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Through Silicon Photonic Via with Si core for Low loss and High Density Vertical Optical Interconnection in 3D-LSI

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1. Introduction

As the scaling-down of the device size, interconnect-related problems such as signal propagation delay and interconnect power dissipation become critical problems for realizing a high performance LSI. To overcome these problems, 3D-LSI has attracted much attention [1]. On the other hand, an on-chip optical interconnection is also promising candidate due to many advantage such as high speed, high density, less crosstalk, and high tolerance to EMI (electromagnetic interference) [2]. These advantages of the optical interconnection further improve the 3-D LSI performance. In order to realize the high performance and high communicating systems, we propose an opto-electronic 3D-LSI as shown in Fig. 1. Optical interconnection in the 3-D LSI allows more high-speed and high-bandwidth communication between local blocks separately placed on the each LSI chip. And they also provide the high-speed and high-bandwidth input-output data transfer for each LSI chip. The opto-electronic 3D-LSI will achieve the high performance computation using a massive parallel operation induced by the 3D-LSI and high-speed and high-bandwidth optical interconnection.

For the opto-electronic 3D-LSI, a vertical through Si optical interconnection is required to provide a light source from an external light emitter to each LSI chip in the 3-D LSI. And such interconnection is also required to realize seamless optical interconnection between on-chip and off-chip devices. To realize such vertical optical interconnection, we proposed through silicon photonic via with Si core (TSPV) as shown in Fig. 1. In this paper, we describe the basic function of TSPV for low loss and high density vertical optical interconnection.

2. Fabrication of TSPV

In recent year, an optical TSV with polymer core has proposed for high performance communication [3]. However the polymer based optical TSV may not suitable for the opto-electronic 3D-LSI, because large RI (refractive index) mismatch between optical TSV and Si photonic devices can induce a large reflection loss. Moreover, the relative refractive index difference of the polymer based optical TSV is very small, hence it cannot realize the high density optical interconnection. To overcome these problems, we proposed TSPV as shown in Fig. 2.

As the core material of TSPV is Si, the low loss optical coupling between TSPV and Si photonic device can be easily realized. In addition, the relative refractive index difference of TSPV is high. Hence, the high density TSPV can be realized due to its strong light confinement property. Moreover, TSPV is more compatible with standard CMOS (complementary metal oxide semiconductor) process. A lot of materials whose refractive index is lower than Si are usable as a cladding material.

In this paper, we fabricated the TSPV with a cladding of epoxy to evaluate the light confinement of the TSPV. Fig. 3 shows the optical images of top view and cross-sectional view of the fabricated TSPV. 11x11 arrays of TSPV with 10μm width Si core and 3μm width cladding were successfully fabricated as shown in Fig. 3(a). Fig. 3(b) shows that there are no voids in the cladding region, therefore good epoxy cladding was obtained.

3. Evaluation of TSPV

To evaluate the light confinement property of TSPV, we measured NFP (Near Field Pattern) of a laser light passing through Si substrate. We compared NFP measurement between two samples as shown in Fig. 4. To irradiate the light into only TSPV array, a thin Ta film was formed on the surface of sample for the shielding of light. Open area of Ta film for TSPV is 7.5μm and the pitch is 13μm, respectively. The core width of TSPV is 10μm, and the cladding width is 3μm. A 1.55μm laser is used as an incident light.

Fig. 5 shows the NFP results of the laser light passed through Si substrate without TSPV (a) and with TSPV (b), respectively. As seen in Fig. 5 (a), the interference between each light beam is clearly observed. However, there is no interference in case of with TSPV as shown in Fig. 5(b). Each light was well passed through the TSPV without the interference. This mean that the TSPV can successfully confine the light. Fig. 6 shows the measured NFP profiles and 2D-FDTD (Finite Distance Time Domain) simulation results. Shaded region is the cladding area. As clearly seen in this figure, TSPV well confined the light beam in the core region. The simulation results show a good match with the experiment result. Hence, 2D-FDTD simulation is a useful method to evaluate a vertical optical interconnection. In order to estimate the efficiency of the TSPV, we simulated the beam loss by using 2D-FDTD simulator as shown in Fig. 7. The beam loss is very small in case of with TSPV. TSPV is highly required to realize the low loss vertical optical interconnection. We simulated the beam loss depend with the TSPV size as shown in fig. 8. A very fine TSPV with 1μm core width and 0.5μm cladding width can be theoretical feasible.

4. Conclusion

We fabricated TSPV for the low loss and high density vertical optical interconnection. TSPV was successfully confined the light without interference. 2D-FDTD simulation result indicates that the very fine TSPV of 1μm core width and 0.5μm cladding width is feasible for low optical loss. From these results, we confirm that TSPV is strongly required for the low loss and high density vertical optical interconnection.

Acknowledgements

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References

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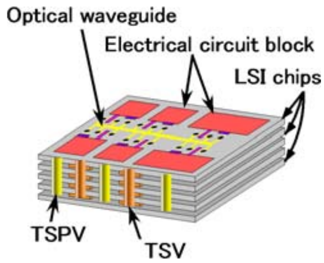


Fig. 1 Concept of the optoelectronic 3D-LSI

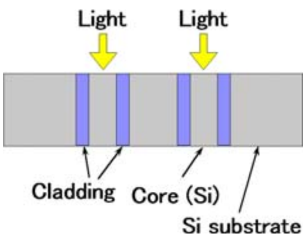
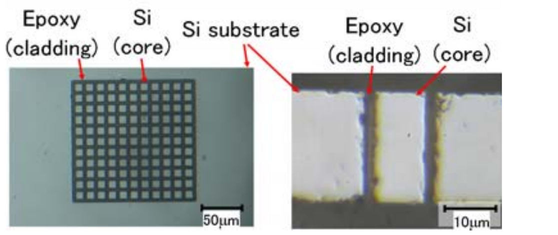


Fig. 2 Structure of TSPV



(a) top view (b) cross-sectional view

Fig. 3 Microscopic image of the fabricated TSPV

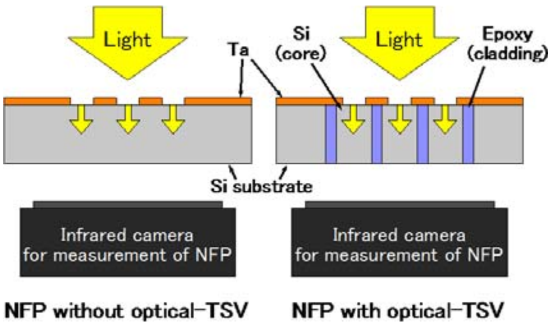
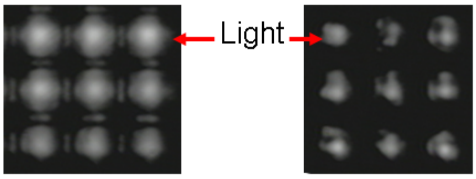
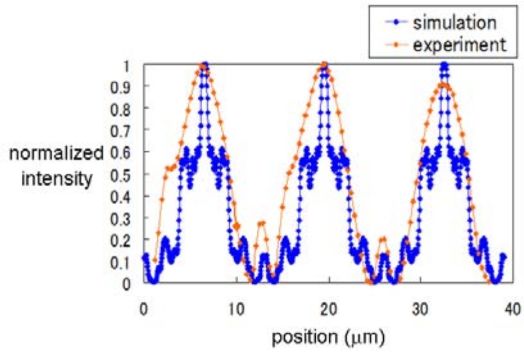


Fig. 4 NFP Measurement

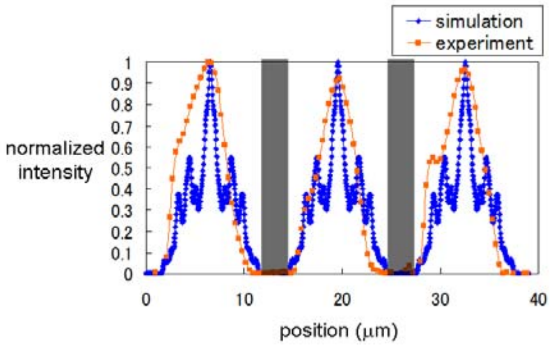


(a) without TSPV (b) with TSPV

Fig. 5 NFP of a laser light passing Si substrate



(a) without TSPV



(b) with TSPV

Fig. 6 Profiles of NFP normalized by peak value

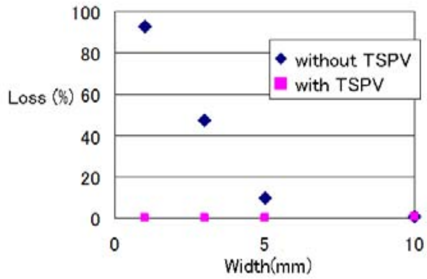


Fig. 7 Simulation results of optical loss attributed to light beam divergence

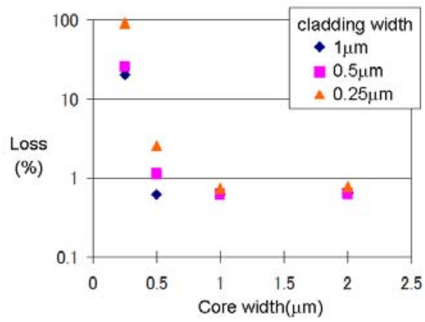


Fig. 8 Simulation results of optical loss depending on the width of core and cladding