SAN098-0680C
SAND--98-0680C

Combined photonics and MEMs function demonstration

CONF-980117--

O. Blum, M. E. Warren, H. Q. Hou, R. F. Carson[a], K. D. Choquette, M. S. Rogers, J. J. Sniegowski
Sandia National Laboratories, MS0603, Albuquerque, NM 87185
[a] Microoptical Devices, Inc, Albuquerque, NM 87109

RECEIVED
MAR 2 0 1998
OSTI

ABSTRACT

We discuss two examples of integration of micro-electromechanical system (MEMs) and a photonic device. In the first instance, a MEMs locking device pin is driven by a voltage generated by photovoltaic cells connected in series, which are driven by a laser. In the second case, a VCSEL emitting at 1.06 μm is packaged together with a metallized MEMs shutter. By appropriate alignment to the opening in the shutter, the VCSEL is turned on and off by the movement of the Si chopper wheel.

Keywords: MEMs, shutter, VCSEL, photonic, integration, microsystem

We have recently demonstrated two prototypes where photonics and microelectromechanical system (MEMS) technologies have been integrated to show proof-of-principle functionality for weapon surety functions. These activities are part of a program which is exploring the miniaturization of electromechanical components for making weapon systems safer. Such miniaturization can lead to a low-cost, small, high-performance "systems-on-a-chip", and have many applications ranging from advanced military systems to large-volume commercial markets like automobiles, rf or land-based communications networks and equipment, or commercial electronics. One of the key challenges in realization of the microsystem is integration of several technologies including digital electronics; analog and rf electronics, optoelectronics (light emitting and detecting devices and circuits), sensors and actuators, and advanced packaging technologies. In this work we describe efforts in integrating MEMs and photonic functions and the fabrication constraints on both system components.

Use of photonic components to activate and power MEMs structures is of interest, because it allows for remote activation of the device, requiring only "line-of-sight" for the source. Furthermore, this scheme provides for optical isolation, preventing inadvertent activation of a component and increasing surety of the system. The first demonstration consisted of powering a micro-mechanical pin-in-maze locking device with series-connected photovoltaic (PV) cells to produce 75 volts

19980420 060

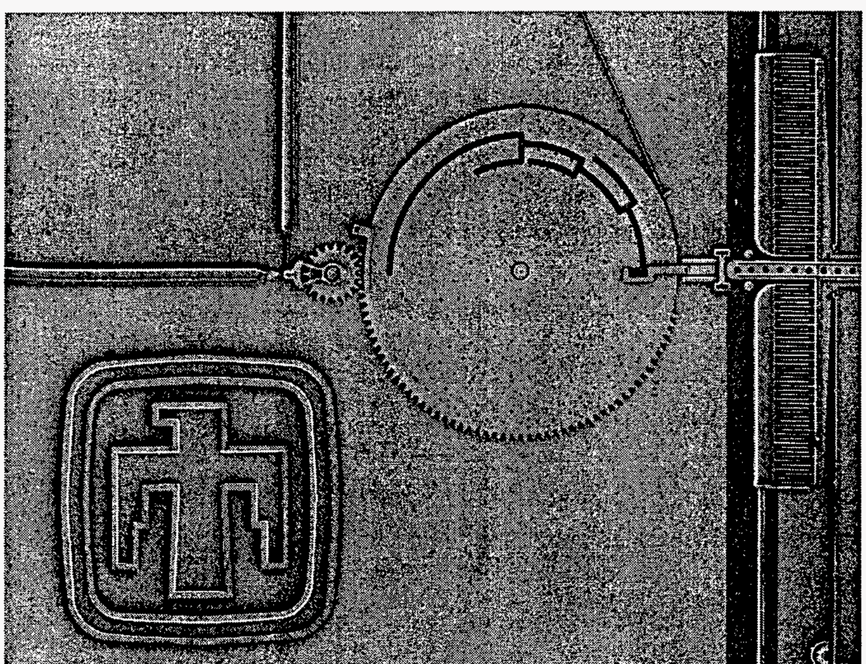

Figure 1. A pin-in-maze prototype lock built using polysilicon surface micromachining technology.

O.B. (correspondence): email: oblum@sandia.gov, telephone: (505)844-3458, fax: (505) 844-8985

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

when illuminated with a fiber-coupled laser diode. Since each junction of a silicon photocell produces less than one volt, it was necessary to use PV arrays with a large number of coupled photocells to provide the 75 volts necessary to drive the MEMS component. The PV cells were mounted in the same package as the MEMS devices and wire-bonded to one of the electrostatic comb drives on the device. The MEMS device, a "pin-in-maze" lock, is shown in Figure 1. Note that the correct voltage (and thus amplitude of the laser light) must be supplied to the guide pin in order to successfully guide it through the maze and unlock the mechanism. If an incorrect value is supplied, the pin ends up in one of the "dead ends" of the maze and the lock remains locked.

The control signals for the maze wheel were conventional electric signals while the pin motion was controlled by the open circuit voltage of the PV cells modulated by a fiber-coupled laser diode. The 850 nm wavelength laser was able to "steer" the pin through the maze as the wheel rotated. The operation of this device demonstrates feasibility of optically isolating MEMS surety components and providing drive signals by transmission of optical power. Improvements are anticipated in both improving the efficiency and drive capabilities of series-connected photovoltaic cells and in reducing the drive voltage requirements of the MEMS actuators.

The second demonstration consisted of a micromachined surety device mechanically shuttering the beam from a Vertical Cavity Surface Emitting Laser (VCSEL). This demonstration was a combination of two technologies that Sandia is well known for: MEMS and VCSELs. Several fabrication and packaging challenges had to be overcome in order to implement the combined MEMS/photonic functionality. Figure 2 shows schematically the cross sectional view of the combined microsystem of the MEMs shutter and the VCSEL.

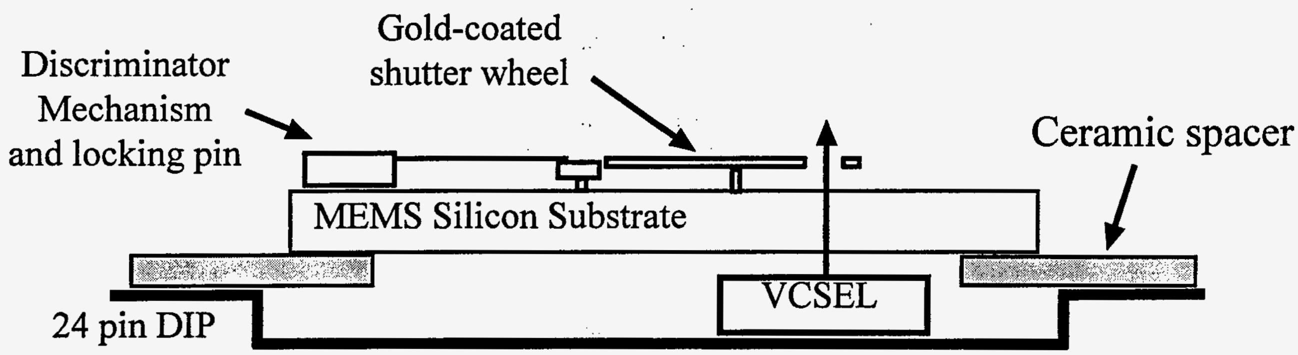

Fig. 2 Schematic cross section of the MEMs and photonics combined functional demo

The VCSEL was a designed to emit at a wavelength of 1.06 microns[1], since at that long wavelength the silicon in the MEMS device is more transparent than at shorter wavelengths. The VCSEL was grown by metalo-organic chemical vapor epitaxy (MOCVD) and consisted three 80 Å thick InGaAs quantum wells with tensile strained $GaAs_{0.8}P_{0.2}$ barriers embedded in 1-λ AlGaAs cavity. The bottom, n-type DBR consisted of 35 periods of $GaAs/Al_{0.94}Ga_{0.06}As$ mirror pairs and the top, p-type contained 20 periods of $GaAs/Al_{0.94}Ga_{0.06}As$. The interfaces were graded parabolically in order to reduce the series resistance of the mirrors. To facilitate formation of the oxide aperture above and below the active region, layers of $Al_{0.98}Ga_{0.02}As$ were grown immediately adjacent to the active region. The n-contact was made to the substrate with a AuGeNi alloy and the p-contact (TiPtAu) was made on top of the mesas with the center open for the light to pass through. Figure 3 illustrates layer structure of the active region and the electric field distribution at threshold.

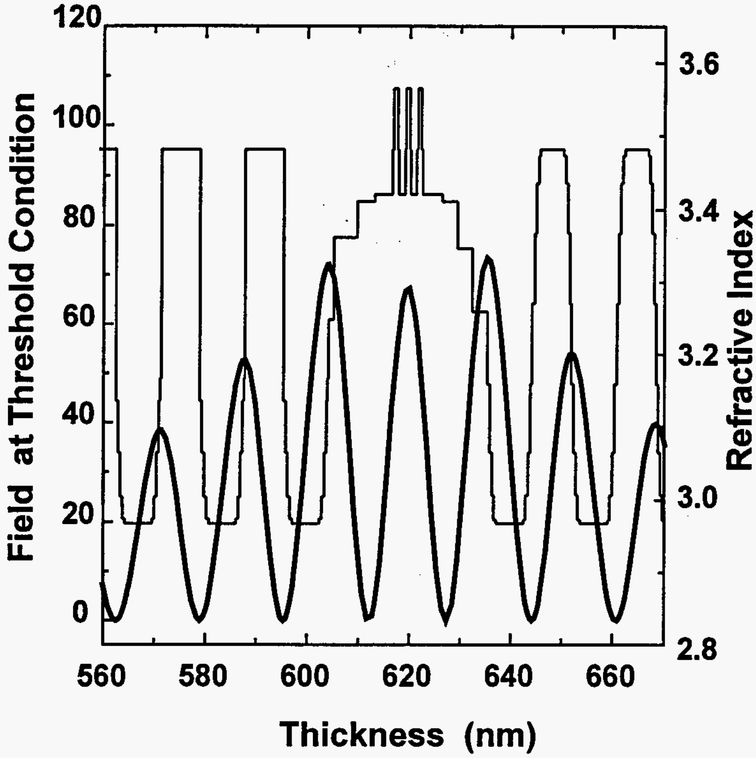

Fig. 3 Structure of the active region of the 1.06 μm VCSEL and the electrical field distribution at threshold

The performance of this VCSEL structure is illustrated in Figure 4, shown below. In a device with a 20x20 μm^2 active region, the threshold is reached at a current of 7 mA and voltage of 1.5V.

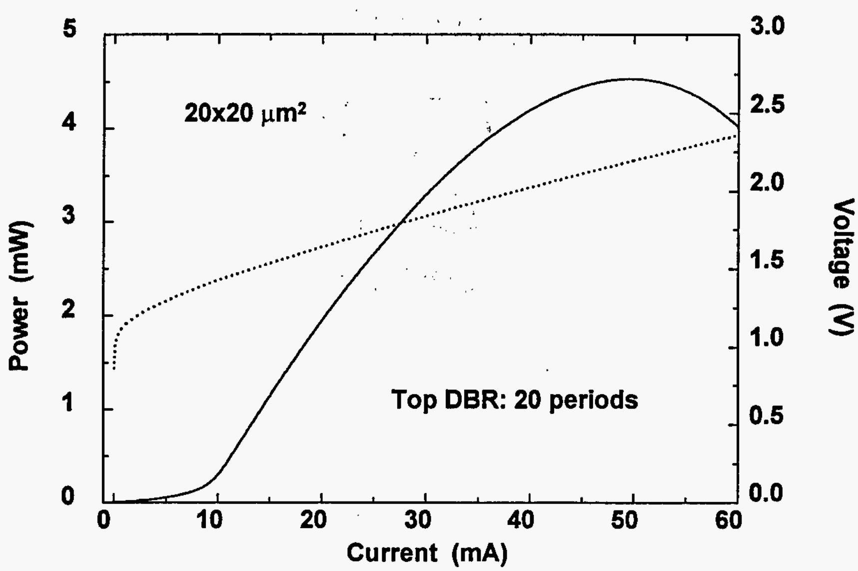

Fig. 4 Light-current-voltage characteristic for the VCSEL. Light out is shown with a solid line using the left axis, whereas the voltage is shown with a dotted line and the right axis.

Surface micromachining uses the planar fabrication techniques common to the microelectronic circuit fabrication industry to manufacture micromechanical devices. The standard building-block process consists of depositing and photolithographically patterning alternate layers of low-stress polycrystalline silicon and sacrificial silicon dioxide. Vias etched through the sacrificial layers provide anchor points between the mechanical layers and to the substrate. At the completion of the process, the sacrificial layers, as their name suggests, are selectively etched away in hydrofluoric acid (HF), which does not attack the polysilicon layers. The result is a construction system consisting of one layer of polysilicon which provides electrical interconnection and one or more independent layers of mechanical polysilicon which can be used to form mechanical elements ranging from simple cantilevered beams to complex systems of springs, linkages, mass elements and joints. Typical in-plane lateral dimensions can be from one micron to several hundred microns, while the film thickness are typically in the range of two to four microns. Because the entire process is based on standard integrated-circuit fabrication technology, hundreds to thousands of devices can be batch-fabricated on a single six-inch silicon substrate.

After the release of the MEMs part, gold had to be evaporated on the top surface of the mechanical shutter in order to ensure opaqueness to the VCSEL incident beam. This is necessary, since the Si is partially transparent at these wavelengths and the shutter would not sufficiently block the beam in the off position. This same feature allows us to position the VCSEL chip below the MEMs chip and propagate the light through a substrate and then through the shutter. Figure 5 shows a plot of the transmission through a 675 μm thick Si substrate of the 1.06 μm VCSEL in the case of the polished and unpolished back side of the substrate. One of the challenges in associated with the metallization capability was the development of a process to evaporate gold on a previously released MEMS structure without hindering its operation. We employed a shadow masking method, such that at no time did the mask touch the MEMs part. Another issue of importance involved good adhesion, and optical properties of the evaporated gold layer. This was achieved upon evaporation of 80 Å of Ti and 500 Å of Au. Another potential problem considered in the development of the process was stress-induced warpage of the wheel after evaporation. This issue was avoided through the use of a low temperature deposition process.

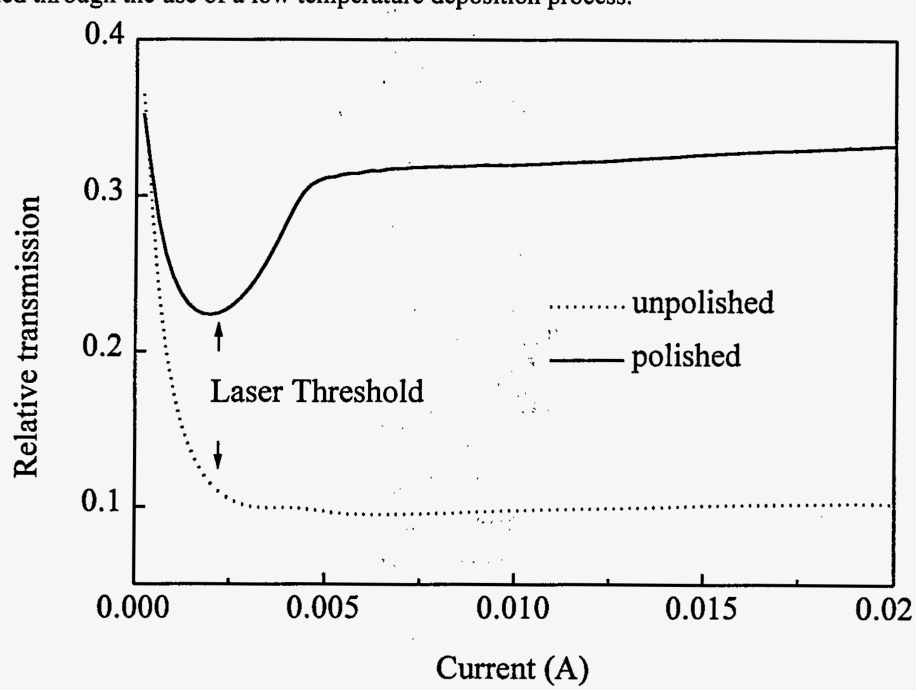

Fig. 5 Transmission of a 1.06 μm VCSEL through a polished (solid line) and unpolished (dotted line) backs side of the a 675 μm thick Si wafer

Finally, packaging issues for compatibility of both photonic and MEMS chips were addressed. A special hybrid package was assembled that allowed the VCSEL to be located close to the MEMS device and enabled the entire optical beam to pass through the shutter aperture without auxiliary optics.

The resulting device is illustrated in Figure 6. Here the VCSEL light is visible through a hole in the gold-covered MEMS shutter. As drive voltages are applied to the electrostatic micromotor, the shutter rotates, thus periodically allowing the VCSEL to transmit as shown in Figure 6. Depending on the control signals, the shutter can rotate in either direction and at a variety of speeds. By thus blocking or passing a laser beam, the MEMS shutter can be used to enable transfer of signals or power by optical means.

Future work in this area includes increasing sophistication of our post-processing capabilities on MEMs to include metallization to be done prior to release. In this way lithographic techniques can be employed, with all their attendant advantages. This however requires metallization scheme which will survive the release process, or perhaps some manner of protection during the release process. Work is ongoing in these areas, as well as development of longer wavelength VCSEL sources to improve transmission through the Si substrate. Another approach to this problem includes etching vias in Si underneath the MEMs parts which are to interact with light. This would allow the use of shorter wavelength VCSELs, perhaps even visible ones.

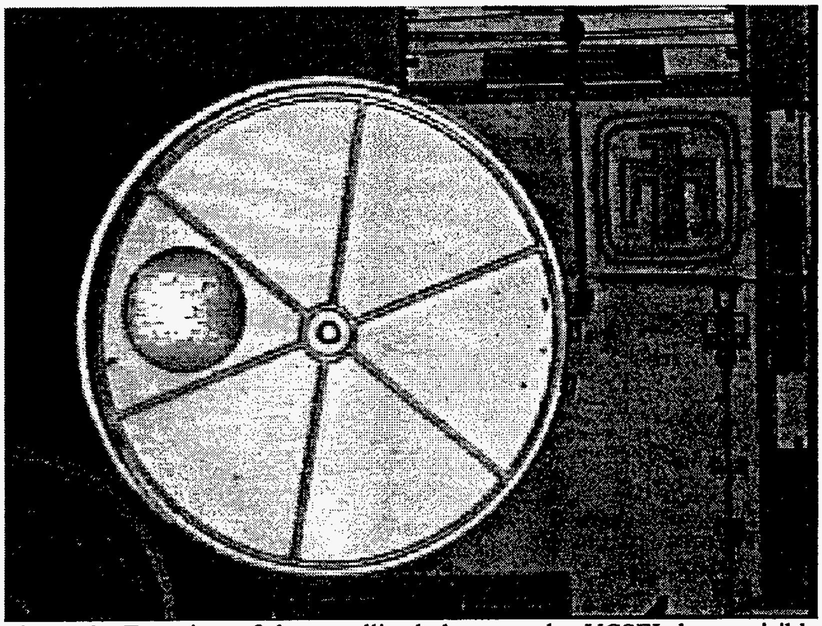

Figure 6. Top view of the metallized shutter and a VCSEL beam visible through a hole in that shutter.

In conclusion, we demonstrated a combined demonstration of MEMs and photonic functions, by integrating a light source (VCSEL) into a package with a MEMs shutter wheel. We also showed that MEMs actuators can powered by photovoltaic cells. Further work is underway to streamline the fabrication process and to develop release-etch resistant metallization, which will allow for a higher level of complexity in post-processing of MEMs for photonic applications.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000

REFERENCES

[1] H. Q. Hou, K. D. Choquette, K. M. Geib, B. E. Hammons "High-Performance 1.06-μm Selectively Oxidized Vertical-Cavity Surface-Emitting Lasers With InGaAs-GaAsP Strain-Compensated Quantum-Wells", *IEEE Photon. Technol. Lett.*, **9**, pp. 1057-1059, 1997

M98003411

Report Number (14) SAND--98-0680C
CONF-980117--

Publ. Date (11) 199801

Sponsor Code (18) DOE/DP, XF

UC Category (19) UC-700, DOE/ER

DOE