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High-Speed Heat Removal for VLSI Using AlN Heat-Spreading Layer and Microchannel Fin

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We propose a microchannel fin package utilizing a passivation layer of AlN as the heat spreader and a microchannel fin as the efficient heat removal method. AlN film has high thermal conductivity and compatibility with the thermal expansion coefficient of Si. A microchannel fin has 4 fold 100 lines of $50\mu m \times 250\mu m$ channels on a $1 cm^2$ chip and is cooled by water coolant. Thermal capability of our new package was evaluated by the simulator of dynamic thermal analysis. We found that the chip temperature was below $47^{\circ}C$ even at a power density of $1.5 kW/cm^2$.

1. INTRODUCTION

As integration density of an LSI chip increases, the dissipation power per chip is increasing. The increasing dissipation power causes the increase of operation temperature in the chip and degrades device reliability. Using the simulator of dynamic thermal analysis, we have reported that the temperature rise in the chip occurred transiently and locally in a very small area such as a channel of a MOS FET, a base-collector p-n junction of a bipolar transistor and so on.¹⁾ The thermal stress associated with the local and transient temperature rise is an important problem which limits the future increase of integration density as well as the temperature rise of the It is, therefore, necessary that the local heat chip. generation should be spread over rapidly inside the chip and after that a cooling fin should remove the spread heat efficiently from the chip.

In this paper, we propose a microchannel fin package utilizing a passivation layer of AlN as the heat spreader and a microchannel fin as the efficient heat removal method. Thermal capability of our new package was evaluated by the simulator of dynamic thermal analysis. Our simulator is based on the time dependent solution of a heat flow equation by the finite element method.²⁾ The numerical calculation was carried out on NEC SX–2 in Tohoku University.

2. MICROCHANNEL FIN PACKAGE



Fig. 2. Schematic of a bipolar LSI with AlN heat-spreading layer.

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Figure 1 shows a cross-sectional schematic of our new package. The microchannel fins were bonded to both the front and the back surfaces of the chip by indium adhesive layers. The microchannel fin was fabricated with Cu. The channel cross-section was designed to be 50μ m wide × 250µm high. The microchannel fin had 4 fold 100 lines of channels on a 1×1cm² chip. Each channel was separated by walls of 50µm wide. A water coolant flowed at a speed of 6m/sec in each channel. The pressure drop became 3.1kgf/cm². The water coolant and the ambient air temperatures were 17°C. Under this condition, the heat transfer coefficient between the microchannel fin and the coolant was 26.6W/cm²·K.

Figure 2 shows a schematic of a bipolar VLSI with the AlN heat-spreading layer. We replaced the SiO_2 passivation layer and isolation layer with the AlN layer in



(b) Local temperature distribution at t=100nsec.



(c) Local temperature rise from 100nsec to 500nsec.

Fig. 3.1. Local and transient temperature profile of a bipolar VLSI with SiO₂ passivation layer.

the LSI chip. AlN was selected for its high thermal conductivity. The thermal conductivity of AlN is $200W/m \cdot K$ which is much larger than that of SiO₂ (1. 38W/m·K). In addition, AlN film has compatibility with the thermal expansion coefficient of Si.

3. RESULTS AND DISCUSSIONS

Figures 3.1 and 3.2 show the results of local dynamic thermal analysis for a bipolar VLSI. In each figure, the simulation area is shown in (a). The local temperature distribution at t=100nsec is shown in (b) and the temperature rise from 100nsec to 500nsec is shown in (c). The dissipation power per bipolar transistor was 3.9mW. In the case of the VLSI with an SiO₂ passivation layer as shown in Figure 3.1, the Al interconnections acted as heat paths and the heat did not propagate to the SiO₂



(b) Local temperature distribution at t=100nsec.



Fig. 3.2. Local and transient temperature profile of a bipolar VLSI with AlN heat-spreading layer.

layer. On the other hand, in the case of the VLSI with the AlN passivation layer as shown in Figure 3.2, the generated heat spread uniformly on the chip in 500nsec. AlN passivation layer acted as high-speed heat spreading layer. Transient temperature rise near the Al interconnections and the emitter electrode was reduced by the AlN heat-spreading layer.

Figures 4.1 and 4.2 show the time dependent temperature profile near the depletion layer of a bipolar transistor. In each figure, the simulation area is shown by the thick solid line (DEPTH=0-20µm) in (a). The temperature distribution is shown in (b). The microchannel fin was bonded to the back surface of the chip. The free convection was assumed to be on the front surface of the chip. The total power density was assumed to be 1.5kW/cm² on the chip. Figure 4.1 shows the thermal analysis for the bipolar VLSI with the SiO₂ passivation layer. The maximum temperature in the chip was 117°C. Figure 4.2 shows the thermal analysis for the bipolar VLSI with the AlN passivation layer. The maximum temperature was 116°C. Therefore, in both cases, allowable power density was 1.0kW/cm2 when



(b) Time dependent temperature distribution.



allowable temperature was assumed to be 80°C. It should be noted that the local heat was spread rapidly by AlN heat-spreading layer as shown in Fig. 3.2. However, most of the generated heat conducted through the Si substrate to the microchannel fin and little heat was removed from the front surface through the AlN layer. In order to remove heat from the chip efficiently, the microchannel fin should be bonded to the front surface of the chip.

Figures 5.1 and 5.2 show the time dependent temperature profile near the depletion layer of a bipolar transistor. The microchannel fins were bonded to both the front and the back surfaces of the chip as shown in Fig. 1. In each figure, the simulation area is shown by the thick solid line (DEPTH=0-20 μ m) in (a). The temperature distribution is shown in (b). The total power density was assumed to be 1.5kW/cm² on the chip. Figure 5.1 shows the thermal analysis for the bipolar VLSI with the SiO₂ passivation layer. The maximum temperature on the chip was 62°C. The high thermal stress associated with the temperature gradient toward the front surface (5000°C/mm) occurred between the Al









(b) Time dependent temperature distribution.

Fig. 5.1. Time dependent temperature profile of a bipolar VLSI with SiO₂ passivation layer. Microchannel fins were bonded to both the front and the back surfaces of a chip as shown in Fig. 1. (dissipation power : 1.5kW/cm²)

interconnections and the SiO_2 passivation layer. This stress reduces the chip reliability. Figure 5.2 shows the thermal analysis for the bipolar VLSI with the AlN passivation layer. The maximum temperature was 47°C and the temperature gradient disappeared.

In a high-speed VLSI chip, the integration density is limited by the thermal capability even at the present time. Using the microchannel fin package, 500,000 gate ECL circuits with a power density of 3mW per gate can be integrated on a 1cm² chip.

4. CONCLUSION

We propose a microchannel fin package using a passivation layer of AlN as the heat spreader and a microchannel fin as the efficient heat removal method. Thermal capability of our new package was evaluated by the simulator of dynamic thermal analysis. Using the microchannel fin package, a dissipation power in a VLSI chip is quite allowable as high as 1.5kW/cm². 500,000 gate ECL circuits with a power density of 3mW per gate are sufficiently integrated on a 1cm² chip.



(b) Time dependent temperature distribution.

Fig. 5.2. Time dependent temperature profile of a bipolar VLSI with AlN heat-spreading layer. Microchannel fins were bonded to both the front and the back and the back surfaces of a chip as shown in Fig. 1. (dissipation power : 1.5kW/cm²)

5. REFERENCES

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