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Optically Coupled Three-Dimensional Common Memory with Novel Data Transfer Method

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An optically coupled three-dimensional common memory has been proposed to perform real-time parallel data processing in a hardware level. In this memory high speed block data transfer is carried out by optical coupling between memory layers. In order to reduce the cell size of this memory, a scalability of the LED and photoconductor used for the optical coupling is evaluated. A novel optical data transfer method of sense amplifier coupling is also proposed for achieving high packing density and large capacity of the three-dimensional common memory.

1. Introduction

The optically coupled three-dimensional common memory, which is abbreviated as 3D-OCC memory, is a kind of intelligent memories for high speed parallel processing[1,2]. The 3D-OCC memory has three-dimensional multilayered structure in which each memory layer is mutually interconnected by optical coupling. Very high speed data transfer is achieved in this memory due to simultaneous block data transfer by optical coupling. Such data transfer is implemented in the vertical direction while the conventional memory operation is done in the horizontal plane. Consequently, highly parallel data processing can be realized by using this 3D-OCC memory.

In the originally proposed 3D-OCC memory, each memory cell had two LEDs and two photoconductors which occupied a significant part of the memory cell area. Therefore, this type of 3D-OCC memory cell needed a cell size of 4∿5 times larger than that of a conventional SRAM cell in the case of 2μm CMOS technology.

In this paper we describe the method to reduce the cell size from the viewpoint of a device scaling and an improvement of data transfer method.

2. Memory Cell Coupled 3D-OCC Memory

An example of parallel processing systems with 3D-OCC memory is shown in Fig. 1. The 3D-OCC memory is composed of two-dimensional memory layers which are vertically stacked. The upper and lower layers are connected each other by optical coupling, and data written in a memory layer are transferred immediately to the other layers by optical coupling. A CPU is

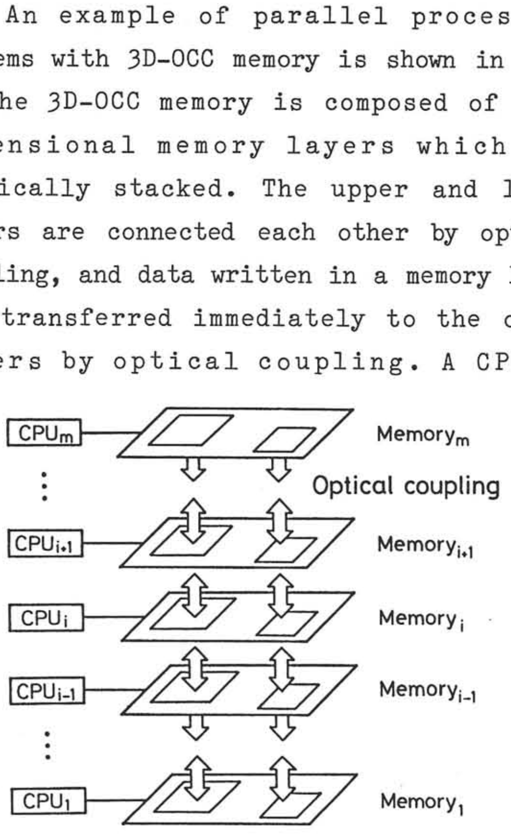

Fig. 1 Parallel processing system with optically coupled three-dimensional common memory.

connected to the respective memory layer of 3D-OCC memory. These CPUs can independently execute the electrical writing and reading operation during the optical data transfer operations. Therefore, very high speed parallel processing system with multi-processors can be realized by using 3D-OCC memory. The Optical coupling in the 3D-OCC memory is carried out by using an optically coupling flip-flop. This flip-flop contains two pairs of LEDs and photoconductors as shown in Fig. 2. "Low" node potential of the flip-flop is changed to "High" when the photoconductor connected to the node receives a signal light because the photoconductor resistance is reduced. The LED connected to "High" node of the flip-flop emits the signal light of "High" to the upper and lower memory layers. Thus, data are transferred vertically by optical coupling through LEDs and photoconductors. This optically coupling flip-flop is employed as a memory cell in the previously proposed 3D-OCC memory as shown in Fig. 3. We call this type of 3D-OCC memory as a memory cell coupled 3D-OCC memory. Very high speed data transfer can be achieved in this 3D-OCC memory, since memory cells are directly coupled. However, it is difficult to realize a large memory capacity in this type of memory unless the LED and photoconductor sizes are significantly reduced.

3. Scalability of LED an photoconductor

In order to reduce the LED and photoconductor sizes, the scalability of LED and photoconductor is evaluated based on the optical coupling efficiency between LED and photoconductor and the memory cell static margin. Figure 4 shows the dependence of the optical coupling efficiency on the horizontal spacing between LED and photoconductor. LED and photoconductor sizes are varied as parameters. As obvious in the figure, the optical coupling efficiency rapidly decreases

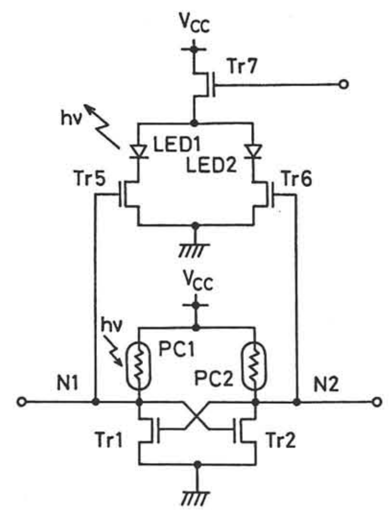

Fig. 2 Optically coupling flip-flop circuit.

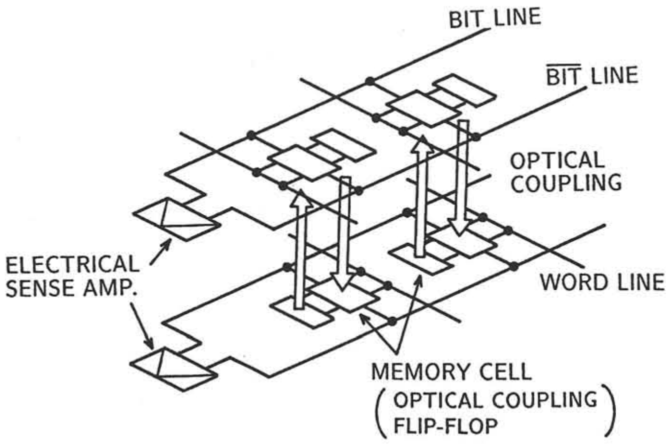

Fig. 3 Memory cell coupled 3D-OCC memory circuit.

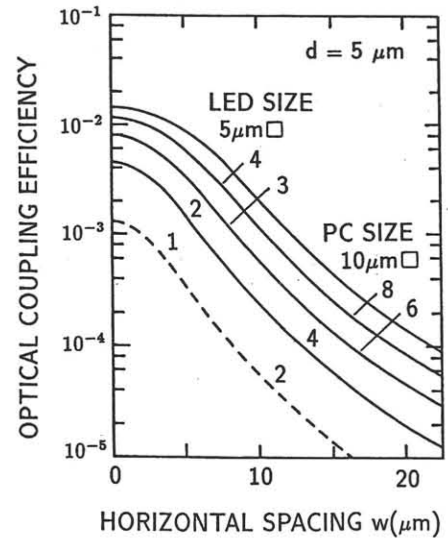

Fig. 4 Optical coupling efficiency vs. horizontal spacing for different sizes of LED and photoconductor(PC) pairs.

with decreasing the size of LED and photoconductor as well as the horizontal spacing. Memory cell static margin is derived from this optical coupling efficiency as shown in Fig. 5, where the normalized static margin is plotted versus scaling factor. The scaling factor is normalized to the value for 2μm technology devices where 2μm CMOS, 5μm × 5μm LED and 10μm × 10μm photoconductor are employed. The memory cell static margin also dramatically decreases with reducing the scaling factor. Consequently, it seems difficult to reduce the size of LED and photoconductor to less than the scaling factor of 0.3.

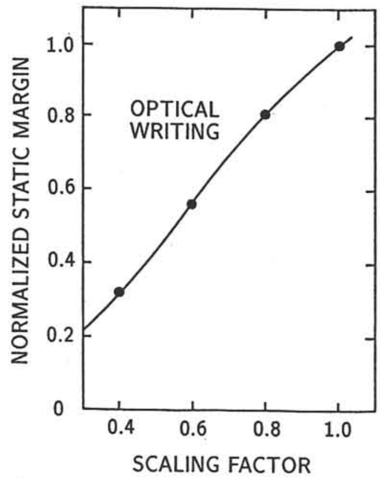

Fig. 5 The normalized static margin of a memory cell vs. the scaling factor.

4. Sense Amplifier Coupled 3D-OCC Memory

In the memory cell coupled 3D-OCC memory, all LEDs can not simultaneously emit the signal lights during the vertical data transfer because the total power consumption for LEDs is limited. This means that each of memory cells does not need LEDs, and hence the optical data transfer part can be separated from the memory cell array part. As a result, we can use the conventional memory cells such as SRAM cell or DRAM cell and reduce the 3D-OCC memory chip size comparable with the conventional SRAM or DRAM. Figure 6 shows an example of this type of 3D-OCC memory. In this memory, optically coupling sense amplifiers are used in the optical data transfer parts. Data transfer between the upper and lower memory cells is implemented through the optically coupling sense amplifier. We call this 3D-OCC memory as a sense amplifier coupled 3D-OCC memory. In Fig. 6, SRAM cell is employed as a memory cell. Therefore, it is a SRAM type 3D-OCC memory with sense amplifier coupling. Suppose that data are transferred from the upper memory cell to the lower memory cell in Fig. 6. Data being read from the upper memory cell are amplified by the upper optical sense

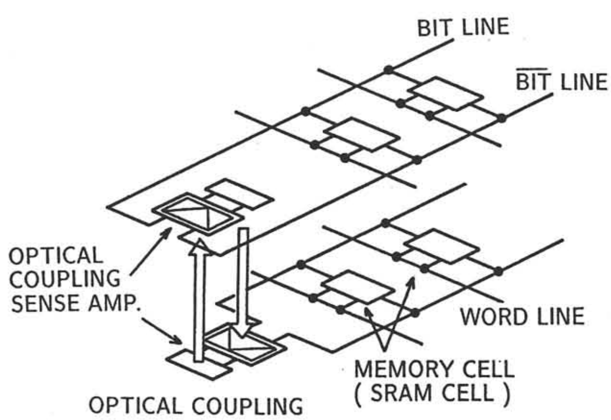

Fig. 6 Sense amplifier coupled 3D-OCC memory circuit.

amplifier and transferred to the lower optically coupling sense amplifier. The transferred data are again amplified by the lower optically coupling sense amplifier and written into the lower memory cell. Thus, the sense amplifier coupled 3D-OCC memory needs two operation steps per cycle, while the memory cell coupled 3D-OCC memory does one step. All data stored in the memory cells which are connected to the one word line are simultaneously transferred in the sense amplifier coupled 3D-OCC memory. The optically coupling sense amplifier circuit is shown in Fig. 7. It consists of an optical coupling flip-flop and an electrical dynamic CMOS sense amplifier. The CMOS sense amplifier is used for amplifying not only

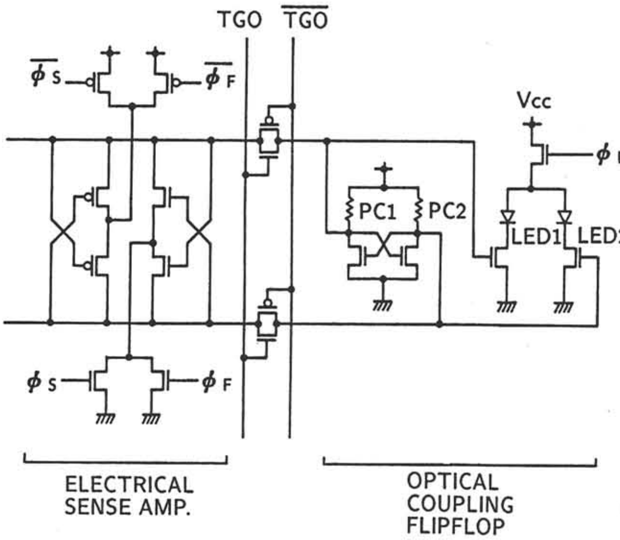

Fig. 7 Optically coupling sense amplifier circuit.

electrically read-out signal but also optically transferred data. Data transferred to the optically coupling flip-flop are written into the memory cell after they are amplified by a CMOS sense amplifier.

Wave forms in the SRAM type 3D-OCC memory with sense amplifier coupling is shown in Fig. 8. As clear in the figure, one data transfer cycle includes the two operation steps of the electrical writing/reading and the optical transfer. In the figure, data "1" are written into the layer 1 memory cell while data "0" are read out from the layer 2 memory cell in the electrical writing/reading step. Furthermore, data "1" written into the layer 1 memory cell are transferred to the layer 2 memory cell through optically coupling sense amplifiers by applying clock pulses, ϕ_{LED} and ϕ_S, in the optical transfer step. Thus, data are successfully transferred by sense amplifier coupling, although the two operation steps are necessary. If the word line and bit line are duplicated and two-port memory cell is employed, one operation step per cycle can be also possible in the sense amplifier coupled 3D-OCC memory.

5. Conclusion

Scaling of LED and photoconductor and a

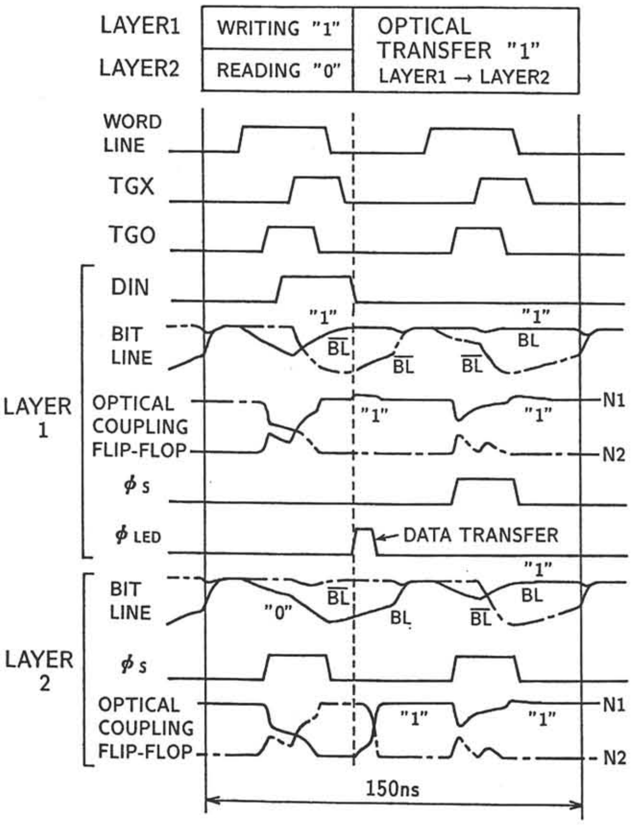

Fig. 8 Wave forms in the SRAM type 3D-OCC memory with sense amplifier coupling.

novel sense amplifier coupling data transfer are evaluated to reduce the 3D-OCC memory cell size. It is found that the scaling of LED and photoconductor to less than a factor of 0.3 is difficult. Successful operation of a sense amplifier coupled 3D-OCC memory, which is very effective to reduce the chip size, was confirmed by the simulation.

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References

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