint AFRL/DAGSI (Dayton Area Graduate Studies Institute) grant, AFOSR, and NASA.

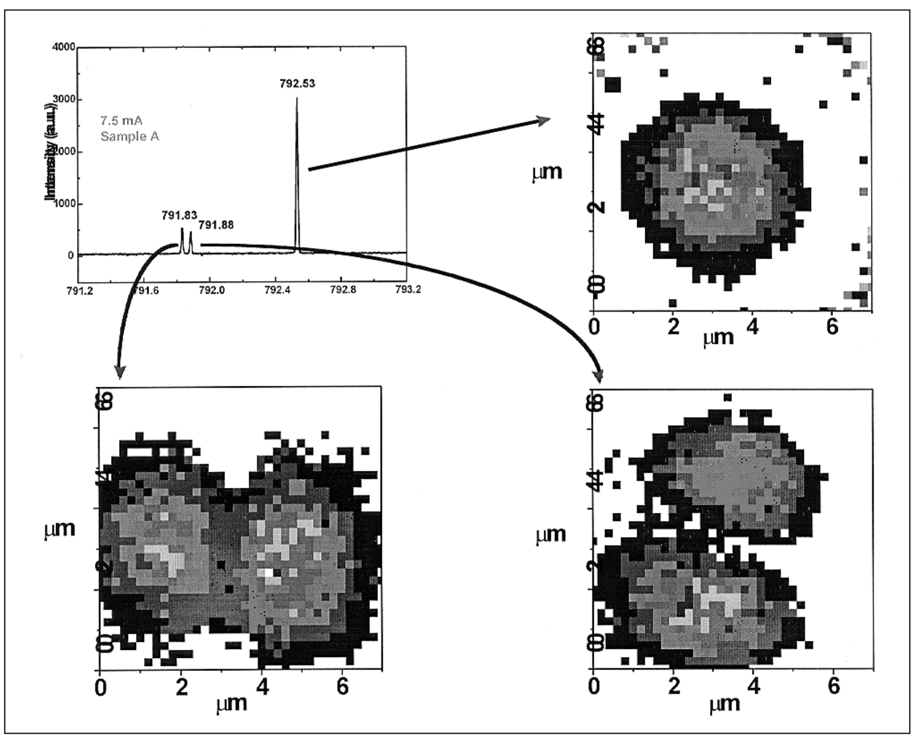
Near Field Imaging of Vertical Cavity Surface Emitting Lasers

Prof H. E. Jackson and Prof J. T. Boyd

Understanding integrated optic structures, including vertical cavity surface emitting laser (VCSEL) structures, requires a spatial resolution which exceeds the diffraction limit. Utilizing near field scanning optical microscopy (NSOM) and spectroscopy, we have studied in detail the spatial electric field intensities associated with optical channel waveguides[3] , directional couplers, y-junctions, and, most recently, vertical cavity surface emitting lasers[4]. VCSELs offer numerous promising applications that take advantage of such excellent VCSEL properties as low threshold, integrability into two dimensional laser arrays, and high coupling efficiency of their light into single mode fibers. We have used spectrally resolved near field imaging to study small aperture proton implanted VCSELs. The spectroscopy is accomplished by coupling the light collected by the ~100 nm near field tip which is scanned about 10 nm above the surface of the sample into a spectrometer.

Consider a small aperture (~6 μm) proton implanted vertical cavity surface emitting laser fabricated by MOCVD with the 1λ active region containing four 8 nm thick $Al_{0.3}Ga_{0.7}As/A1_{0.6}Ga_{0.4}As$ quantum wells. We have studied the spontaneous emission, the above threshold emission (lasing), and the mode structure of such a microcavity structure. The spatial distribution of below threshold and above threshold emissions sharply narrows as one goes above threshold, a phenomena resulting from gain guiding. If one now makes a near field spectroscopic measurement, we find that the spatial extent of the fundamental mode is distinctively different from the higher order modes. The lasing spectrum showing three lines as well as the individual intensity images for the fundamental mode and the two first-order modes over a 7μm x 7μm area are displayed in Fig. 2. The fundamental mode has a Gaussian profile at the aperture center with a 2.5 μm full width at half maximum; the first-order modes have a double lobed shape with a null at the center. The fundamental width (2.5 μm) is much less than the 6 μm width which indicates the presence of index guiding at this injection current. An analysis of these data allow the calculation of a lateral index gradient across the aperture due to local carrier or temperature variations.

Very recently we have used the same technique to study selectively oxidized VCSELs. Selective oxidation is an efficient and convenient current confinement scheme which, because of superior electrical confinement within the active area, is leading to lower threshold currents. The existence of an oxidized layer also provides optical confinement in the laser cavity and thus optical modes are more tightly confined in the active area than for an implanted VCSEL; this results in low diffraction loss enabling high efficiency. The higher optical confinement behavior in oxidized VCSELs also results in more distinct and complex multimode emission, demanding a novel method to identify the VCSEL modal structures. We have obtained spatially and spectrally resolved images of both subthreshold emission and lasing emission from a selectively oxidized VCSEL operating at a wavelength of 850 nm. Below threshold, highly local high gain regions, emitting local intensity maxima within the active area, were observed; these same areas were found to serve as lasing centers just above threshold. Above threshold, the near field spatial modal distributions of low-order transverse modes were identified by spectrally analyzing the emission; these were found to be complex and different from those measured in the far field. Several graduate students (J. Kim, D. Naghski, and S. M. Lindsay) have been participating in this research, which is partially sponsored by ARO.



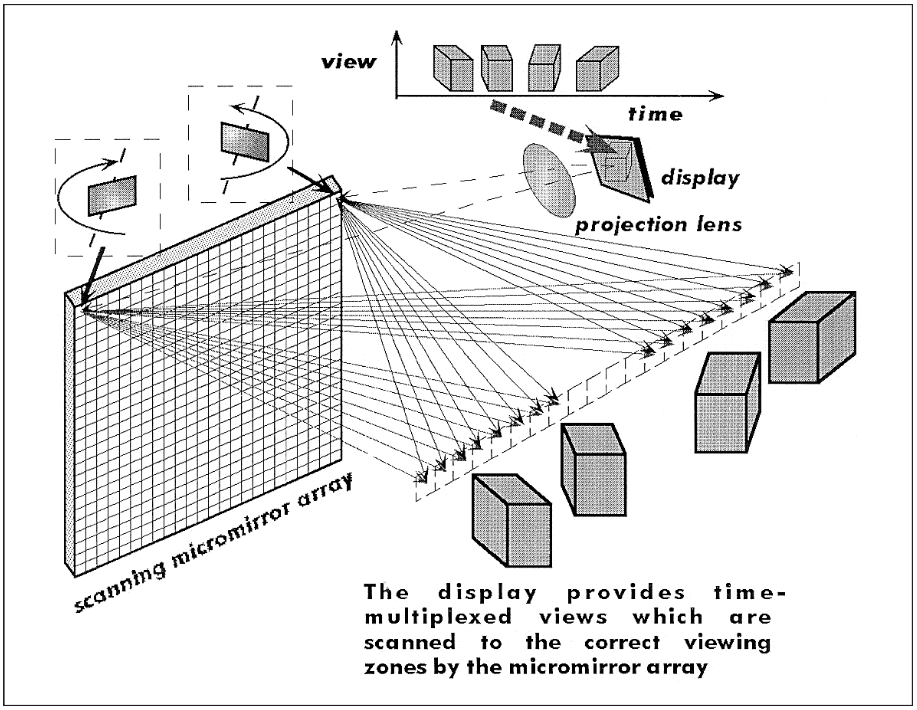
▼ *Figure 2. VCSEL lasing spectrum showing three lines as well as the individual intensity images for the fundamental mode and the two first-order modes over a 7μm x 7μm area.*

[3] C.D. Poweleit, D.H. Naghski, S.M. Lindsay, J.T. Boyd, and H.E. Jackson, Appl. Phys. Lett, Vol. 69, p. 3471, 1996.

[4] J. Kim, D. E. Pride, J. T. Boyd, and H. E. Jackson, Appl. Phys. Lett, Vol. 72, p. 3112, 1998.

3-D IC Vision Display using MEMS Technology

Prof S. T. Kowel (Stephen.Kowel@UC.Edu)



▼ *Figure 3. Scanning micromirror array for 3-D ICvision display*

The goal of IC Vision is to produce a real-time, full-color, autostereoscopic display. Depth perception and motion parallax are provided by integrating flat-panel displays with directing optics. A directing array directs modulated light to a set of virtual viewing zones in space, displaying a series of stereoscopic image pairs which can be easily fused by the viewer. No headgear is required to view these images generated with incoherent light. Two approaches have been investigated - diffractive gratings and reflective MEMS micromirrors. Prototype displays were based on the diffractive partial pixels approach, in which gratings direct different views into appropriate viewing zones.[5] However, the major challenge is how to make a larger screen display while maintaining color and high resolution. Since the partial pixels were spatially multiplexed for eight stereo pairs (16 views) and three prime colors, a large number of pixels is required to maintain resolution. As an example, a color VGA (640×480) display with 16 views will need $640 \times 480 \times 16 \times 3 \approx 14.7$ million partial pixels, far beyond current capabilities.

An alternative time-multiplexed approach based on reflective micromirror arrays is being investigated. As shown in Fig. 3, for every pixel of a 3-D image, one scanning micromirror produces the 16 views sequentially. Thus we eliminate the factor of partial-pixel number, and the factor of prime colors by reflection. The views are written sequentially on a spatial light modulator focussed on the micromirror array. The scanning micromirrors are designed for two goals: (1) light redirection - directing the light to the appropriate viewing slits; (2) image quality - mirror dimensions less than the resolving limit of human eye. Current research activities and plans include the following: (a) optical system design for scanning micromirror approach; (b) design and fabrication of static micromirrors; (c) design and fabrication of dynamic micromirrors; (d) auto-stereoscopic image processing for real imagery. Graduate student J. Yan is also participating in this research, which is partially sponsored through an NSF grant at the University of Alabama, Huntsville.

Optical Memory Storage and Display Devices in the Blue Region Using Organic Materials

Prof. S. J. Clarson and Prof. A. J. Steckl (scalrson@uceng.uc.edu)

Over the past two decades organic materials have shown an increasingly important potential for application in the fields of lasers and electro-optics. Exploiting the high flexibility of synthetic routes of organic systems as opposed to conventional mineral compounds, a wide variety of organic materials can be addressed.

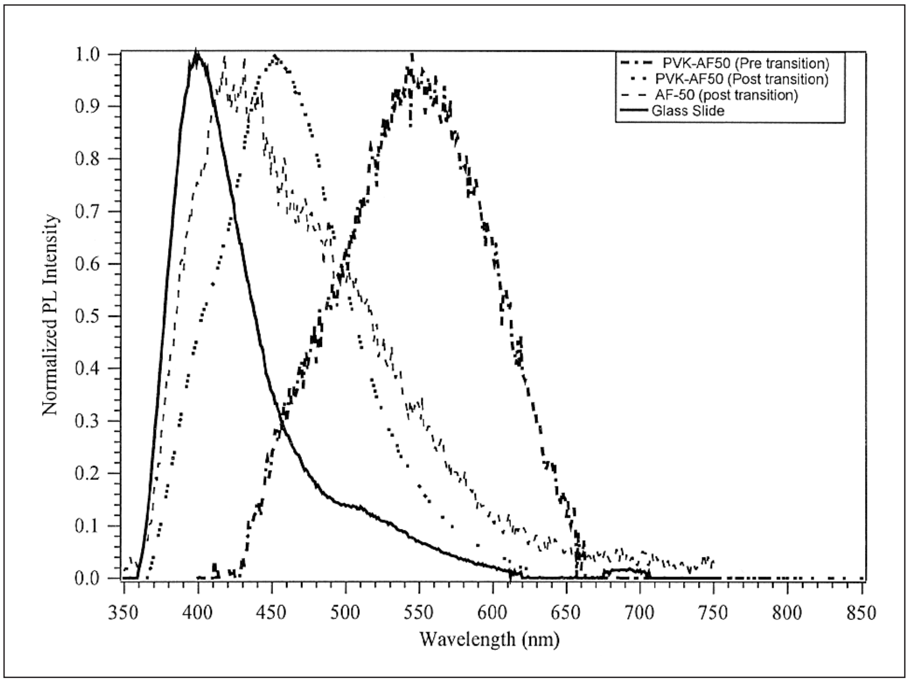
There are a great number of widely diversified applications of two-photon technology consisting of optical memory devices to lithography and imaging. There has been a tremendous need for large memory storage devices in the last few years with storage densities of the order of 10^{12} bits/cm^3. Currently compact discs offer about 650 MB of storage space with writing and reading, both in the red region of the spectrum. With a layer that can be easily processed and deposited on the CD as an active layer that can be written on in the blue region the memory space that the device can offer would triple. The driving forces behind developing two-photon based memory systems are the low cost and ease of fabrication and high data storage densities among others. The use of two-photon materials for data storage in the red region using a high two-photon absorption cross-section chromophore has recently been demonstrated. Organic materials are also excellent candidates for electroluminescent devices as they can be designed to have large area light emitting displays, which can be operated at low drive voltages. Thin films of polymers can be very easily obtained by either spin-coating them or by dip-coating. Generation of light in these systems is by recombination of holes and electrons injected from the electrodes.

We currently have a research program to fabricate devices that can be used as image storage devices operating in the blue region. This work has also led to the fabrication of low drive voltage organic LED's emitting in the blue. Efficient organic LED's are currently being considered as low cost alternatives

5 G. P. Nordin, M. W. Jones, J. H. Kulick, R. G. Lindquist and S. T. Kowel, *Optical Engineering*, Vol. 35, p. 3404, 1996.

for applications such as backlights in liquid-crystal displays, automotive dome lights and other illumination purposes.

The commercially available polymer poly(vinyl-carbazole) (PVK) was used in the fabrication of these devices. The active layer in the storage device consisted of the polymer doped with a high two-photon cross section chromophore (N,N-Diphenyl-7-{2-(4-pyridinyl)-ethenyl}-9, 9-di-n-decyl-9H-fluorene-2-amine) (AF-50). The data was written onto the sample using a He-Cd laser and read using an Ar^+ laser. The organic LED we have fabricated utilizes three principal organic layers. The device uses the same polymer as the hole transport layer and the addition of an exciton confinement layer and the use of polyaniline doped to be an effective electron transport layer have helped in the fabrication of the low drive-voltage device. The device emits in the blue and can be operated with less than 1 volt. Several graduate students (R. Sivaraman, B. K. Lee) are participating in this research, which is partially sponsored by WPAFB and DAGSI.



▼ *Figure 4. Photoluminescence spectra of the chromophore and the polymer doped with the chromophore showing the blue shift on irradiation with the He-Cd laser at 325 nm.*

Smart Optical Storage Read Head Devices Implemented with Photonic CMOS Technology

Prof F. R. Beyette Jr.

As the incorporation of CD technology into electronic computing systems has demonstrated, optical storage device can play a significant role in the archival storage of digital information. Over the next decade, storage requirements are expected to reach the terabyte level for personal users and the petabyte level for large database and knowledge base applications. While considerable effort is being devoted toward the development of optical storage media to meet this demand, relatively little work has been done to develop the optical read head technology that will be necessary to interface these ultra high density storage devices with existing electronic computing hardware.

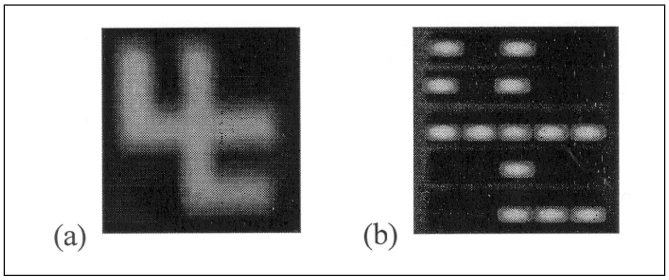
One difficulty faced in the design of ultra high capacity optical storage systems is the von Neumann bottleneck that exists between the memory system and a computers microprocessor. To illustrate the impact of this problem, consider the time required to search through every bit in a petabyte storage space. Assuming a 50 Mbyte/sec read rate (consistent with a 400 MHz clock) this search operation would take ~230 days. To overcome this problem, it has been suggested that the next generation of high-density optical storage devices must provide page-oriented access. In a page-oriented environment, the data read rate is multiplied by the page size. Even with a modest page size (100×100 bits) the search time on a petabyte storage device can be reduced to less than 1 hour. To date, predictions of enhanced performance have been based on the ability of next generation optical storage media to produce page-oriented optical output. While the ability to output data in a page-oriented format has been a necessary condition for the demonstration of large capacity high data rate optical storage media, the development of practical optical storage systems will depend on the demonstration of optical read head technologies that are capable of processing data in a page-oriented fashion.

In order to demonstrate the viability of page-oriented optical storage devices, we are pursuing research along two paths. First, we have been working to develop a photoreceiver array[6] technology that can be easily integrated into the read head of future optical storage systems. Based on a Photonic VLSI device technology that combines the uniformity and reliability of CMOS circuitry with the two dimensional accessibility of optics, we have recently demonstrated a 5×5 detector array that was fabricated entirely in a standard CMOS device process. Designed to detect the very low power levels expected from optical storage devices, individual photoreceivers in the 5×5 array have produced a digital logic swing (0 volt to 5 volt on the output pin) for changes in optical power of less than 1 nWatt. To illustrate the ability of this detector array to interface with existing electronic processing circuits, the detector array has been connected to a digital logic circuit that includes a buffer circuit and a 25 element array of digital line drivers. The line drivers were used to drive a 5×5 LED array arranged to mimic the input pattern detected by the photoreceiver array. Fig. 5 shows the input and output patterns generated during the evaluation of the photoreceiver array.

The second path of our investigation involves the development of smart pixel based processing circuitry suitable for manipulating page-oriented data.[7] While the ability to generate and detect page-oriented data are clearly necessary components of an efficient high capacity storage system, they are not sufficient to overcome the von Neumann bottleneck associated with getting data from the storage device into the CPU of an elec-

[6] J. Tang, B. Seshadri, S. Konanki and F. R. Beyette Jr., Proc. SPIE Annual Meeting, Advanced Optical Memories and Interfaces to Computer Systems II, Denver CO, July 1999.

[7] F. R. Beyette, Jr., P. A. Mitkas, M. Schaffer, E. Hayers, R. Pu. R. Jurrat, and C. W. Wilmsen, SPIE Proc. Vol. 3110, p. 838, The 10th Meeting on Optical Engineering in Israel, Sept. 1997.



▼ *Figure 5 (a) Input pattern used to evaluate the 5×5 photoreceiver array. (b) Image captured from a 5×5 LED array driven by the 5×5 photoreceiver array.*

tronic computing system. Unfortunately, current microprocessor designs are I/0 pin limited to word-oriented bus architectures. Further, the electronic nature of microprocessors available in the foreseeable future, suggests that word-oriented bus architectures are likely to dominate over the next decade.

To appreciate the underlying problem with a word-oriented bus architecture, consider the execution of a search operation in a large database management system. Current search techniques frequently require passing the entire database into the CPU where the search operation is executed. Since the results of many database search operations includes less than 10% of the total volume of data searched, better than 90% of the data passed into the CPU is discarded. Thus, the low bandwidth, word-oriented connection between storage device and CPU is predominately used to carry useless data that is subsequently discarded by the CPU. To overcome this potentially significant problem we are currently working to design and demonstrate smart read head devices that pre-process the data prior to transfer between the storage device and the CPU. The smart read head device currently being developed integrate the photoreceiver technology described above with CMOS based logic circuits to produce a compact smart pixel device suitable for incorporation directly into the read head of a page-oriented optical storage device.

One example of this technology is a smart read head device that is specifically designed to execute search operations in a relational database system. The chip is designed to accept page-oriented data from an optical storage device and produce word-oriented data as output to the host computer. By pre-processing the page-oriented data, it is possible to discard unwanted data prior to conversion between page-oriented and word-oriented data. In addition to the circuitry required for searching and data reformatting, the proposed database filter chip includes word-oriented data buffers that hold valid data that is waiting for transfer into the host computer. The capacity of these buffers (along with full buffer indicators) insures that storage device read operations and electronic host data transfers will proceed independently with out the loss of valid data during the search process. By reading data in a page-oriented fashion, pre-processing the data in the read head and then passing only valid data through the von Neumann bottleneck, it will be possible to significantly reduce the search time in a petabyte memory device. Several graduate students (J. Tang, and B. Seshadri) are participating in this research, which is partially sponsored by NSF.

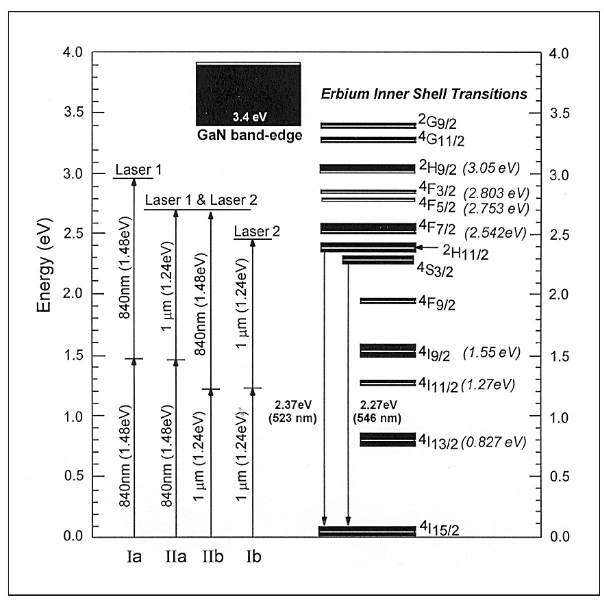
High Density Optical Memory Based on Erbium-Doped GaN by Focus Ion Beam Implantation

Prof A. J. Steckl and Prof F. J. Beyette

The advent of digital technologies, such as database systems, full text electronic publishing, and multimedia, has fueled the ever-increasing demand for archival data storage. Current planar optical storage devices such as CD-ROM, WORM, CDR, CDRW, MO, DVD are insufficient to cope with the explosive growth of storage capacity requirements which are expected to exceed the terabyte level. Nor are their current access speeds on the order of 10 Mbits/s adequate to deal with the terabyte level of data processing time. We have recently initiated an investigation of optical memory systems based on rare-earth dopants such as Erbium. (Er) which could provide simultaneous increases in density and access time through 3D storage approaches.

In these storage systems, information is stored by implanting a closely spaced pattern of Er ions into the optically transparent wide band-gap semiconductor GaN. This *write* process is carried out using focused ion beam implantation (FIB) which is capable of spatial resolutions nearly 2 orders of magnitude smaller than the optical diffraction limit. Data bits would consist of pattern of implanted locations as "1"s and unimplanted locations as "0"s. In principle, this could result in an area bit density of 10^{10} to 10^{12} bits/cm^2. To *read* the stored information we take advantage of the upconversion process in Er ions. Upconversion involves the absorption of two photons of same or different energies producing the emission of a third photon of energy higher than that of either of the incident photons. This process permits utilizing high power IR lasers to excite visible emission. Upconversion emission has been obtained[8] from Er implanted GaN by FIB. As shown in Fig.6, a pair of visible (green) emission peaks at 523 and 546 nm are excited by either one or two IR lasers with wavelengths of 840 nm and 1 μm.

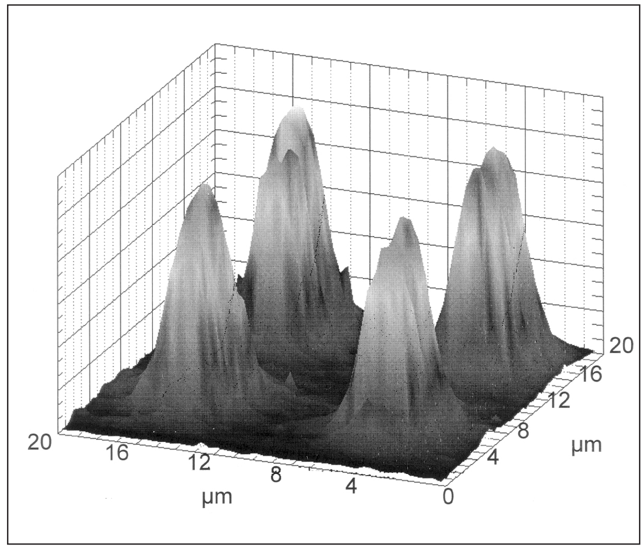
A demonstration of the GaN:Er optical memory concept based on upconversion emission of Er ions is shown in Fig. 7. An array of Er-doped GaN bits was written



▼ *Figure 6. Upconversion processes and Er energy levels for FIB implanted GaN optical memory device.*

8 L.C. Chao, B. K. Lee, C. J. Chi, J. Cheng, I. Chyr, and A. J. Stecki, Appl. Phys. Lett., Vol. 75, p. 1833, Sept. 1999.

by FIB implantation using an Er-Ni liquid alloy ion source developed[9] for this purpose. Fig. 7 shows the optical upconversion signal from a 2×2 segment of the implanted bit array when interrogated by the 1 μm laser. The spatial scanning profile of each implanted bit (~3×6 μm) is currently limited by the laser beam diameter. This approach can be extended to a 3D memory by growing multilayer GaN films, with bits written into each layer by FIB Er implantation. This can greatly increase the obvious increase of storage density (to ~10^{11} bits/cm^3) due to more effective use of three-dimensional space. Our research results have also showed that upconversion intensity changed with implanted Er dose. At least 2^2 gray scale levels for each written bit can be created. With this scheme, 3D storage density can be further boosted. Furthermore, more than one RE species can be implanted into GaN films. For each additional n number of species used, a 2^n increase of storage states is possible. In this work, we have demonstrated a simple method of utilization of RE-based optical storage implemented by FIB Er-GaN. It is therefore very attractive to construct 3D optical memory devices based on RE doped wide band-gap semiconductor. Several graduate students (R. Chi, B. Lee, J. Tang) and post-doctoral fellow Dr. L. C. Chao are participating in this research, which is partially sponsored by NSF.

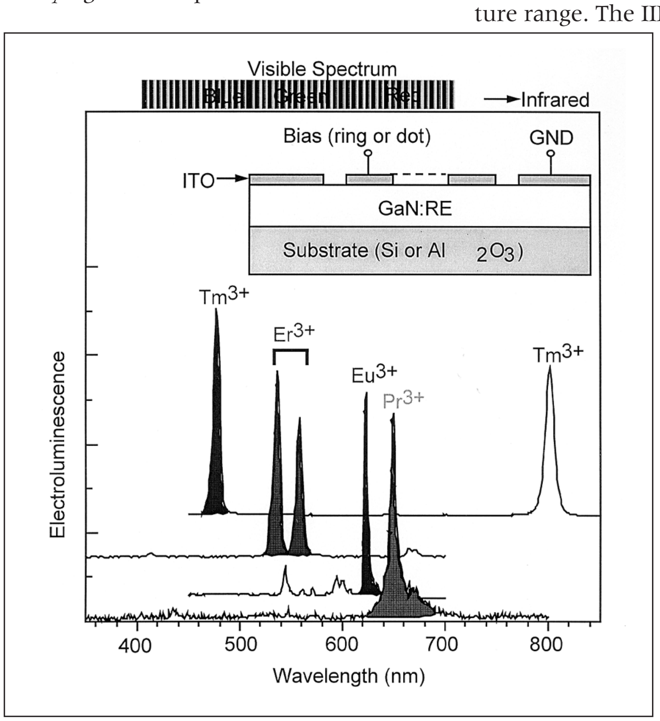


▼ *Figure 7. Visible upconversion signal obtained by IR excitation 2×2 bit pattern produced by FIB implanted ER-GaN.*

Rare Earth Doping of GaN for Light Emission Applications

Prof A. J. Steckl

The rare earth (RE) elements in the lanthanide series have been exploited for their optical emission properties primarily by being incorporated in glasses and ceramics, such as Er-doped glass fiber used in telecommunications. We have been studying RE-incorporation in the wide bandgap semiconductor (WBGS) GaN with the goal of making semiconductor-based electroluminescent devices[10] (ELDs). The advantages of WBGS over smaller gap semiconductors and glasses include greater chemical stability, carrier generation (to excite the rare earths), and physical stability over-a wide temperature range. The III-N semiconducting compounds are of particular interest because of their direct bandgap and generally high level of optical activity. The large GaN bandgap also makes transparent to infrared and visible RE emission. We have grown RE-doped GaN films grown by molecular beam epitaxy (MBE) in a Riber MBE-32 system on primarily on (111) Si and sapphire substrates. Solid sources are employed to supply the Ga and RE fluxes, while an rf-plasma source is used to generate atomic nitrogen. Typical GaN growth rates are 0.8-1.0 μm/hr at growth temperatures of ~750°C. As shown in Fig. 8, emission of the three primary colors has been accomplished using Er^{3+} doping for green light, Eu^{3+} or Pr^{3+} doping for red light, and Tm^{3+} doping for blue light. These very sharp emission lines are due to $4f$ inner shell radiative transitions of RE ions caused by impact excitation from energetic carriers injected into the GaN. The GaN:RE ELD structure which we are utilizing is shown in the insert to Fig. 8. It uses an indium-tin oxide (ITO) layer patterned to form both rectifying (small) and relatively ohmic (large) contacts to the GaN. ITO has the advantage of being both optically transparent and highly conducting. The primary color GaN:RE ELDs match very well the specifications chosen for the US standards for color television displays. In addition to the primary colors, mixed colors of various hues have been achieved by the appropriate combination of RE multiple doping. For example, the combination of Er and Tm has yielded a blue-green color ("aqua").



▼ *Figure 8. Visible electroluminescence spectra from four rare-earth-doped GaN devices: Tm for blue emission, Er for Green emission, Eu and Pr for red emission. The insert shows the cross-section schematic of GaN:RE ELDs.*

Visible emission from RE-doped GaN has also been accomplished by RE focused ion beam (FIB) implantation. FIB technology is a maskless and resistless "direct-write" process, which can be applied with great versatility[11] to the fabrication of photonic devices. FIB micro- and nano-fabrication (with ion beam diameters ranging from less than 100 nm to a few μm) can be utilized to reduce the complexity required of conventional photonic fabrication technology (in

[9] L. C. Chao and A. J. Steckl, J. Vac. Sci. Technol. B Vol. 17, pp. 1051-1053, May 1999.

[10] For a review and additional references see A. J. Steckl and J. M. Zavada, MRS Bulletin, Vol. 24, p.33, Sept. 1999.

[11] A. J. Steckl, Proc. Advanced Workshop on Frontiers in Electronics, IEEE Cat.# 97TH8292, 47 (Jan. 1997).

particular lithography, etching and implantation), which has to satisfy various requirements for different components fabricated on the same substrate. FIB can be used to effect local changes in topology (through micromachining), in electrical and optical properties (through dopant ion implantation and/or mixing). For example, we have used Ga+ FIB to achieve the micromachining of waveguides and gratings in GaN. Er and Pr ion sources suitable for FIB implantation have been developed by combining the rare earth elements with other metals to form alloys with lower melting points and vapor pressures. The emitted spectrum from FIB RE-doped GaN is essentially identical to that obtained with in-situ doped GaN, thus establishing the feasibility of FIB direct write with REs for GaN ELD fabrication. Finally, frequency upconversion and other nonlinear optical properties of GaN:RE in-situ and FIB-doped are being investigated. Several post-doctoral fellows (R. Birkhahn, L.C. Chao) and graduate students (M. Garter, J. Heikenfeld, I. Chyr, D. S. Lee) are participating in this research, which is partially sponsored by ARO/BMDO, and NSA.

First CPMT/LEOS Workshop on Fiber-Optics, Optoelectronics, Photonics Assembly, Packaging and Manufacturing Yields Prosperous Results

The inaugural IEEE sponsored workshop on Fiber-Optics, Optoelectronics, Photonics Assembly, Packaging and Manufacturing was held Sept. 15-17, 1999 in scenic Vail, Colorado. The workshop was organized jointly by CPMT and the LEOS to provide an open forum information exchange environment that complements current ongoing committee activities germane to optoelectronics packaging and manufacturing (namely ECTC and the LEOS Annual Meeting). Both NIST and NSF provided grant support for this first time event.

The workshop attracted 170 attendees from around the globe, including participation from Australia, Europe, Far-East, Middle East, and North America. The workshop covered topics ranging from Package Design, Package Components, High Speed Packaging, Array Packaging, Alignment Techniques/Tools, Bonding and Sealing, Hermetic and Non-Hermetic Packaging, and WDM Component Assembly and Packaging.

10 invited speakers and approximately 15 contributed presentations were given throughout the three day event. Session panelists added insight to the workshop topics during lively question and answer discussions following the various presentations. Due to heightened interest developed during the daily sessions, a special evening session was added to enable all presentations to be heard and discussed. And during “off-hours”, a special case study problem challenged workshop attendees to design the *OPTO VEHICLE* of the future. Many innovative designs were presented during the workshop’s Case Study judging segment.

Workshop Invited Presentations

Badri Gomatam, *Vitesse Semiconductor*, “Advances in High Volume Optoelectronic Component Manufacturing”

Chip Mueller, *W.L. Gore*, “VCSEL Technology - Enabling Parallel Optics Solutions”

Fumihiro Ashiya, *NTT*, “Multi-fiber Optical Connector Interface and Alignment Technologies for PLCs and Optical Transceiver Modules” Gilbert Lecarpentier, Karl Suss, “Alignment and Bonding Solutions for Optical Packaging”

David Ramsey, *Lucent Technologies*, “Hermetic Packaging Overview”

John Osenbach, *Lucent Technologies*, “Non-Hermetic Optoelectronic Packaging: Opportunities and Constraints”

Michael Chow, *Lucent Technologies*, “Packaging Platform for Isolated Analog and Digital Laser Modules”

Jean-Noel Dody, *EGIDE*, “Standardization in Material and Design Shape on Ceramic 14 pin Butterfly Packages"

Robert McLeod, *E-TEK Dynamics*, “WDM Component Packaging Design Methodology”

David Wardle, *JDS Uniphase*, “Manufacturing Issues for Component WDMs”

From Left to Right: Michael Lebby, Mario Dagenais, Werner Hunziker, Mino Dautartas, Dariusz Sieniawski, Mark Beranek, Robert Payer.

John Rowlette and Werner Hunziker running special evening session on alignment techniques/tools.

Workshop Session Panelists

Al Benzoni, *Ortel;* Michael Meis, *3M*; James Guenter, *Honeywell*; Randall Heyler, *Newport*; Mark Beranek, *Boeing*; Bob Comizzoli, *Lucent Technologies*; Hongtao Han, *Digital Optics*; Mark Voitek, Kyocera; Joe Ford, *Lucent Technologies;* Dariusz Sieniawski, *Nortel*.

As the fiber-optics industry moves into the next millenium and market demand for optoelectronic components continues to soar, the issues of manufacturing and testing automation, packaging standardization, higher speed packaging, higher density packaging, and packaging integration are becoming more significant. The workshop setting