Self-Aligned Integration Of 8×1 Micromachined Micro-Fresnel Lens Arrays And 8×1 Vertical Cavity Surface Emitting Laser Arrays For Free-Space Optical Interconnect

S. S. Lee, L. Y. Lin, K. S. J. Pister, M. C. Wu, H. C. Lee* and P. Grodzinski*

UCLA, Electrical Engineering Department
* Motorola Inc. Phoenix Corporate Research Laboratories, Tempe, Arizona

Abstract

A novel, three-dimensional 8×1 micro-Fresnel lens array has been realized by surface micromachining technique; three-dimensional alignment blocks and supporting structures for both the micro-Fresnel lens array and the 8×1 vertical-cavity surface-emitting laser (VCSEL) array are also realized during the same process. With the help of these three-dimensional structures, self-aligned integration of the micro-Fresnel lens array and the VCSEL array are realized with passive alignment. Individual addressing of the VCSEL/micro-lens element is also successfully demonstrated. With their three-dimensional and array structural characteristics, they are very attractive for free-space optical interconnect and optoelectronic packaging.

Introduction

Free-space optical interconnect has drawn more and more attentions due to its high density routing and interconnection capabilities[1]. Compare to other types of interconnects such as electronic and planer waveguide approaches, free-space optical interconnect offers many unique advantages. For example, free-space optical interconnect could significantly improve the communication bottlenecks in VLSI system[2]. Because of its free-space implementation, much higher bandwidth (diffraction limited) can be achieved. In order to satisfy the requirement of massively parallel computers, free-space optical interconnects with high bandwidth, high density, and array form are desirable. Several implementations of using array devices have been reported[3-4]. However, the optical elements used in these approaches lie on the surface of the substrates and are not suitable for monolithic integration. In this paper, we present a new free-space optical interconnecting scheme for chip to chip, board to board and intra-chip communications. The core element of this scheme is a micromachined micro-Fresnel lens array. We have also developed a hybrid integration scheme for incorporating vertical cavity surface emitting laser (VCSEL) array with micro-Fresnel lens array using micromachining technique. The unique advantages of this scheme are that all passive micro-optical elements are monolithically integrated and, therefore, the time required for optical alignment is dramatically reduced. Micromachined micro-optical elements are made to stand perpendicular to the Si substrate using micro-hinges and micro-spring latches[5]. Therefore they are very attractive in dense free-space optical interconnect. Furthermore, VCSELs are attractive for this application because they can be made into two-dimensional arrays. The combination of vertical three-dimensional micro-Fresnel lens arrays and VCSEL arrays are very suitable for free-space optical interconnect and other integrated micro-optical system.

Fabrications

A. Micromachining Process

An 8×1 micromachined micro-Fresnel lens array has been fabricated using a similar process as the single micro-Fresnel lens[6]. First, a 2-μm-thick of phosphosilicate glass (PSG) layer is deposited on silicon substrate and serves as a sacrificial layer. Then, the first structural polysilicon layer of 2 μm thickness is deposited on top of the first PSG layer. Part of micro-hinges and micro-spring-latches are defined by lithography on this polysilicon layer. After a 0.5-μm-thick second PSG layer is grown, the second polysilicon layer of 1.5 μm thickness is deposited. The Fresnel zone pattern, side supporting structures, and the rest of micro-hinges and micro-spring-latches are defined on the second polysilicon layer. The schematic diagram of the layer structure and the surface-micromachined micro-optical element before assembly are shown in Fig. 1(a) and (b), respectively. After selectively removing the PSG layers with HF, the micro-Fresnel lens array is freely rotated out of the plane of the silicon wafer. It is fixed and locked at 90° to the substrate by the micro-spring latches and the side supporting structures. The schematic diagram and SEM picture of the 8×1 micro-Fresnel lens array and the 8×1 VCSEL array after assembly are shown in Fig. 2(a) and (b), respectively. The micro-Fresnel lens array plate is 2 mm wide and 350 μm tall. The center of the Fresnel zone rings are defined to be 254 μm above the substrate plane. The focal lengths of each micro-Fresnel lens are designed to be 500 μm. The side supporting

0-7803-2111-1 $4.00

structures consist of folded polysilicon plates similar to the lens array except that the folding direction is orthogonal to that of the lens array plate. The side supporting structure has a V-shaped opening at the top to guide the lens array plate into a 2 μm wide groove in the center. The side supporting structures are folded from two sides of the lens array plate and lock the lens array firmly at 90° to the substrate. The side supporting structures not only help the lens array stand precisely perpendicular to the substrate but also improve the mechanical strength of the lens array. Figure 3 shows the SEM picture of the side supporting structure, micro-hinges and micro-spring latches. Similar side supporting structures are also developed for VCSEL arrays. The design and fabrication of these structures are the same as those for lens array except they have wider V-groove to accommodate the thickness of the VCSEL. The V-groove for supporting VCSELs has asymmetric opening: the front edge of the V-groove is flat so that the VCSEL array is pushed forward to the focal plane when the supporting structure lower down.

B. VCSEL

The VCSEL is grown by metalorganic chemical vapor deposition (MOCVD). It consists a 35-pair n-doped quarter wave GaAs/AlGaAs bottom distributed Bragg reflector (DBR) stack, three InGaAs/GaAs strained quantum well active layers, a 25-pair p-doped top DBR mirror, and a P^+ GaAs cap layer. The VCSEL is designed to operate at 0.95 μm wavelength. Typical threshold currents are 4 mA for 10μm × 10μm VCSELs, and the maximum output powers are 1.2 mW. The VCSEL array is 2-mm-wide and the spacing between two adjacent VCSEL elements are 260 μm. To match the optical axises of the micro-Fresnel lens array, the VCSELs are precisely scribed into 2 mm x 350 μm chips and the emitting spots are located at 254 μm from the scribed edge. When the VCSEL is mounted on the side, the emitting spots are aligned with the micro-Fresnel lens array. The mounting and alignment blocks and electrical contacts for each individual VCSEL elements of the array are defined by lithography during the fabrication of the micro-Fresnel lens arrays.

Experiment and Results

After the micro-Fresnel lens array is assembled and locked onto the silicon substrate by micro-spring latches and side supporting structures, the VCSEL array is mounted in the designed slot. The VCSEL and the contact pads on Si are electrically connected by conducting contact epoxy. Each VCSEL element is individually addressable. We demonstrated the ON-OFF characteristics of this integrated device by individually pumping two different elements of the VCSEL array. Similarly, all eight VCSEL elements can be individually modulated. In this demonstration, we operated the VCSEL at pumping currents less than 1 mA and below threshold for each VCSEL array element, and the signals are detected by a high resolution CCD camera. The CCD images of the ON-OFF characteristics of two individual VCSEL elements of the array are shown in Fig. 4. We believe that this integrated device is suitable not only for free-space optical interconnect and micro-optics but also for low-power applications, such as internal interconnects for microprocessors.

Conclusion

In conclusion, we have demonstrated the fabrication of an 8×1 vertical three-dimensional micro-Fresnel lens array using micromachining technique for the first time. We have also demonstrated a scheme to implement free-space optical interconnect using hybrid integration of an 8×1 micromachined micro-Fresnel lens array with a passively-aligned vertical cavity surface emitting laser (VCSEL) array for the first time. With these unique three-dimensional and array structures, they are suitable for integration with other similarly fabricated micro-optical elements such as rotatable mirrors, rotatable gratings and beam splitters as well as other passively aligned active micro-optical devices. The performance of this integrated devices as an optical interconnect source is characterized by the ON-OFF switching characteristic which is obtained by individually modulating two different elements of the VCSEL array. The results indicate that this new technology is very promising for implementing optical interconnect and many other micro-optical systems.

Acknowledgment

The work at UCLA is supported in part by ARPA NCIPT, ULTRA, and Packard Foundation. S. S. Lee is supported by Rand Corporation Fellowship.

References

(1) B. Dhoedt, P. Dobbelaere, L. Buydens, R. Baets, and B. Houssay,"Optical free-space board-to-board interconnect: options for optical pathways," Applied Optics, Vol. 31, No. 26, pp. 5508-5516, 1992.

(2) J. W. Goodman, F. J. Leonberger, S. -C. Kung, and R. A. Athale, "Optical interconnection of VLSI systems," Proc. of IEEE, Vol. 72, No. 7, pp. 850-866, 1984.

(3) T. Sakano, K. Noguchi, and T. Matsumoto, "Novel free-space optical interconnect architecture employing array devices," Electronics Letters, Vol. 27, No. 6, pp. 515-516, 1991.

(4) S. Kawai, "Free-space multistage optical interconnection networks using micro lens arrays," J. of Lightwave Tech. Vol. 9, No. 12, pp.1774-1779, 1991.

(5) K. S. J. Pister, M. W. Judy, S. R. Burgett, and R. S, Fearing, "Microfabricated hinges," Sensors and Actuators A, Vol. 33, pp. 249-256, 1992

(6) L. Y. Lin, S. S. Lee, K. S. J. Pister, and M. C. Wu, "Three-dimensional micro-Fresnel optical element fabricated by micromahining technique," Electronics Letters, Vol. 30, No. 5, pp. 448-449, 1994.

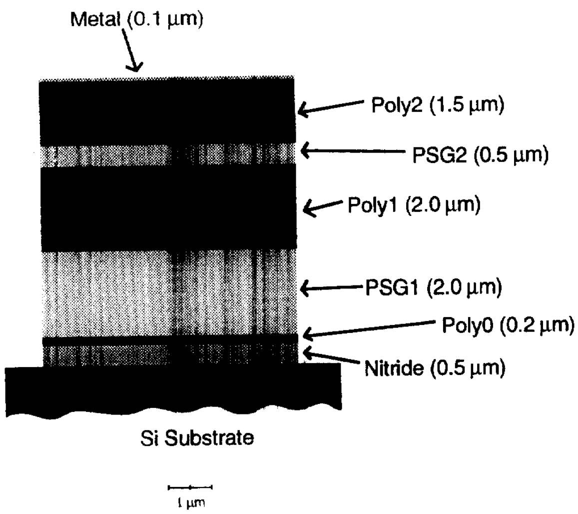

Figure 1(a) The schematic diagram of the layer structures.

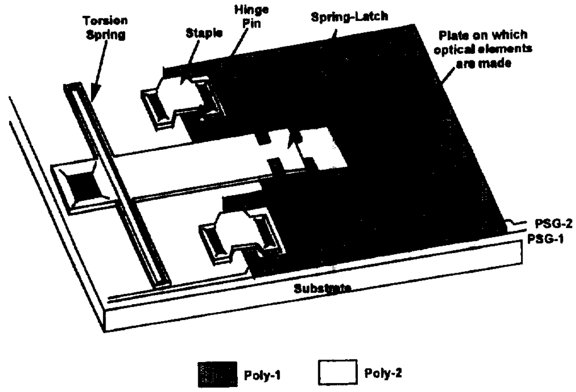

Figure 1(a). The schematic diagram of the surface-micromachined micro-optical elements before assembly.

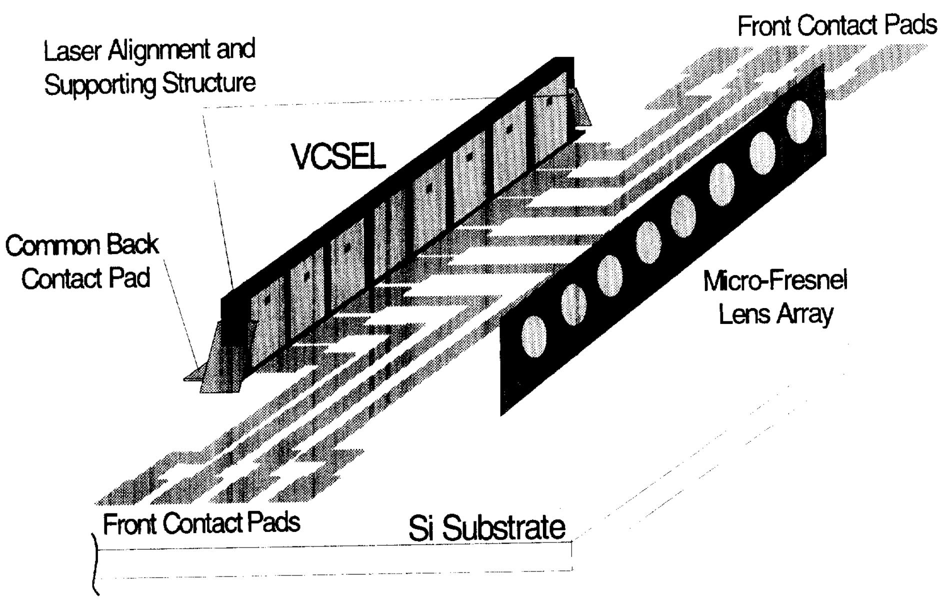

Figure 2(a). The schematic diagram of the self-aligned integration of the 8x1 vertical three-dimensional micro-Fresnel lens array and the vertical cavity surface emitting laser (VCSEL) array

31.2.3

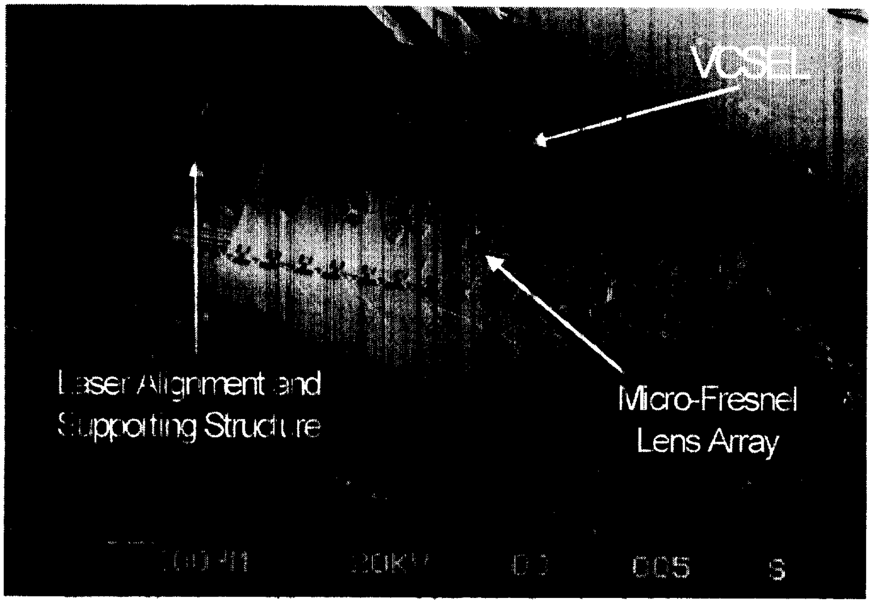

Figure 2(b) The SEM picture of the self-aligned integration of the 8x1 vertical three-dimensional micro-Fresnel lens array and the vertical cavity surface emitting laser (VCSEL) array

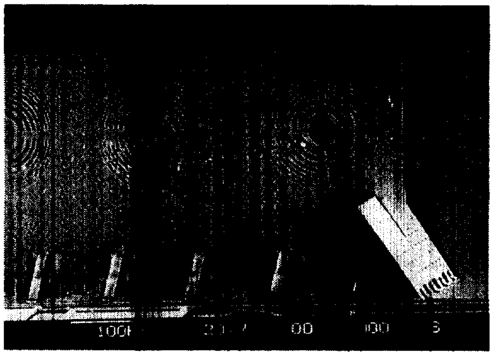

Figure 3. The alignment and supporting structure for the micro-Fresnel lens array

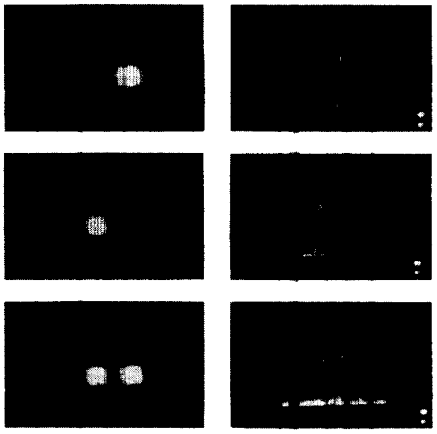

Figure 4. The CCD images of the ON-OFF switching characteristics of two individual VCSEL elements of the array

31.2.4