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Multi-Chip Shared-Memory Module with Optical Interconnection for Parallel Processor System

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1. Introduction

The performance of LSI chips has been dramatically improved as a result of scaling down the device size. However, such improvement of performance in LSI level is not always reflected to the improvement of performance in system level. This is because the performance of a system is eventually limited by the data transfer speed of electrical wirings which are employed as buses to send and receive the data among LSI chips. Such a bus-bottle neck becomes more serious in a parallel processing system. In order to overcome such issues in future parallel processing system, we have proposed a new multi-chip shared-memory module with optical interconnection which can connect several processors without serious bus-bottle neck. We designed and fabricate a multi-chip shared-memory test module with optical interconnection using SRAM. In this paper, we describe the fundamental characteristics of this test module.

2. Concept of shared memory with optical interconnection

Figure 1 shows the configuration of parallel processor system with shared memory units. A processor element (PE) is connected to the respective shared memory unit in this system. Shared memory units are connected by the optical interconnections. Therefore, the data written to a shared memory unit by the corresponding processor element are simultaneously transferred to other shared memory units through the optical interconnections. Consequently, these shared memory units connected by the optical interconnections act as a large shared memory. Many processors can be connected using this new shared memory without serious bus-bottle neck. We implement this new shared memory by using a multi-chip module with the optical interconnections as shown in Fig. 2. SRAM chip which is denoted as an LSI chip in the figure is used as a shared memory unit. Several SRAM chips are connected by polyimide optical waveguides which act as optical interconnections in the figure. The polyimide optical waveguides are formed on a Si substrate or a ceramic substrate which is called the optical plate [1]-[3]. Vertical-cavity surface emitting laser diodes (VCSELs) and photodiodes are integrated onto SRAM chips. These SRAM chips with VCSELs and photodiodes are mounted on the optical plate through copper bumps by using flip-chip bonding technique. The optical coupling between the waveguide, VCSEL and photodiode is achieved by using the Al micro-mirrors which are formed underneath the polyimide optical waveguide.

3. Design of SRAM test chip with O/E and E/O circuits

We designed a small SRAM test chip as shown in Fig.3 which is used as a shared memory unit. This SRAM test chip has the O/E (Optical/Electrical) receiver circuit and the E/O transmitter circuit for optical data transfer. Figure 4 shows the photomicrograph of fabricated SRAM test chip that consists of memory cell array (4×8 bits), sense amplifies, O/E receiver circuit and E/O transmitter circuit and peripheral circuit. The photodiodes are fabricated together with SRAM circuits in the test chip by using CMOS technology. VCSEL array chip with 6×6 VCSELs is integrated in the test chip using a beam lead bonding technique. Therefore, the metal electrode for VCSEL is prepared in the test chip.

4. Fabrication of shared-memory test module with polyimide optical waveguides

Figure 5 shows the photomicrograph and the SEM microphotograph of the optical plate fabricated using Si wafer. It is clearly observed in the figure that the polyimide optical waveguides and many copper bumps are formed on the optical plate. The Al wirings for the electrical signal lines and the power and ground lines are also formed on the optical plate. Several SRAM test chips with VCSELs and photodiodes were bonded onto this optical plate by using flip-chip bonding technique. The SRAM test chips were electrically connected with the optical plate through the copper bumps. Electrical connection and mechanical bonding between the copper bumps and the Al pads on the optical plate were accomplished by the electrically conductive adhesive printed onto the top surfaces of copper bumps. The photomicrograph for cross-sectional structure of test module with polyimide optical waveguides is shown in Fig.6. It is clear in the figure that SRAM chip is flip-chip bonded onto the optical plate through the copper bumps and a VCSEL array chip is integrated onto the SRAM chip using the beam lead bonding. It is also obvious in the magnified picture that the SRAM chip is aligned to the optical plate so that VCSELs are faced to the polyimide optical waveguides.

5. Evaluation of shared-memory test module with polyimide optical waveguides

Figure 7 shows the experimental set-up to evaluate the fundamental characteristics of fabricated test module. In this work, the optical signal emitted from external He-Ne laser was introduced into the polyimide optical waveguide through the glass fiber in order to evaluate the data transfer characteristics of the polyimide optical waveguide and the optical writing characteristics to SRAM. Figure 8 shows the photomicrograph of optical plate introducing the external optical signal to the polyimide optical waveguide through the optical fiber. The SRAM chip is removed in the figure in order to observe the optical signal which is guided through the waveguide and reflected at the Al micromirror. As a result, the optical signal reflected at the Al micromirror is clearly observed in the figure. The waveforms measured in the test module with optical waveguides are shown in Fig. 9 where the optical writing and electrical reading operation is demonstrated both for the data “0” and the data “1”. In the optical writing operation, the optical signal is detected and converted by the photodiode and then amplified by the receiver circuit. This amplified signal is transferred to the sense amplifier and amplified again by this sense amplifier by applying the clock signal to the Op-In-En terminal which acts as write-enable signal for optical writing. Eventually, this amplified signal is written into a SRAM memory cell. Then, this signal data written into the memory cell is successfully read-out in the electrical reading operation as is clear in Fig.9 . By the way, the data is also read-out to the electrical output terminal in the optical writing operation since the output signal from the receiver circuit is transferred to the electrical output terminal as well when the clock signal is applied to the Op-In-En terminal. Thus, it was demonstrated that the optical data transfer through the polyimide optical waveguide and the optical writing and electrical reading operation in SRAM which is used as a shared memory unit are successfully implemented in the fabricated test module.

6. Conclusion

We proposed a new multi-chip shared-memory module with optical interconnection which acts as a large shared memory for a parallel processor system. We fabricated the test module by employing the SRAM chip as the shared memory unit and the polyimide waveguide with Al micromirrors as the optical interconnection. Both VCSELs and photodiodes are integrated onto the SRAM chips. It was confirmed that the optical data transfer through the polyimide optical waveguide and the optical writing and electrical reading operation in SRAM are successfully implemented in the fabricated test module.

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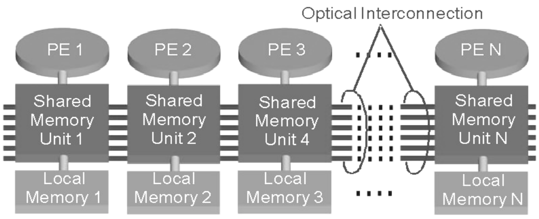

Fig.1. Parallel processor system with shared memory units connected by optical interconnections.

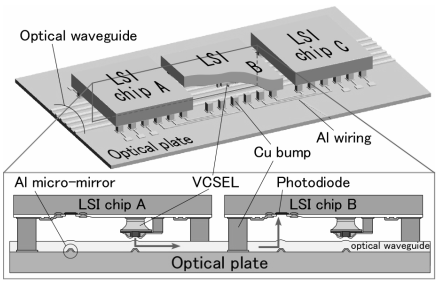

Fig.2. Structure of multi-chip shared memory module with optical interconnection.

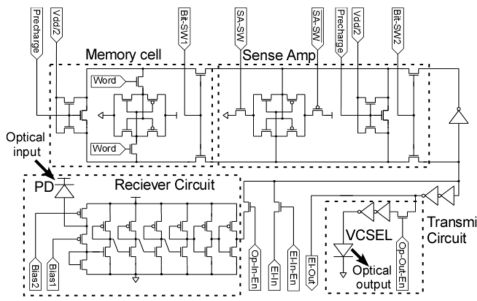

Fig.3. Schematic circuit for SRAM test chip with O/E and E/O circuits.

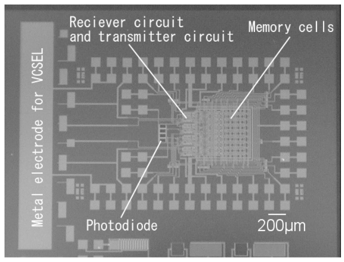

Fig.4. Photomicrograph of SRAM test chip with O/E and E/O circuits.

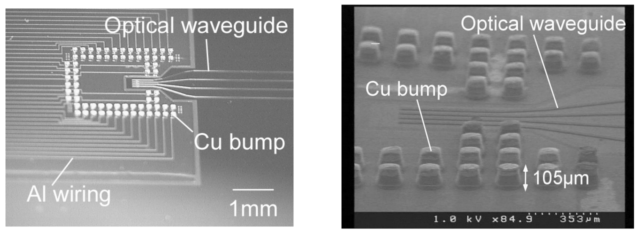

Fig.5. Photomicrograph and SEM micrograph of the fabricated optical plate.

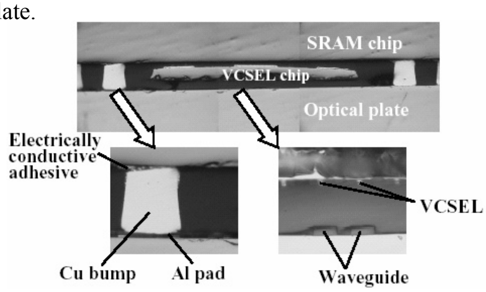

Fig.6. Photomicrograph of test module with polyimide optical waveguides

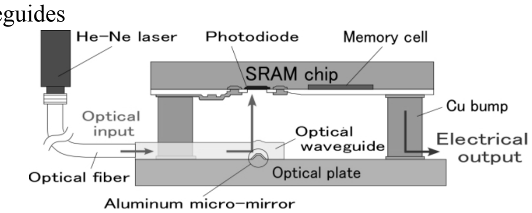

Fig.7. Experimental set-up to evaluate the fundamental characteristics of test module.

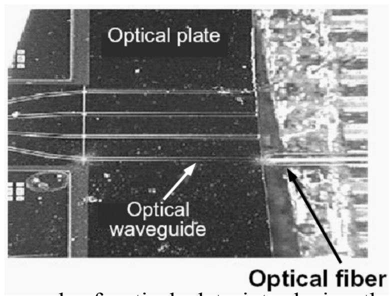

Fig.8. Photomicrograph of optical plate introducing the external optical signal to the polyimide waveguide through the optical fiber

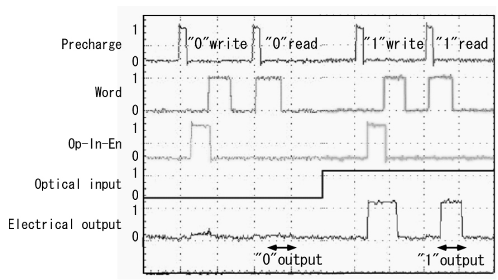

Fig.9. Waveforms measured in the test module with optical waveguides.