The Analysis of Electrothermal Conductivity Characteristics for SOI(SOS) LIGBT with latch-up

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The electrothermal characterisics of a high voltage LIGBT(Lateral Insulated Gate Bipolar Transistor) using thin silicon on insulator (SOI) and silicon on sapphire (SOS) such as thermal conductivity and sink is analyzed by MEDICI. The device simulations demonstrate that the thermal conductivity of the buried oxide is an important parameter for modeling of the thermal behavior of SOI devices. In this paper we simulated the thermal conductivity and temperature distribution of a SOI LIGBT with an insulator layer of SiO_2 and Al_2O_3 at before and after latch-up and verified that the SOI LIGBT with the Al_2O_3 insulator had good thermal conductivity and reliability.

Keywords : LIGBT, SOI, SOS, HEAT SINK, MEDICI

1. INTRODUCTION

Silicon-On-Insulator(SOI) structure in which an insulator film is between an active layer and a semiconductor wafer such as silicon wafer is very suitable for many applications. Many SOI devices have been proposed and a SOI Insulated Gate Bipolar Transistor have recently been studied. SOI devices are more commonly used than bulk silicon devices and a SOI lateral insulated gate bipolar transistor(LIGBT)is a promising power device for use in high voltage power IC applications, due not only to its superior isolation performance but also to the good characteristics of flat lateral power device on SOI films.

Many advantageous characteristics of the SOI LIGBT devices, such as low on-sate resistance, high input impedance, high breakdown voltage, dielectric isolation, high switching speed, and high packaging density, have been reported. Unfortunately, the SOI LIGBT structure suffers from a low current capability and contains a parasitic thyristor. The device latch-up, which leads to loss of gate control, may occur at high current due to the existence of a parasitic thyristor. Since device failure due to latch-up prevents the use of an SOI LIGBT in practical applications, it is very important to improve the latch-up characteristic of the device[1-6].

As research of SOI technology smartens up, research for material of insulating layer is gone abuzz. The one is Silicon On Sapphire(SOS) in which a silicon film is grown by epitaxial growth method on whisker insulator using heteroepitaxial SOI technology. The lattice constant of the whisker insulator is similar to that of the silicon film. The SOI structure is suitable for high temperature devices, which requires to have small leakage current, fast drive force, low power dissipation and low latch-up occurrence. However, because of self-heating effect during operation, the mobility of carriers is reduced and function of devices is not achieved smoothly. SiO_2 is used as insulating material in conventional SOI structure. Alternating an insulating layer to Al_2O_3 can improve thermal conductivity and heat sink in the SOI LIGBT.

In this paper we simulated the thermal conductivity and temperature distribution of a SOI LIGBT with an insulator layer of SiO_2 and Al_2O_3 at before and after latch-up and verified that the SOI LIGBT with the Al_2O_3 insulator had good thermal conductivity and reliability.

2. DEVICE STRUCTURE AND CHARACTERISTICS

Power devices used in Power Integrated Circuits (PIC's) are generally required to have low on-resistance, fast switching speed, and high breakdown voltage. silicon-on-insulator (SOI) Lateral Insulated Gate Bipolar Transistor (LIGBT) has several advantages such as complete dielectric isolation, high packaging density and high switching speed. However, one of the biggest problems of LIGBT is the latch-up of a parasitic thyristor. IGBT have an inherent thyristor structure that is composed of p+ anode – n- drift region – p- base – n+ cathode and MOS gate does not control the electron currents when latch-up occurs. Latch-up due to the parasitic thyristor limits the maximum operating current of IGBT. Therefore, the prevention of latch-up is very important when designing power devices with wide SOA (Safe Operating Area).

In order to increase latch-up current density, several IGBT structures such as deep p+ implantation under the n+, reverse channel and p+ diverter have been proposed. Previous studies could reduce the voltage drop due to hole currents in the p-base region and increase the latch-up current density. In spite of previous efforts the latch-up of parasitic thyristor remains a key problem that limits the maximum operating current of LIGBT. Recently, a Lateral Trench-gate IGBT (LTIGBT) with improved the latch-up characteristics was proposed. LTIGBT is an effective structure to increase the latching current density as the p base length under n+ cathode layer is controlled. However the LTIGBT is not driven in scaling down because the length of n-drift layer cannot be reduced due to rating voltage[7-9].

Operation principle of LIGBT is basically the same as that of IGBT. At low forward bias, electrons that flow from the channel through the drift region are collected by the anode. As the forward voltage is increased, the electrons flow underneath the p+ diffusion and to the forward-biased p+ anode/n- drift diode and cause minority carrier injection, resulting in a conductivity modulation of the drift region; thus, a low on resistance is achieved. LIGBT has advantage that have high input impedance of MOSFET and fast switching special quality and superior forward direction conduction special quality of a bipolar transistor at the same time as the device that combine input terminal of MOSFET gate structure and current conduction structure of bipolar transistor, but because latch-up affects LIGBT special quality by parasitic thyristor that LIGBT is formed on structure interior, it must consider attentively about MOSFET dynamic characteristic and dynamic characteristic of bipolar transistor and dynamic characteristic of parasitic thyristor to analyze LIGBT dynamic characteristic exactly.

A general SOI LIGBT has DMOS (Double-diffusion MOSFET) cell and SOI substrate including low-doped n-Epi layer of several or several tens μm thickness and the p base region and n+ cathode area are formed by duplex spread process (Double Diffusion Process) using polysilicon gate as a mask. The channel length is determined by difference of lateral diffusion of two areas[10].

The input terminal of the SOI LIGBT consists of a MOSFET and the output terminal is a npn transistor which involves p-base region (collector), n-Epi-layer (base) and p+ anode area (Emitter). The npn transistor and pnp transistor formed parasitic thyristor. Minority carrier injection in drift region leads high current-driving ability because of the high resistivity but if latch-up of the parasitic pnpn thyristor occurs, the gate cannot control current. Thus the maximum operating current of SOI LIGBT is decided by latch-up characteristic of parasitic thyristor.

3. SIMULATION AND RESULTS

This paper examined thermal conductivity distribution and thermal temperature distribution before and after latch-up by MEDICI comparing the conventional insulator SiO_2 and the proposed Al_2O_3 .

Fig. 1 and 2 show conventional SOI LIGBT structure and I-V characteristics curve respectively. Fig. 3 and Fig. 4 display temperature distribution before latch-up using SiO_2 and Al_2O_3 as an insulating layer material respectively. In the general SOI LIGBT using SiO_2, heat is concentrated on the insulating layer but in the SOS LIGBT heat is transferred to the substrate.

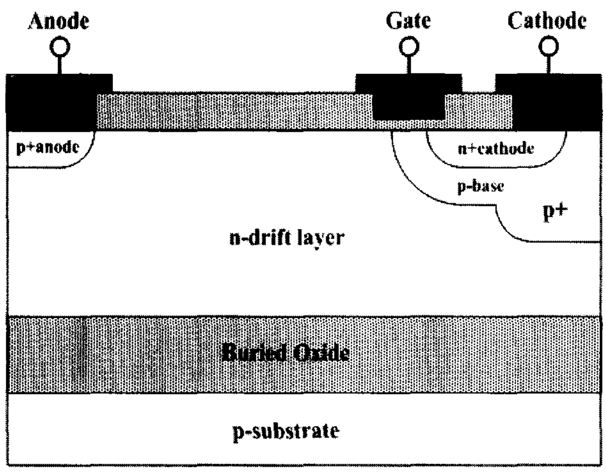

Fig. 1. Conventional SOI LIGBT structure.

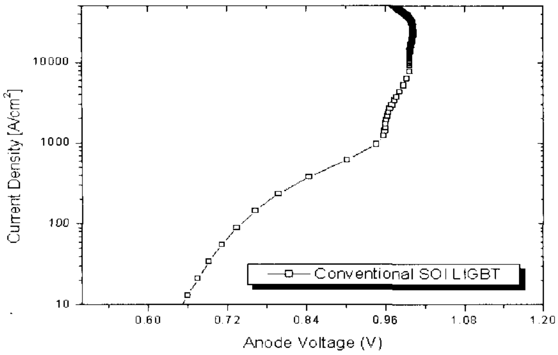

Fig. 2. I-V Characteristics of conventional LIGBT.

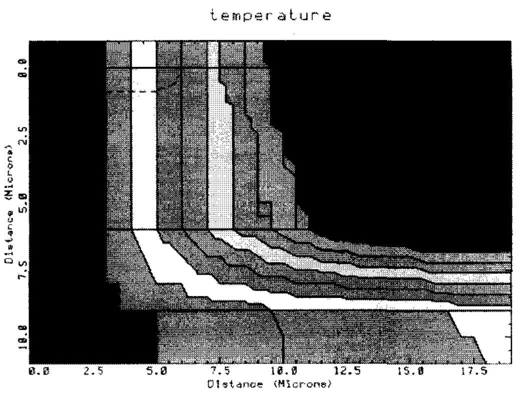

Fig. 3. Thermal conductivity distribution of SOI LIGBT before latch-up.

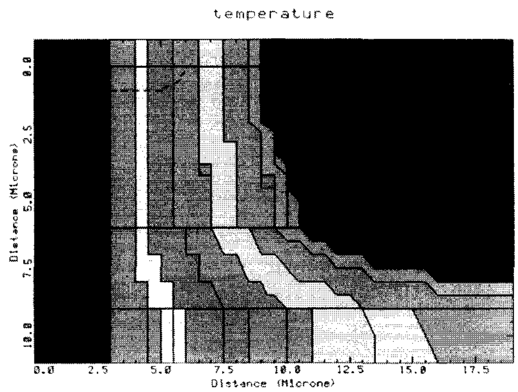

Fig. 4. Thermal conductivity distribution of SOS LIGBT before latch-up.

Fig. 5 and Fig. 6 show thermal conduction distribution after latch up. In the general SOI LIGBT, heat is still concentrated on the insulating layer. On the other hand, the thermal distribution of in the SOS LIGBT remains stable after latch-up because heat is transferred to the substrate.

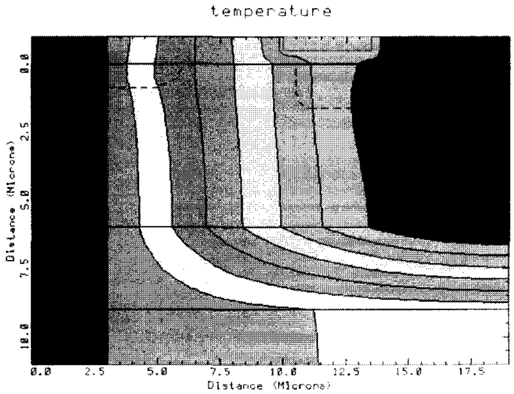

Fig. 5. Thermal conductivity distribution of SOI LIGBT after latch-up.

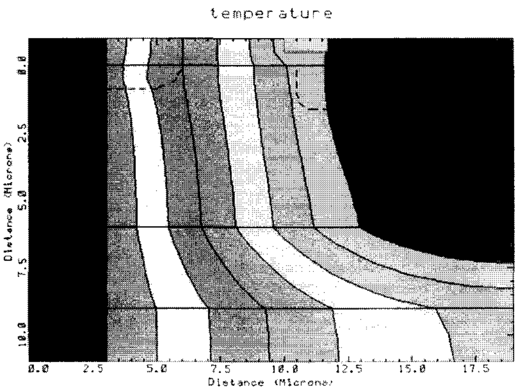

Fig. 6. Thermal conductivity distribution of SOS LIGBT after latch-up.

Fig. 7 is 3D temperature distribution of the SOI and SOS LIGBT before latch-up and Fig. 8 and Fig. 9 show 3D temperature distribution of the SOI and SOS LIGBT after latch-up respectively. The temperature difference of the SOS LIGBT is smaller than that of SOI LIGBT.

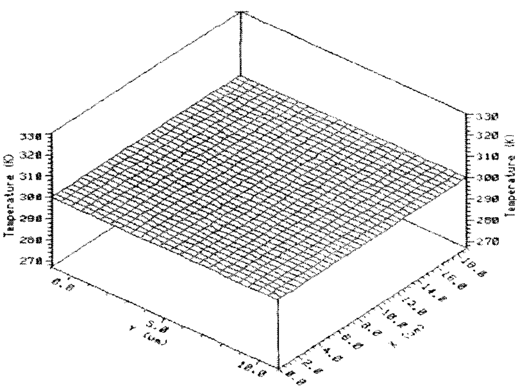

Fig. 7. SOI/SOS - 3D temperature distribution before latch-up.

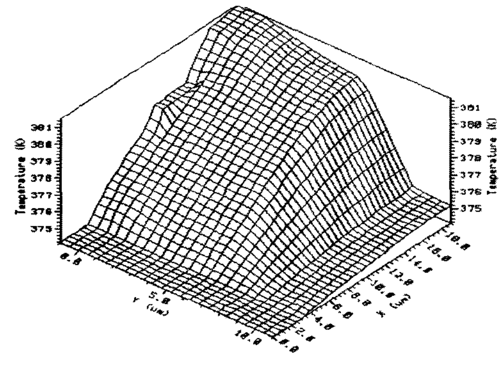

Fig. 8. SOI - 3D Temperature distribution after latch-up.

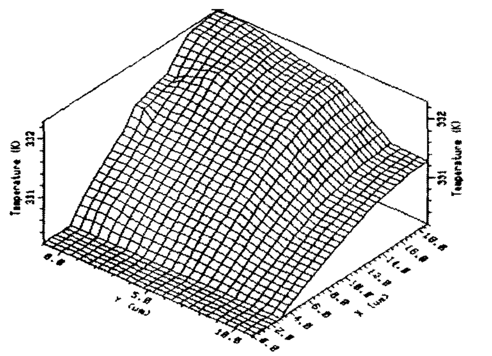

Fig. 9. SOS - 3D Temperature distribution after latch-up.

4 . CONCLUSION

In this paper we compared the thermal characteristics of SiO_2 and Al_2O_3 as an insulating layer of SOI LIGBT by using MEDICI. The stability and efficiency of the device improved as changing the insulating material to Al_2O_3 because heat which is generated between the active layer and the substrate is efficiently removed from the device. Thus we conclude that Al_2O_3 can be better than SiO_2 as an insulating material.

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REFERENCE

[1] E. G. Kang, S. H. Moon, and M. Y. Sung, "New trench electrode IGBT having superior electrical characteristics for Power IC system", Microelectronics Journal,Vol. 32, No. 8, p. 641, 2001.

[2] B. J. Baliga, "An overview of smart power technology", IEEE Trans. Electron Dev. 38, p. 1568, 1991.

[3] K. Sheng, S. J. Finney, and B. W. Williams, "Improved understanding of IGBT forward conduction", Proceedings of the IPEMC, p. 48, 1997.

[4] D. W. Kim, M. Y. Sun, and E. G. Kang, "A New EST with Dual Trench Gate Electrode (DTG-EST)", J. of KIEEME(in Korean), Vol. 4, No. 2, p. 15, 2003.

[5] E. G. Kang and M.Y. Sung, "A novel EST with trench electrode to immunize snap-back effect and to obtain high blocking voltage", J. of KIEEME(in Korean), Vol. 2, No. 3, 2001.

[6] E. G. Kang, S. H. Moon, and M. Y. Sung, "Simulation of a new lateral trench IGBT employing effective p+ diverter for improving latch-up characteristics", Microelectronics Journal, Vol. 32, No. 9, p. 749, 2001.

[7] E. G. Kang and M. Y. Sung, "A novel lateral trench electrode IGBT for super electrical characteristics", J. of KIEEME(in Korean), Vol. 15, No. 9, p. 758, 2002.

[8] W. B. Choi, "A study on the Development of SOI Wafer Using Hydrogen Plasma Activation and Application to Fabrication of Power Semiconductor Device", PhD. Thesis, University of Korea, 2001.

[9] W. B. Choi, W. J. Sung, C. I. Park, and M. Y. Sung, "New Lateral Insulated-Gate Bipolar Transistor on Silicon-on-Insulator", J. Korean Phys. Soc., Vol. 40, No. 4, p. 645, 2002.

[10] A. E. Schmitz and J. Y. Chen, "Design, Modeling and Fabrication of Subhalf-Micrometer CMOS Transistors", IEEE Trans. Electron Devices, Vol. ED-33, No. 1, p. 148, 1986.