Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp961-962

Impact of the semiconductor on hexagonal-BN structure for power-supply on chip applications

Yoshiki Sato[1], Kota Ono[1], Masanari Nomura[1], Satoshi Matsumoto[1], and Masataka Hasegawa[2]

[1]Kyushu Institute of Technology

1-1 Sensui-cho Tobata-ku, Kitakyushu-shi, Fukuoka 804-8550, Japan

Phone: +81-93-884-3234 E-mail: sato.yoshiki744@mail.kyutech.jp

[2]The National Institute of Advanced Industrial Science and Technology

1-1-1 Higashi,Tsukuba-shi, Ibaraki, 305-8565, Japan

Abstract

This paper evaluates the semiconductor on hexagonal-BN (h-BN) structure for power-supply on chip applications based on numerical simulations. Hexagonal-BN is used as an insulator of semiconductor -on-insulator (SOI) structure. Hexagonal-BN based SOI structure with through-silicon-via(TSV) shows higher heat dissipation performance without degrading electrical characteristics compared with the conventional SOI structure.

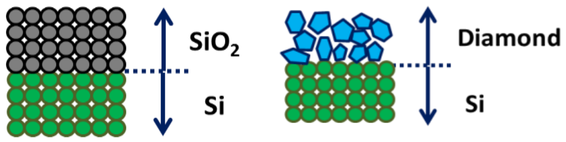
1. Introduction

Recently, power supply on chip (power-SoC), which integrates Si-LSI, power device and passive devices in one chip, has been attracting attentions because it can realize ultimate miniaturization of power supply[1]. The one of the most promising ways to minimize the size of the power supply is to reduce the volume of the passive components such as inductors and capacitors. To increase the switching frequency is an effective approach to do this. The semiconductor on insulator (SOI) technology is the one of the promising candidates for realizing power-SoC because this technology is suitable for high frequency switching, that is resulting from its smaller parasitic capacitance[2]. However, the conventional SOI structure has a problem of self-heating because of law thermal conductivity of SiO_2. Semiconductor-on-Diamond (SOD) structure, which uses thin diamond film as an insulator, has been proposed because the diamond have higher thermal conductivity than SiO_2[3,4]. But it was only about half of exhaust heat effect which is expected from the thermal conductivity of the nano-crystalline diamond[5]. The nano-crystalline diamond has a surface roughness of several nanometers and this film cannot cover the surface of the heat source(in this case Si shown in Figs. 1) and these prevents the heat transfer from heating element to nano-crystalline diamond(Figs.1). This result reveals that higher thermal conductivity and atomically flat surface are required to obtain higher heat exhaust performance. In such situations, hexagonal-BN(h-BN) is attractive for the buried insulator layer of SOI because it has higher thermal conductivity with atomically flat surface (Ra of h-BN < 0.25 nm)[6,7]. It has not been clarified the impact of the semiconductor on h-BN structure for power supply on chip applications.

In this paper, we explore impact of the semiconductor on h-BN structure for thermal property and device performance based on numerical simulations with comparing SOI structure. In addition, we also discuss the impact of the through silicon via(TSV) for heat dissipation.

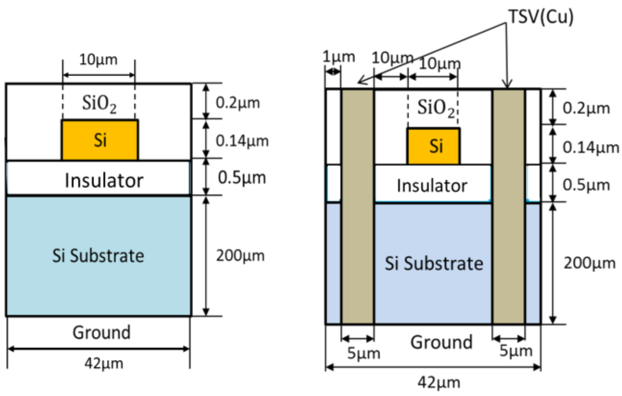
2. Device structure

The schematic cross sections of the SOI and the TSV inserted SOI structures used in the simulations are shown in Figs.2 (a), (b). The materials constants of used in the simulations are listed in Table 1. Also the thermal conductivity of the materials is listed in Table 2.



(a)SOI structure (b)SOD structure

Figs.1 Cross sections of (a)SOI and (b)SOD.



(a) SOI structure model (b) TSV inserted model

Fig.2 Schematic cross section of the SOI structure used in simulations.

Table 1 Material constants used in simulations

Material	Density [kg/m^3]	Specific heat [J/(kg・K)]
Si	2330	713
SiO_2	2650	760
h-BN	2100	800

Table 2 Thermal conductivities

material	Thermal conductivity [W/(m・K)]	
Si	145	
SiO_2	1.38	
h-BN	Vertical	2
	Horizontal	390

3. Result & Discussion

We numerically obtained the temperatures of the active Si layer and insulator at center using ANSYS Fluent[8]. Temperature at center for both materials are shown in Figs. 3 (a). The results of TSV inserted structure are also shown in Figs. 3 (b). In simulations, we consider only heat conduction and give amount of heat which is correspond to keeping temperature of 373 K for the active silicon layer (active Si layer as a heat source) of the conventional SOI structure. The temperature increase suppresses when h-BN is used as an insulator because the thermal conductivity of h-BN is higher than that of SiO_2 and it makes easier to dissipate heat. TSV can effectively suppress temperature increase by 10-20 K in both insulator materials. Thermal conduction of Cu used as TSV is 398 W/(m・K), which is higher than other materials. These results indicated that heat exhaust is improved by h-BN and TSV.

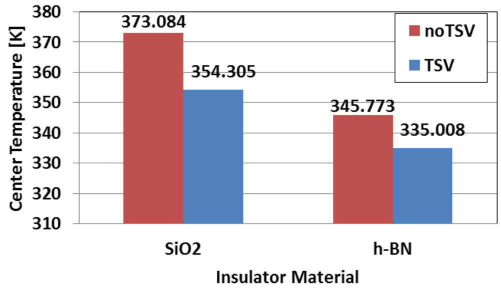
Figure 4 shows dependence of the breakdown voltage on the impurity concentration in drift region obtained by 2D-device simulation(Sentaurus [9]). In simulations, the relative permittivity of SiO_2 is 3.9 and that of h-BN is 4.0. The relative permittivity of these materials is exceedingly close value, and there is not much difference in the breakdown voltage. Therefore, it is concluded that using h-BN as an insulator does not degrade the breakdown voltage compared with conventional structure.

4. Conclusions

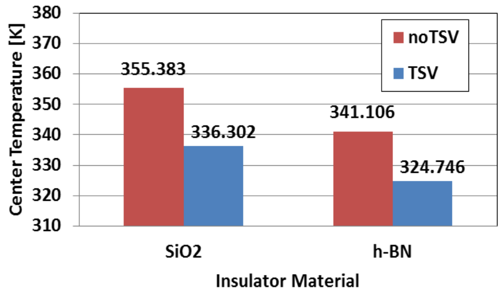
We evaluated the semiconductor on h-BN structure for thermal property and device performance based on numerical simulations. Hexagonal-BN based SOI structure with through-silicon-via (TSV) shows higher heat dissipation performance without degrading electrical characteristics compared with conventional SOI structure.

Acknowledgements

The part of this work was supported by JSPS Grant Number 18H01430.



(a) Center of active Si layer



(b) Center of insulator

Figs.3. Temperature at center of heat source (Si) and insulator with and without TSV.

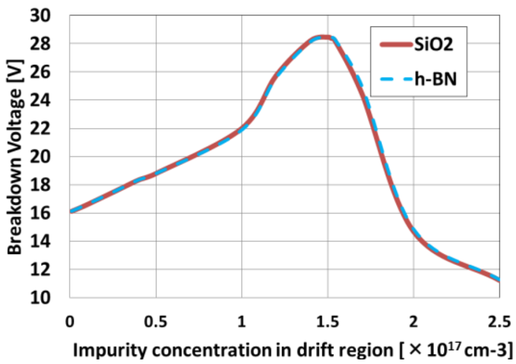


Fig.4. Dependence of breakdown voltage on the impurity concentration of the drift region

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