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Measurement of Thermal Diffusivity by Photopyroelectric Method for the Density Controlled Sintered SiC
密度制御した SiC 焼結体の光焦電法による熱拡散率の評価

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1. Introduction

The next generation high power and high frequency devices are in the stage of practical use. They are made from semiconductors such as GaN, SiC and *etc.* These semiconductors have superior properties than Si in many fields, such as wide gap, high breakdown electric field, high saturation carrier velosity. The heat dissipation problem is very important especially in the high power and integrated devices.

In general, the heat sink of such device is made of Al or Cu. From the view point of heat conduction and "self-cooling device structure",[1] the devices are favorable to be constructed in one piece structure from device chip to heat sink.

SiC is one of the materials which has largest thermal conductivity in next generation semiconductor materials. Then, SiC devices have superior thermal property. There is one problem that SiC single crystal is difficult to shape into the heat sink. So, we have focused on sintered SiC. In this study, we investigated the relationship between the porosity and the thermal conductivity of SiC.

Thermal diffusivity was measured by using PPE (Photopyroelectric) method.[2] PPE method is one of the variations of photoacoustic spectroscopy in which PVF_2 (Polyvinylidine di-fluoride) are used as a pyroelectric transducer to increase the sensitivity. The PPE method has many advantages in comparison with the conventional laser flash method, such as high sensitivity, non-destructive measurement, use of small power laser, small temperature increase, good spatial resolution and *etc*.

2. Experiments

SiC single crystal (Cree; non-dope 6H-SiC) and Sintered SiC (Sumitomo Osaka Cement; β-SiC ultra-fine powder T-1) samples were measured. Sintered SiC samples were prepared in different conditions to vary the porosity.

The sintering was carried out as follows, uni-axial press molding, CIP (cold Isotropic Press) and sintering in RF induction furnace.

Figure 1 shows the schematic diagram of the PPE method. As shown in the figure, laser light irradiates the sample placed on the stage. The heat converted from absorbed laser light propagates to the temperature sensor PVF_2. The propagation distance can be changed by repositioning the sample stage. The signal phase is detected by using a lock-in amplifier. The PVF_2 film is very sensitive, so the irradiated laser power can be small. (typically < 20 mW) Therefore, temperature increase is estimated less than 10 mK.

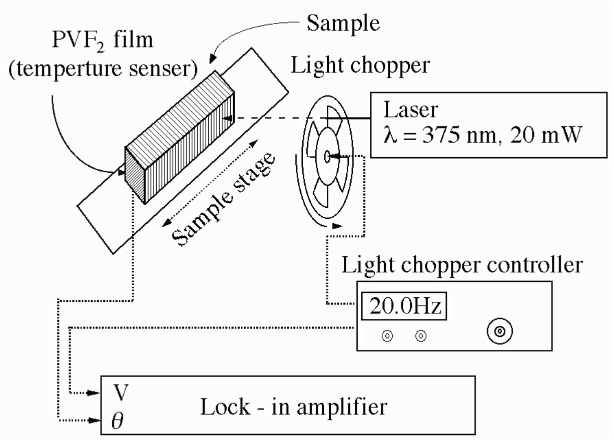

Fig. 1 The schematic diagram of the PPE method.

We used PPE analysis modes (V - L and θ - L mode), where V, L and θ are signal amplitude, heat propagation distance, and signal phase respectively. Thermal diffusivity was calculated using the θ - L mode with a constant f (chopping frequency of the laser). Equation 1 shows the relation of V and L.

$$V \propto \exp(-L / \mu), \quad \mu = (\pi f / \alpha)^{-1/2}, \qquad (1)$$

where μ and α are thermal diffusion length and the thermal diffusivity respectively. The V signal is affected not only thermal conduction, but also the light absorption. So the V signal is also affected surface condition. Therefore, the V - L mode is only used to verify the measurable range of L.

The thermal diffusivity α was calculated using equation 2, from the θ - L mode

$$\theta = (\pi f / \alpha)^{1/2} L + \theta_0 \,. \tag{2}$$

where θ_0 is the offset determined by the relative position between beam and aperture. From the derivative of equation 2, α is obtained as equation 3,

$$\alpha = f\pi \left(\frac{d\theta}{dL} \right)^{-2} . \tag{3}$$

The θ - L mode is more accurate than the V - L mode. Because, it is not affected surface condition.

3. Results and Discussion

Figure 2 shows the PPE measurement results of sample A. From $V - L$ mode analysis, phase date were selected for α calculation. The closed squares were used to calculate. The measured results of signal phase were fitted to the line by using the least squares method with very small error. Thermal diffusivity was calculated from the gradient ($d\theta/dL$) of the line.

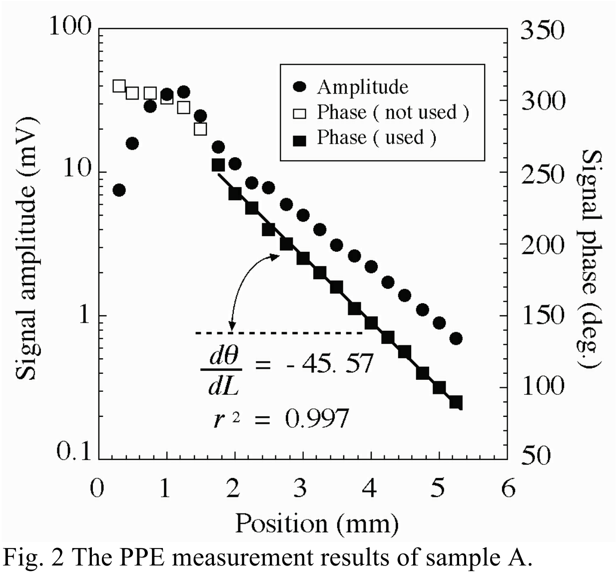

Fig. 2 The PPE measurement results of sample A.

The thermal conductivity was calculated from equation 4.

$$\kappa = \alpha \rho C_p \,, \tag{4}$$

where, κ, ρ and C_p are thermal conductivity, density and specific heat, respectively. The value of C_p is 0.673 × kJ kg^{-1} K^{-1}.[3)] The measured results of density, thermal diffusivity and thermal conductivity are summarized in Table I.

The thermal conductivity of SiC single crystal is almost the same to the published values (490 W m^{-1} K^{-1}).[3)] So, PPE is a simple method, that can be applied to the wide range of materials from porous sintered body ($\kappa \sim$ 6 W m^{-1} K^{-1}) [4)] to single crystal ($\kappa \sim$ 500 W m^{-1} K^{-1}).

From the comparison of the thermal conductivity, sample A has thermal conductivity 40 % of single crystal sample. We can deduce that the grain boundary scattering is mainly responsible to this 60 % reduction in thermal conductivity.

The sample A has 207 W m^{-1} K^{-1} thermal conductivity. As this value is comparable to the value of metal Al (236 W m^{-1} K^{-1}), SiC can be used as a heat sink instead of metal Al.

However, the sample A has only 97.1 % packing density. The value of thermal conductivity is only about half of single crystal value. So it is expected to increase the thermal conductivity more.

The thermal conductivity increased with packing density in comparison with sample A, B and C. The dependency of the thermal conductivity could not be explained only by the change of conduction cross section. It was deduced that there must be some effects of grain boundary.

Table I. The measured results of density, thermal diffusivity and thermal conductivity.

sample	density ($g\ cm^{-3}$)	packing density (%)	thermal diffusivity ($\times 10^{-6} m^2 s^{-1}$)	thermal conductivity ($W\ m^{-1} K^{-1}$)
Single crystal	3.18	100	201	495
A	3.09	97.1	99	207
B	1.67	52.3	38	42
C	1.35	42.1	35	31

4. Conclusion

From the measurement of thermal diffusivity by PPE method, the dense sintered SiC was found to have high thermal conductivity comparable to the metal Al. In order to use sintered SiC as a heat sink, it is important that SiC sintered to high density.

References

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