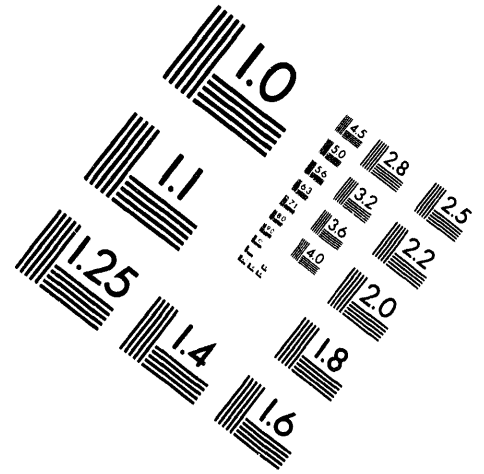
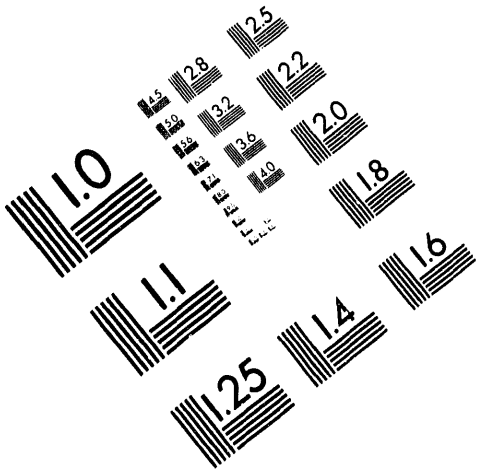




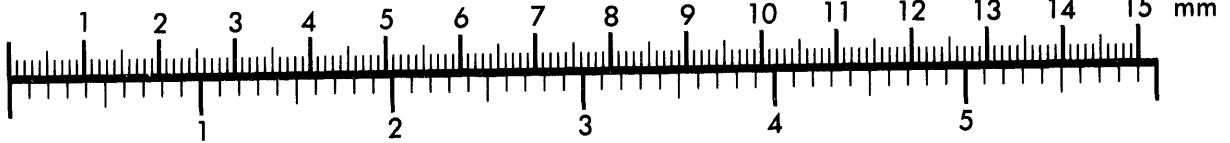
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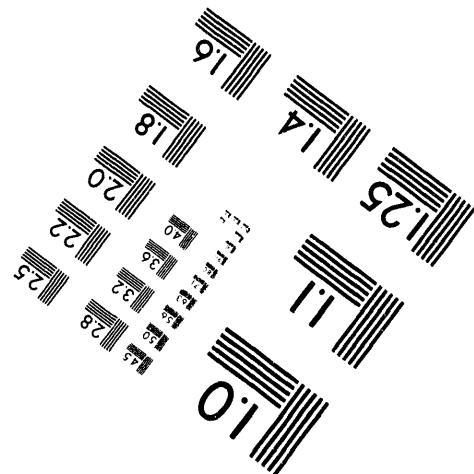
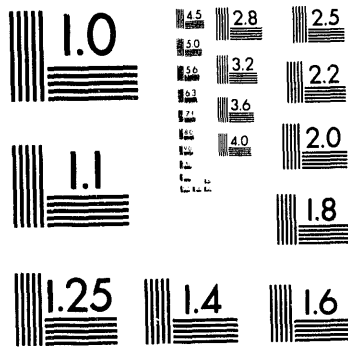
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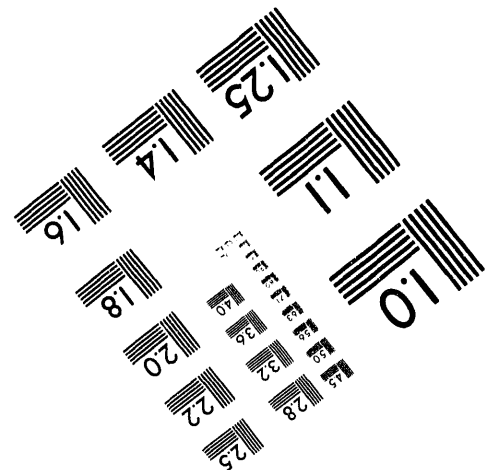
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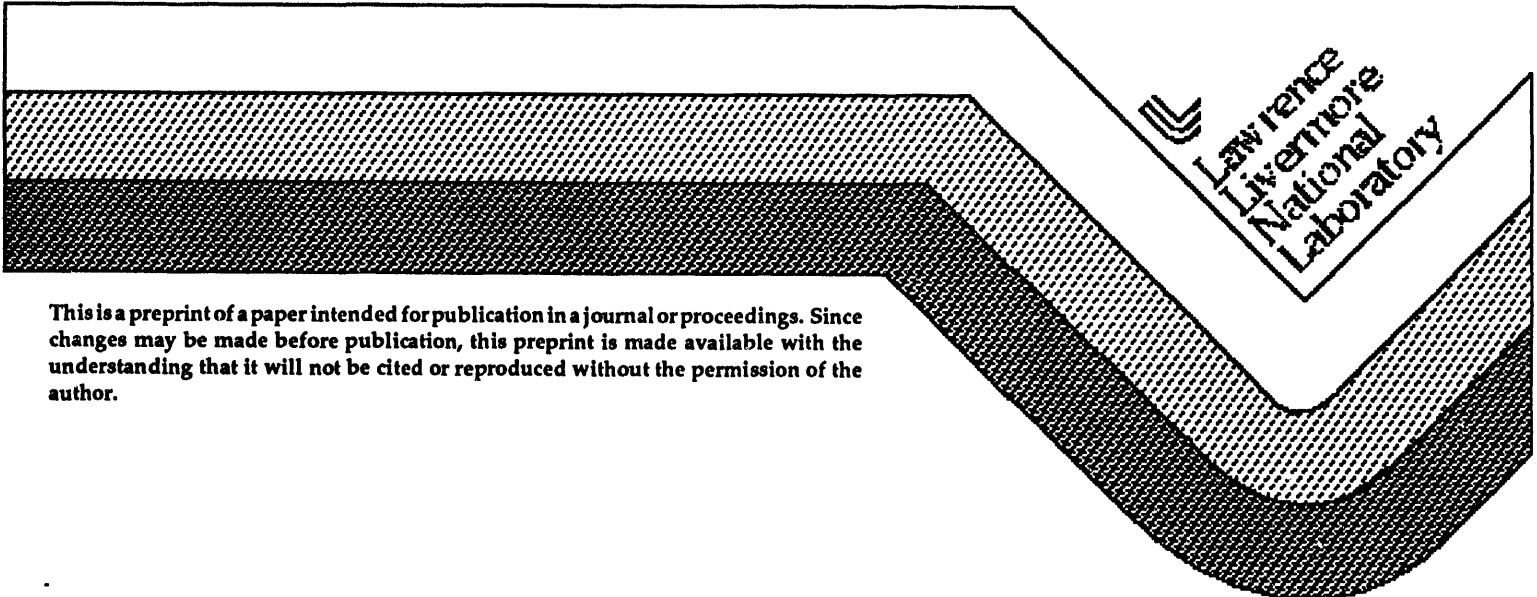
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**An Overview of Photonics Research at Lawrence
Livermore National Laboratory**

**Frank Roeske, Bob Deri, Howard Lee, Mark Lowry,
Frank Patterson, Ted Strand**

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Overview of Photonics Research at Lawrence Livermore National Laboratory

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ABSTRACT

Much of Lawrence Livermore National Laboratory's (LLNL) expertise in photonics was acquired in the execution of the Nuclear Testing mission. As LLNL refocuses its resources into areas that have dual benefit for the nation, our photonics program is beginning to apply our unique capabilities to key national issues involving high-speed communications, while retaining the expertise to apply the technology to defense missions. Much of the exciting work being done at LLNL will have applications in photonics systems and experiments to be used in space.

We will describe research being conducted in the following areas: high-speed, 50 ohm, phased-matched modulators and their applications to digital links; promising new research on flat-panel displays that will be full color, fast response, very thin, and have a very high resolution; all optical switches that are extremely fast, integrable and do not have the latency problems that exist with current optical switches; semiconductor optical amplifiers that are monolithically integrable, more flexible and less expensive than existing fiber amplifiers; novel, semiconductor waveguide devices; and automated packaging techniques that will lower the cost of photonics components.

Much of this research can directly benefit the development of space systems where reliability, size and cost are important considerations. Additional applications in commercial communications and in military systems qualifies the photonics research at LLNL as multi-use technology.

1. INTRODUCTION

Until recently, a large fraction of effort at Lawrence Livermore National Laboratory had been devoted to the design and testing of nuclear weapons. In the Nuclear Test Program, we were faced with the challenge of obtaining large quantities of data in a very short time interval. The experimental environment was extremely hostile and the data had to be recorded at a safe, distant location from the detectors. Size was often an issue since a large quantity of detectors and experimental apparatus had to be located near the nuclear device and was placed in a large metal canister which was buried deep underground with the device. Reliability of the data acquisition systems was very important since the turn-around time for experiments could exceed a year.

These requirements led us to develop photonics means for gathering and recording the data. Fiber optic transmission systems have the bandwidth capability to allow us to transmit the large quantities of data in the short time intervals available to us. Integrated optical techniques allowed us to make small, reliable and radiation-insensitive instrumentation to be placed in close proximity to the nuclear device. These photonics techniques led to the development of instrumentation systems that could transmit high-resolution pictures to the recording trailer in a fraction of a second. An analog system was developed that transmitted data over a 1 km optical data link with an equivalent digital rate of 80 Gbit/s. This system has measured the fastest phenomena on a nuclear event that has ever been recorded.

In response to the challenging nuclear test driven requirements, we have gathered and built a vast amount of photonics equipment and capabilities. We have the knowledge and expertise to progress from the conception and design stages of developing an optical data gathering system to the fabrication, testing and implementation of the system.

With the waning of the requirements to conduct nuclear tests, we are focussing our solid core of knowledge and large amount of equipment in integrated optical and electrooptical systems to key areas of National interest involving high-speed communications. A few of these areas are described below. The experience and expertise gained from fielding rugged, reliable, high-bandwidth photonics systems in hostile, remote environments with size and costs restrictions could be valuable to the area of Space Systems where there is obvious overlap in many of the requirements.

2. HIGH-SPEED, 50 OHM, PHASED-MATCHED MODULATOR

Important characteristics of an electrooptic modulator are the bandwidth, drive voltage and characteristic impedance. Higher bandwidth modulators are fabricated by introducing a traveling-wave electrode structure so that the optical and electrical signals propagate through the interaction region at nearly the same velocity. The closer the velocity match, become the higher the possible bandwidth. Theoretically, if we ignore packaging limitations and losses, for an electrode structure that is perfectly velocity-matched to the optical index we should be able to achieve bandwidths exceeding several hundred gigahertz. Practical limitations in packaging and electrode losses limit the bandwidth of phased-matched devices to ≤ 50 GHz.

Low drive voltage is also important to get the maximum modulation depth when the modulators are driven with typical signals used in communication transmission systems. Improved velocity matching requires thicker electrodes which in turn, lowers the device impedance. Lower impedance, however, means higher drive voltage and is undesirable for good device performance. However, velocity matched devices can have longer electrodes which can mitigate some of these effects and can achieve a lower $V\pi$ than a non-velocity matched device.

The modulators should have a characteristic impedance of 50 ohms since most communications systems use that value. Any device with non-50 ohm characteristic impedance will introduce unwanted reflections on the signal lines. Typically this problem has been circumvented by adding impedance matching resistors in the device package or reactively matching over some narrower bandwidth. This approach complicates the packaging and lowers the bandwidth of the packaged device.

2.1 Device Structure

We have designed and built modulators using the thick electrode/buffer layer approach that comes very close to achieving the desired 50-ohm characteristic impedance and a velocity match, while maintaining a reasonably low drive voltage.

Fig. 1 shows how these devices differ from the conventional modulator design. Our devices use X-cut Lithium Niobate crystals with a co-planar electrode design. The waveguides were fabricated using the annealed proton exchange process and these devices were designed to operate at 800 nm.

The desired characteristics of the modulator are obtained by using a thick electrode structure and the combination of a relatively thick SiO_2 buffer layer and a large gap between the signal and ground plane electrodes. This combination of design parameters gives us a nearly phased matched device approaching the 50-ohm characteristic impedance goal. Fig. 2 shows the ideal parameters that we are striving for and two devices we have fabricated.

2.2 Device Performance

One concern with the approach we are taking is that most of the methods we use to phase-match and obtain a 50-ohm characteristic impedance tend to push the drive voltage up. In order to bring the drive voltage back down it is necessary to make the device as long as possible. For a truly phased-matched, lossless device, this is not a serious drawback since there will not be bandwidth degradation due to the optical and microwave walkoff. Electrode loss, however, comes into play at higher frequencies.

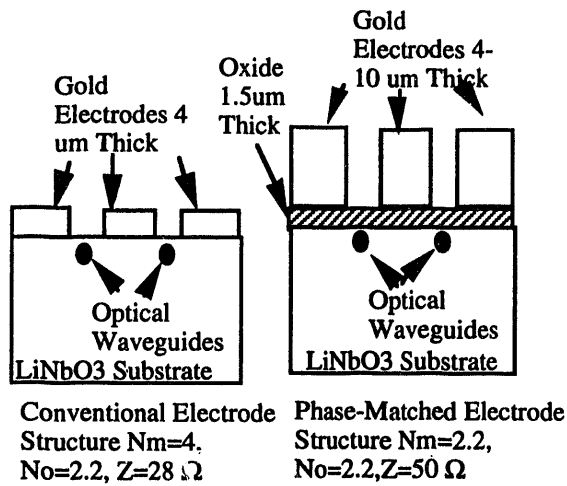


Figure 1: Cross Sections of Electrode Structures Used In Conventional and Phase Matched Devices

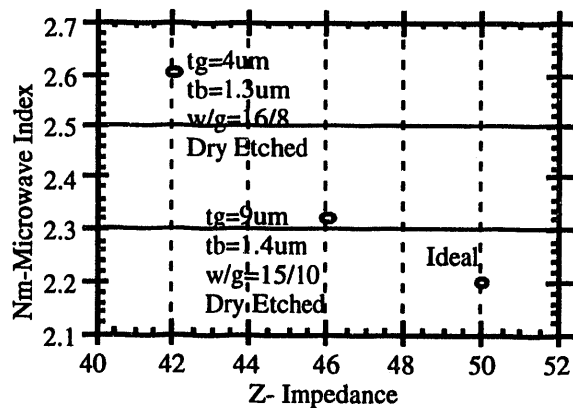


Figure 2: Ideal and obtained microwave refractive index and characteristic impedance t_g is the gold electrode thickness, t_b is the buffer-layer thickness and w/g is the electrode width-to-gap ratio.

We have been able to obtain a very reasonable value of 5 volts for the drive voltage for devices that have electrode structures 10 mm long. The frequency response of the device up to 26 GHz is shown in Fig. 3. The -3db point falls at about 24 GHz for this device. Past 24 GHz the device shows a region with serious resonances in the response as well as a faster than desired falloff in response. The problem in this area is most likely due to the tapers that interface the electrodes to the Wiltron connector. To correct this, we are considering fabricating the tapers off of the niobate chip. While this may solve the frequency performance problems, it will complicate the packaging procedure.

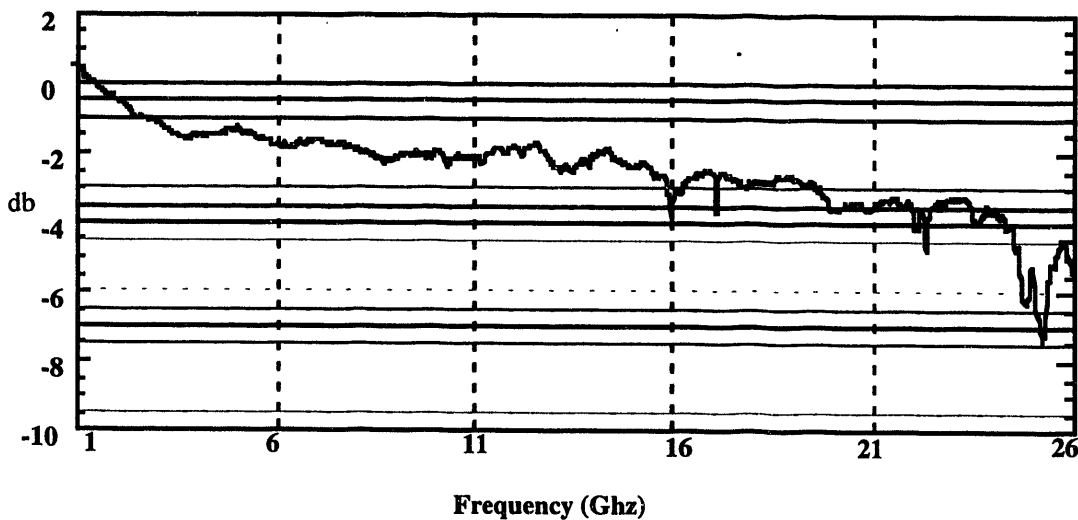


Figure 3 Swept Frequency Data for 50 ohm/phase matched Device

3. NEW MATERIALS FOR OPTOELECTRONIC AND PHOTONIC APPLICATIONS

The goal of this effort is to develop and implement new materials for optoelectronics and photonics. This is directed towards improving present capabilities and perhaps enabling new and

unforeseen technologies. Two examples of systems under study are nanocrystals (porous silicon) and fullerenes.

3.1 Nanocrystals

Nanocrystals have two attractive properties for optoelectronics and photonics: enhanced light emission and enhanced optical nonlinearities. Improved luminescent properties benefit color flat panel and three-dimensional displays, light emitting diodes (LED), and lasers, while an enhanced nonlinear optical response can be applied towards optical switching, optical limiting, and harmonic conversion applications.

Silicon nanocrystals fulfill several important requirements in this effort. It has long been desired to develop silicon light emitting devices. This would enable optoelectronics to be based entirely on silicon. There presently exist silicon-based devices to accomplish this (waveguides, detectors, etc.) save for the crucial light emitting device. Optical devices of silicon integrate easily with standard silicon microelectronics and their fabrication exploits mature silicon microprocessing techniques. Silicon crystals are more economical and easily grown than compound semiconductors. Unfortunately, the indirect bandgap in silicon greatly diminishes its light emission and limits its luminescence to a spectral region near its bandgap (1.15 eV). However, porous silicon and silicon nanocrystals show efficient photoluminescence and electroluminescence in the infrared and visible.

In collaboration with the University of California at Davis, we have made silicon nanocrystals that photoluminesce in the red, green, and blue, depending on the details of the processing, and with efficiencies of a few percent. The photoluminescence spectra are shown in Figure 4a. These silicon nanocrystals are being developed as economical and efficient multi-color phosphors for displays. We have also succeeded in fabricating arrays of miniature porous silicon-based LED's emitting throughout the visible and in the near infrared region. The visible electroluminescence (EL) would enable color flat panel displays to be made from arrays of porous silicon-based LED's. The infrared EL, shown in Figure 1b, covers the technologically important region near 1300 and 1500 nm and represents the first infrared LED made from porous silicon. Our results validate porous silicon as a useful material for optoelectronic devices. We are continuing to develop porous and nanocrystalline silicon as light sources (coherent or incoherent) for optoelectronics and phosphors for displays.

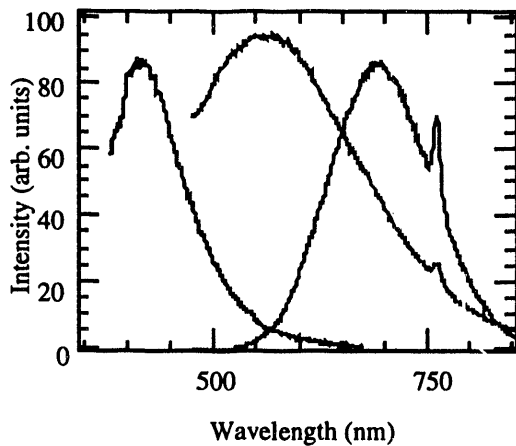


Fig.4a Photoluminescence spectra of Si nanocrystals

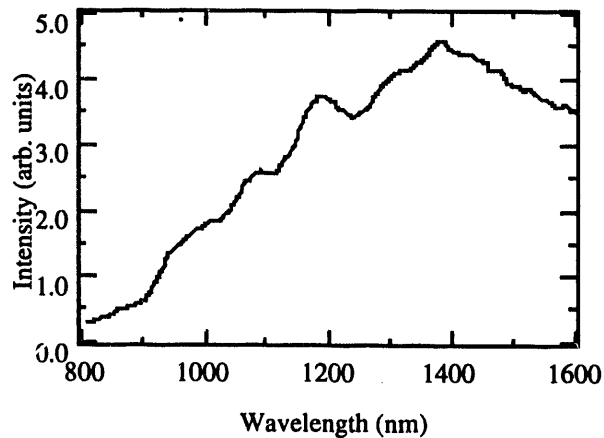


Fig 4b Electroluminescence spectrum of porous Si LED

3.2 Fullerenes

Fullerenes are soccer ball-shaped carbon molecules consisting mainly of C₆₀ and C₇₀. They represent a new class of materials with interesting properties for optoelectronic and photonic applications. We have focused on their potentially large and fast nonresonant $\chi^{(3)}$ nonlinearity for broadband switching applications. In addition, the simplicity of fabricating high optical quality thin films and guided wave

structures, and the economy of producing large quantities of material enhance their value. Potential applications include all-optical switching, nonlinear waveguides, and optical limiting.

We have completed a comprehensive study of the nonlinear optical properties of fullerene thin films. We found their nonlinear optical response to be surprisingly large and fast. The figure of merit (FOM) of fullerenes for all-optical switching is competitive with optical fibers, which has one of the largest FOM of existing materials for all-optical switching. However, the large FOM for optical fibers results not from a large n_2 , but rather from small two-photon absorption. Consequently, all-optical fiber switches are hundreds of meters to kilometers in length, making them cumbersome and creating significant latency problems. Alternatively, the much larger Kerr index (n_2) along with the ultrafast nonlinear optical response of fullerenes enables considerably smaller switches (millimeters) to be fabricated in an integrated optics approach and potentially high-speed operation in the Tbit/s regime. This effectively eliminates the latency problem. We have demonstrated the first fullerene-based all-optical switch using a C₇₀ thin film and a new device design. In this initial effort, we demonstrated a conservative switching speed of 82 MHz along with a switching energy of a few 10's of picojoules. The output of this switch is shown in Figure 5. We are working to optimize and improve this performance. To implement an integrated optics approach, we also developed a process to pattern C₆₀ into guided wave structures. Though fullerenes are a new material, their unique optical and nonlinear properties warrant close scrutiny for optoelectronic and photonic applications.

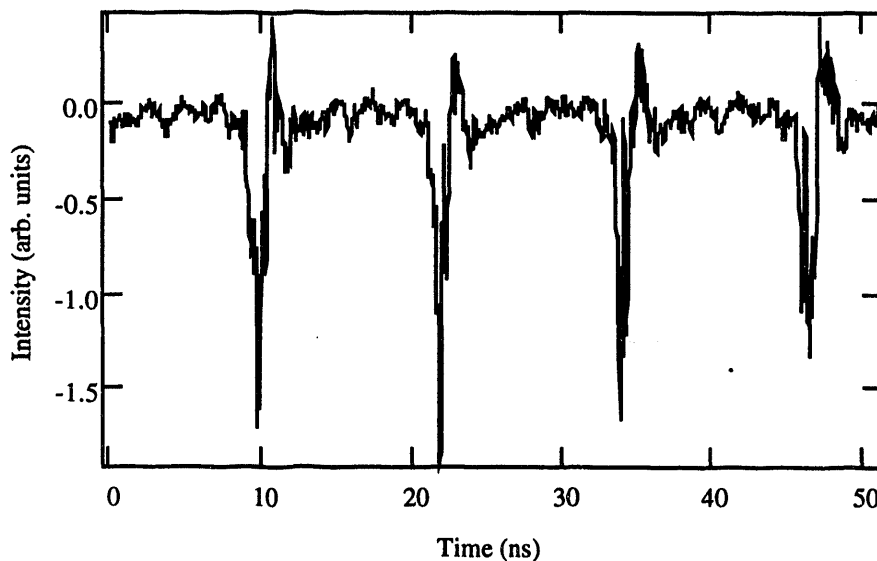


Figure 5 Output from all-optical switch using C₇₀ thin film

4. DEVELOPMENT OF SEMICONDUCTOR OPTICAL AMPLIFIERS FOR FIBER-OPTIC DATA LINKS

Optical amplifiers have revolutionized the design of fiber-optic communication systems. Erbium-doped fiber amplifiers (EDFA), have enabled hundreds of thousands of simultaneous telephone conversations across continents on a single fiber-optic cable. However, the use of EDFA's is limited due to their large cost (\$40,000) and size as well as several performance issues like their relatively narrow and uneven gain spectrum, an inability to perform as switches and because they are not monolithically integrable with other devices. Semiconductor optical amplifiers (SOA) are attractive alternatives because they are inexpensive, miniature, extremely wavelength flexible and can be used as external modulators or as switches in networks. Several obstacles have prevented the mass deployment of SOA's into today's optical communication systems: 1) polarization sensitivity, 2) unacceptable noise figure, 3) limited output power, 4) large input and output coupling losses, 5) limited data rate -- time domain crosstalk, and 6) wavelength division multiplexing (WDM) crosstalk. Recent work at Philips Optoelectronics¹ and AT&T² using

strained multiple quantum well (MQW) amplifiers has significantly impacted problems 1-4. LLNL has invented a technique to eliminate SOA crosstalk in both the temporal and spectral domains (obstacles (5) and (6)).

4.1 Capabilities for semiconductor optical amplifier development

Several capabilities are required to fabricate and package SOA's. We have developed a self-aligned narrow ridge waveguide process for single quantum well GRINSCH InGaAs/GaAs/AlGaAs lasers. The lasers routinely achieve 20 mA thresholds for 1mm long devices and 12 mA for 500 μm long devices. These thresholds are comparable to the best thresholds reported for uncoated devices. Incidental to this self-aligned ridge waveguide process, we have developed a thick oxide liftoff process for ridge structures in GaAs/AlGaAs material. High gain, high fidelity SOAs require facet reflectivities below $\approx 10^{-4}$. We have developed laser diode based in-situ monitored anti-reflection coating hardware. For convenience and ease we are presently utilizing a combination of moderately tilted facets (3) and SiO or Al₂O₃ coatings.

Another key technology is the ability to package and fiber pigtail the SOA's. We are developing automated techniques to reduce the cost of packaged optoelectronic (OE) devices. This will be discussed in section 6.

4.2 Crosstalk Elimination in Semiconductor Optical Amplifiers

For time division multiplexing (TDM) applications, the main limitation of standard semiconductor amplifiers operating at the milliwatt power level is the gain recovery time which is limited by the carrier lifetime to about 1 ns. This gain recovery problem limits the data throughput of semiconductor optical amplifiers to about a GBit/s due to gain saturation cross-talk (intersymbol interference (ISI)). This data rate is insufficient even for today's optical links such as the synchronous optical network (SONET) OC-48 standard, which operates at a 2.5 GBit/s.

Fig. 6a and Fig 6b show experimental pump-probe data for standard GRINSCH and double heterostructure SOA's compared with the LLNL process. Here a saturating optical pulse is coupled into the SOA followed by a weaker, probe pulse with adjustable delay. The transmission of the probe pulse as a function of time delay directly maps out the gain recovery of the SOA. In Fig 6a, the standard process recovery doesn't occur until approximately 2 ns and in Fig 6b, it takes roughly 1 ns for the standard process to reach zero. Our process is an order of magnitude improvement over the standard.

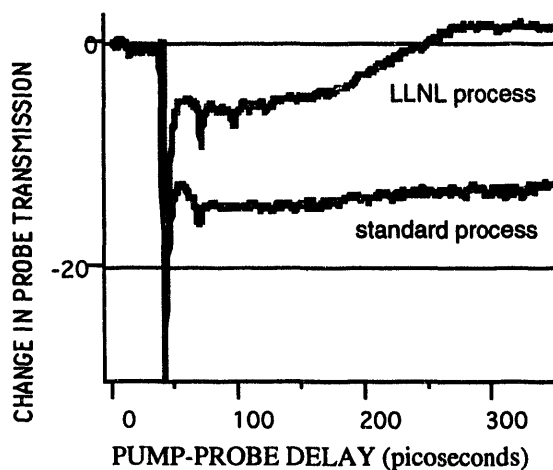


Fig.6A. Quantum well GRINSCH SOA.

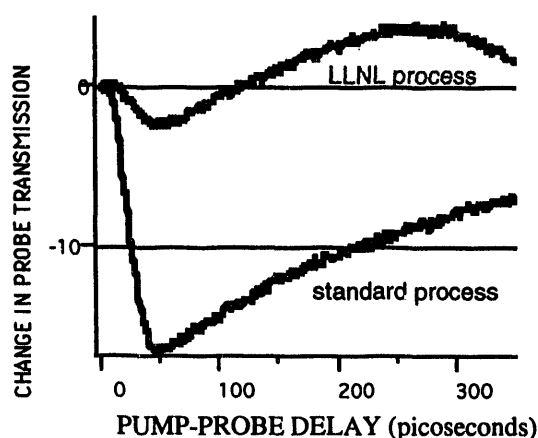


Fig. 6B. Double heterostructure SOA.

Using our SOA process, the gain recovery times are shortened by more than an order of magnitude for both quantum well and double heterostructure devices. Calculations indicate the error-free data transmission up to 20-30 Gbit/s will be possible with SOAs.

For wavelength division multiplexing (WDM) applications, the gain saturation induced by one wavelength channel causes disruptive modulation of other wavelength channels. This problem has prevented SOAs from useful application in WDM systems. Fig. 5 shows the results of WDM crosstalk measurements on a standard SOA (Fig. 7A) and on the LLNL SOA (Fig. 7B)

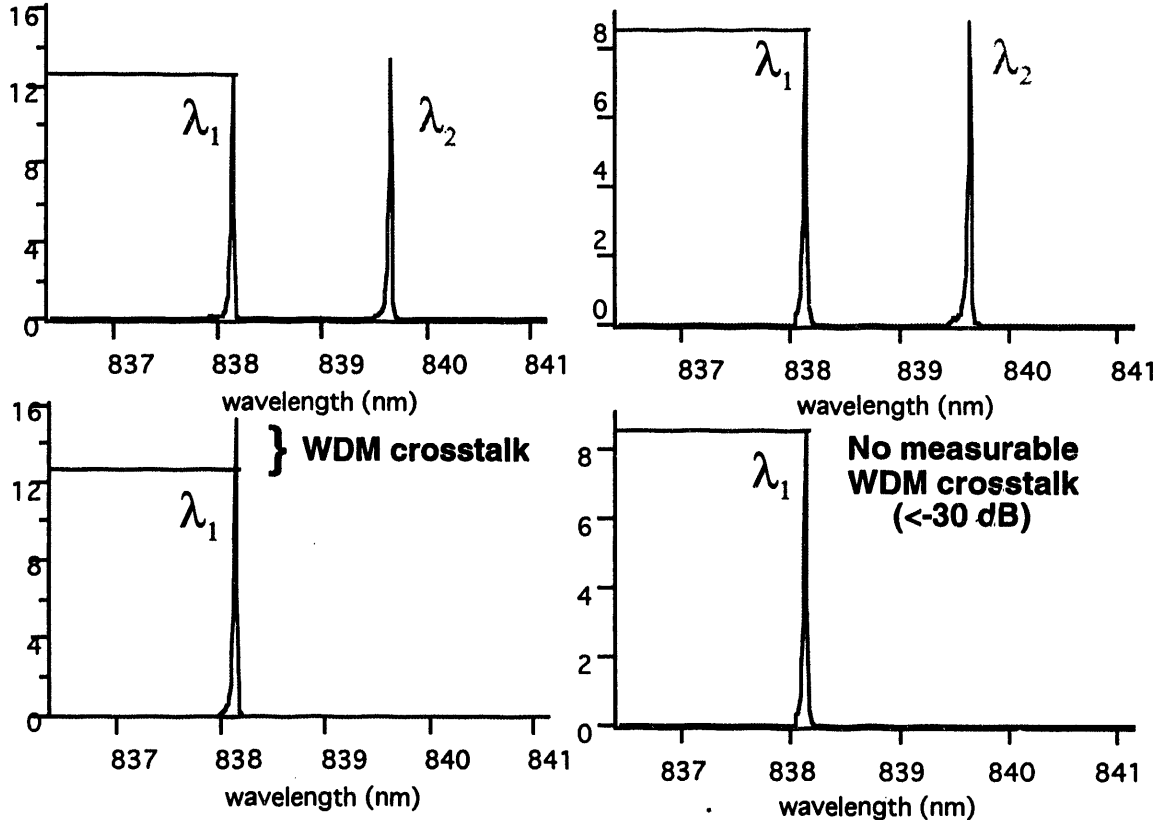


Fig.7A. Large WDM crosstalk is observed in a standard SOA.

Fig. 7B. WDM crosstalk is immeasurably small in the LLNL SOA.

This dramatic suppression of the crosstalk will allow our SOA device to be employed in WDM multi-channel links. For reference, AT&T Bell Lab's best published suppression of crosstalk distortion is 14 dB and their technique is limited to "tuning" the gain of an electrical amplifier to that of the optical amplifier in a feed-forward manner³. We believe that our crosstalk suppression technology will facilitate the widespread deployment of SOAs into fiber-optic systems.

5. SINGLE CHIP WAVELENGTH DIVISION MULTIPLEXED TRANSCIVER

Wavelength division multiplexing (WDM) is a very powerful technique to multiply the number of channels of information that is carried on a single optical fiber. The main drawback preventing the implementation of WDM currently is the lack of a good low cost transceiver to convert the electrical signals to light of different frequencies and multiplex them onto a single fiber, and to convert them back to electrical signals at the other end. Recently, researchers at Bellcore have developed a laser source using a curved grating and an array of laser diodes on a single chip that provides a discretely tunable transmitter⁴ Using a passive grating chip they have also made a wavelength demultiplexer for a receiver⁵. We are building on this work to develop a quickly (nanosecond) reconfigurable WDM transceiver that will simultaneously operate at many wavelengths.

The structure we have Designed is shown in Fig. 8. It is a single GaAs chip encompassing a passive grating and active waveguide amplifier sections. The input/output waveguide is designed to be gain leveled and the rest of

the array of active lasers (p-n junction ridge waveguides) have two electrodes instead of just one. Gain leveling of the input/output waveguide would be used to stabilize the gain characteristics. The split electrodes on the remaining waveguides could be used to change the active region under the end electrode (by changing the bias) from a lasing to an absorbing region and thus act as a detector of the signal in that channel. The second electrode region would provide preamplification of the signal to compensate for grating losses. Careful design of these electrodes is necessary to provide the proper balance between amplification and absorption of the signal.

Technical challenges include development of the fabrication process for the slab waveguide gratings and monolithic integration of the active and passive guides by epitaxial regrowth. We have established the etching and regrowth technology and are in the process of fabricating a set of passive gratings as a proof of principle experiment.

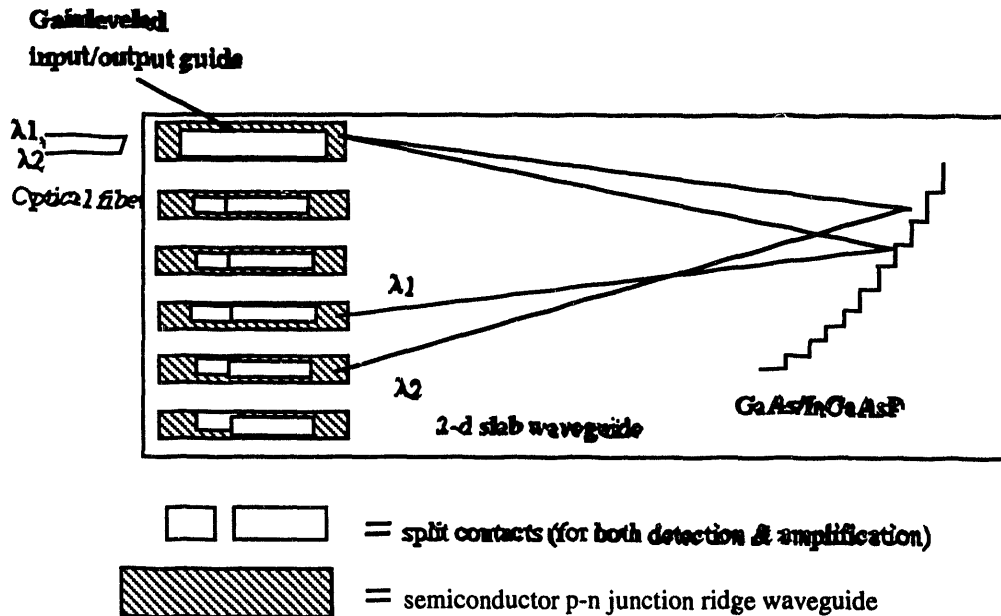


Fig. 8. WDM source, receiver and transceiver module with agile reconfigurability.

6. AUTOMATED OPTOELECTRONIC PACKAGING AND FIBER PIGTAILING

At present, the cost of optoelectronic (OE) devices is dominated by the effort required to package those devices into an integrated system. Components such as laser diodes and modulators, designed for high-performance applications, are single-mode devices; they must be connected together using optical fibers or other type of waveguide with sub-micron alignment accuracies. Presently, OE packaging is usually performed by highly skilled technicians looking through microscopes and manually adjusting sub-micron stages. Once the alignment is correct, the components must be held in place using epoxy, solder, or other attachment technique in such a manner that none of the components move during the attachment process. This labor-intensive process results in only a few packages being produced per day by each technician. The packaging costs are usually by far the highest fraction of the total cost of an assembled OE package, particularly for high-performance, single-mode devices. The consequences of this low-volume labor-intensive process of packaging OE devices are readily apparent. The costs are too high to allow the advantages of fiber optics to penetrate such markets as on-chip interconnects, interboard connections in computers, local area networks, or fiber to the home.

At LLNL, we believe that automation of the packaging could significantly reduce the costs of OE devices. The electronics industry has successfully reduced the costs of its products through the massive use of automation, including robotics, parts handling and feeding, and in-situ quality control. A simple model, which takes into account the initial cost of the automated machinery, the labor costs of an operator, and the

material costs of the devices, shows that substantial cost savings may also be realized in the optoelectronic industry at even modest production rates. Unfortunately, the sub-micron precisions required for OE packaging greatly exceed the requirements of the electronics industry. The automated systems developed to assemble integrated circuits cannot be applied to the problem of packaging optoelectronic circuits.

To help the US OE industry progress in this crucial area, we are designing and building a machine for automating the packaging of OE devices. The initial task of our Automated Fiber Pigtailling Machine (AFPM) will be to align a single-mode fiber to each end of a Mach-Zehnder modulator. The AFPM uses a two-step alignment procedure to achieve sub-micron accuracies. The first step of the alignment, the so-called coarse alignment, uses a two-view camera system and object-recognition software to identify and locate the optical fiber and the waveguides in the lithium niobate substrate. The computer then sends the commands to move the fiber within a few microns of the waveguide; this is sufficiently accurate to couple some light between the waveguide and the fiber. For the second step of the alignment, which we call the fine alignment, a laser diode is turned on and the light passing between the components is monitored with a photodiode while the sub-micron stages complete the alignment. The fine adjustments are made by maximizing the amount of light coupled between the fiber and the modulator. This combination of coarse and fine positioning techniques will result in faster, less expensive automated systems.

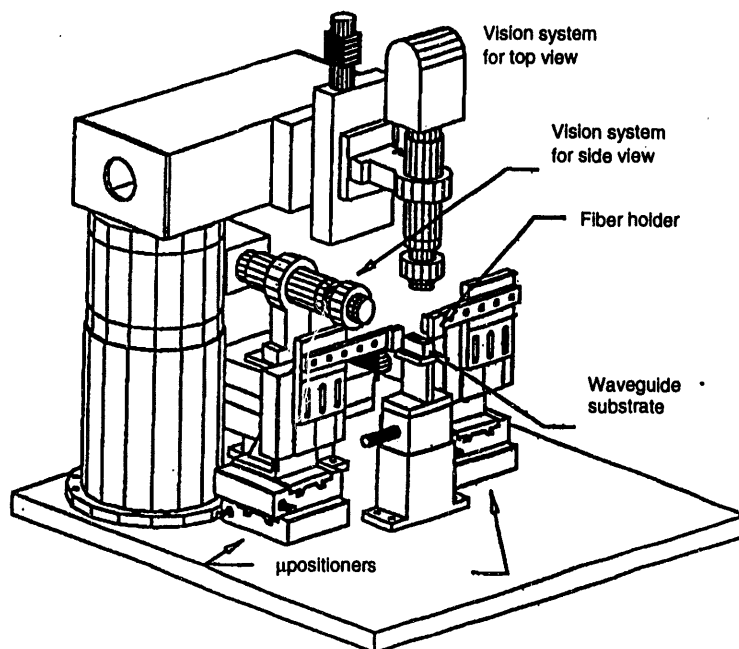


Fig. 9 A CAD drawing of the AFPM

The software that controls the AFPM and analyzes the camera images is presently in C-language on a 486-based PC; we are planning to make the software compatible with a Macintosh, also. The views of the top and side CCD cameras are recorded by a frame grabber with 480 x 640 pixels which provides approximately 800 micron fields-of-view with 1.44 micron resolution. Both cameras are mounted on translation stages to provide automatic zoom and focus as well as to view different areas on the modulator; in addition, the top camera is mounted on a rotary stage to move that camera out of the way for the application of epoxy to attach the fibers. The stages that position the fibers have 25 mm of travel and 0.05 micron resolution. These stages have sufficient travel and sufficient resolution to satisfy the requirements for both the coarse and fine alignment procedures. At present, the computer takes approximately 10 seconds to acquire and analyze the images from the cameras; the subsequent coarse alignment motion of the stages takes less than 1 second. Generally, 6 to 10 images are needed to move the fiber from outside the camera field of view to within a few microns of the modulator waveguide. This means that the coarse alignment takes one to two minutes. The fine alignment of maximizing the amount of light passing between

the components uses the patented AutoAlign "hill-climbing" algorithms developed by Newport/Klinger. This procedure also takes one to two minutes for a total time to perform sub-micron alignments of less than five minutes. Future hardware and software upgrades should reduce this time by nearly an order of magnitude. A CAD drawing of our AFPM is shown in Fig. 9.

The active alignment procedure being applied to the modulator in this prototype AFPM is also directly applicable to pigtailed laser diodes. We are also working on fiber attachment techniques which are compatible with high-volume production rates. There are many applications, however, in which passive components require high precision alignments. We are investigating the use of tactile feedback to perform the fine alignment of, say, flip-chip bonded components or fibers into silicon V-grooves. Performing sub-micron alignments at high production rates suggests that machine vibrations may be a concern; we are also addressing ways to incorporate active vibration control into the design of the AFPM.

We are designing and building silicon microbenches with geometries that are compatible with automated processes. Silicon microbenches provide the stability required to maintain the sub-micron alignment tolerances necessary for single mode operation. We design our microbenches with discrete areas for OE device attachment and areas for fiber attachment. For example, the microbench shown in Fig. 8 is for packaging a 1550 nm DFB laser. This microbench is 13 mm long by 6 mm wide and 0.5 mm thick. On the left half of the microbench, we photolitho-graphically pattern gold pads to provide a ground plane for the laser and stress relief pads for the wire bonds. To attach the fiber on the right half of the microbench, we pattern two heating elements made of polysilicon which are connected to gold bonding pads for electrical contact. In the center of each heater, we pattern a gold pad on a layer of silicon dioxide. This gold pad provides the solder attachment base while the silicon dioxide electrically isolates the gold pad from the polysilicon heater. The gold pads are 1 mm by 0.5 mm each and are sufficiently large to solder a 250 micron diameter fiber at each attachment pad. Presently, we use either 100-micron diameter solder balls or solder paste to attach the metalized fiber.

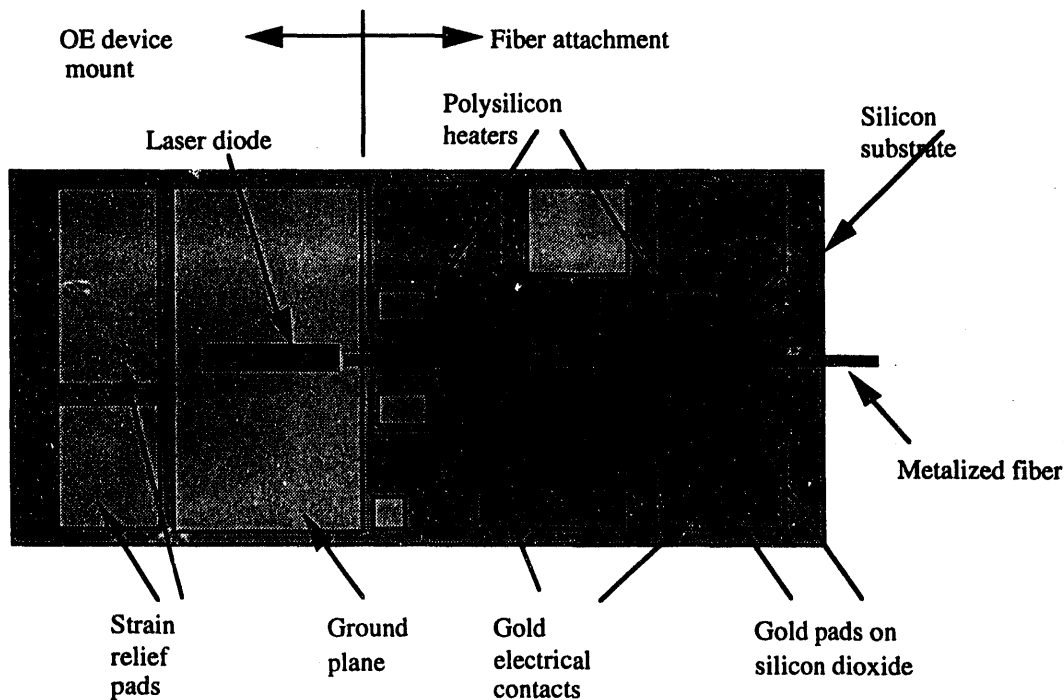


Fig.10 Microbench for packaging DFB laser

We originally built silicon microbenches with on-board heaters to pigtail single-mode fibers to high-powered 800 nm laser diodes. The performance of the polysilicon heaters on this prototype is very reproducible using a power supply that allows us to accurately control the magnitude and time of the applied current. For this application, we use active feedback to align the fiber to sub-micron accuracies.

While the fiber is held in the position that maximizes the optical coupling, current is passed through the heater to reflow the solder; the solder then wicks around the metalized fiber. We typically apply one amp of current for approximately 0.5 sec to reflow the solder. We observe no decrease in the light coupled from the 800 nm laser diode into the single-mode fiber after the solder has cooled and have achieved up to 65% optical coupling efficiency with conically tapered fibers. Commercially available single-mode laser-diode pigtailed typically have 25 - 30% coupling efficiencies.

Our microbench geometries with on-board heaters allow rapid attachment of not only the fiber but also other components to be placed on the microbench. Applying larger currents for longer periods of time allows solder reflow at other locations on the microbench. Using solders with different melting temperatures and judiciously choosing the order of attachment allows a variety of components to be soldered to the microbench without movement of previously attached components. Generally, components furthest from a heater are attached first using a high current through the heater. We can hand solder a thermo-electric cooler, a thermistor, and a laser diode onto our microbench at different distances from the heaters in less than 15 minutes. The placement of these components does not require sub-micron alignment; we envision that the placement and soldering of these components onto the microbenches could be performed by an automated system in only a few seconds. As the last step, the fiber must be aligned to sub-micron accuracies and then be attached using the least current through the heaters.

The idea of on-board heaters lends itself to applications other than packaging laser diodes. We are presently designing a longer microbench with heaters at each end to pigtail both ends of a semiconductor optical amplifier. We are also investigating geometries compatible with high speed applications in which on-board transmission lines will be needed to provide sufficient bandwidth for the OE device.

7. CONCLUSION

LLNL has expanded its photonics effort, based upon high-speed photonics research for nuclear testing, to address key national issues involving high-speed communications and photonics components. The philosophy at LLNL has been to embrace a hybridization approach that will allow access to the full spectrum of existing opto-electronic and electronic materials sooner than awaiting full integration. This approach, called a hybrid Optoelectronic Multi-chip Module (OEMCM) uses a silicon waferboard on which optical components (modulators, lasers, optical receivers, waveguides, optical amplifiers, etc.) are interfaced with micro-electronic circuits. The areas of research described in this paper are key developments that will lead to the hybrid OEMCM, as well as have valuable applications on their own. Because of the requirements of high-bandwidth, small size, high reliability and low cost these developments should be a significant benefit for the Aerospace industry, as well as many other US industries - particularly as the information age fully matures.

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