Evaluation of Thermal Cycle Stress in SiC Power devices by Raman Spectroscopy

Reduction of thermal stress in power devices is important in terms of device reliability because power devices are used under extremely wide range of temperature. Raman spectroscopy can quantitatively evaluate the stress of the devices.

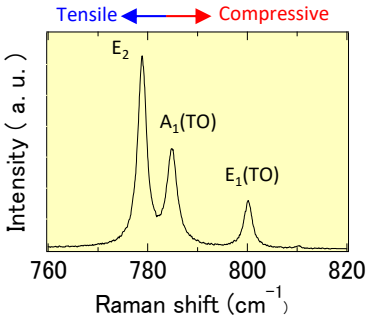
1. Stress evaluation of 4H-SiC by Raman Spectroscopy

Raman system
Spectrometer: Horiba Jobin Yvon U1000
Excitation source: 457.9 nm of an Ar^+-ion laser
Peak frequency is determined within 0.02 cm^{-1}.

- ✓ When the stress is applied to the samples, the force constant between atoms change and the peak frequency is shifted.
- ✓ In the cross section of 4H-SiC, the stress components σ_{11} and σ_{33} are expressed as follows[1, 2]:

$$\sigma_{11} = \frac{b_{E2}'\Delta\omega_{A1} - b_{A1}'\Delta\omega_{E2}}{[a_{A1}'b_{E2}' - (a_{E2}' \pm c_{E2}')b_{A1}']}$$

$$\sigma_{33} = \frac{(a_{E2}' \pm c_{E2}')\Delta\omega_{A1} - a_{A1}'\Delta\omega_{E2}}{[(a_{E2}' \pm c_{E2}')b_{A1}' - a_{A1}'b_{E2}']}$$

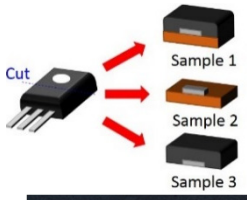


An example of Raman spectra of 4H-SiC (*a*- plane).

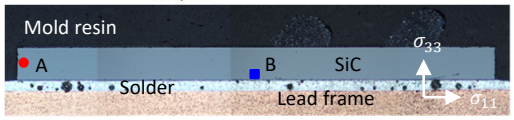
$a_{A1}', b_{A1}', a_{E2}', b_{E2}'$ and c_{E2}' are phonon deformation potentials. (Constant values)

2. Sample

Commercially available 1200V SiC MOSFETs with TO-247 discrete package was used in this experiment.
The cross section was made by mechanical polishing.

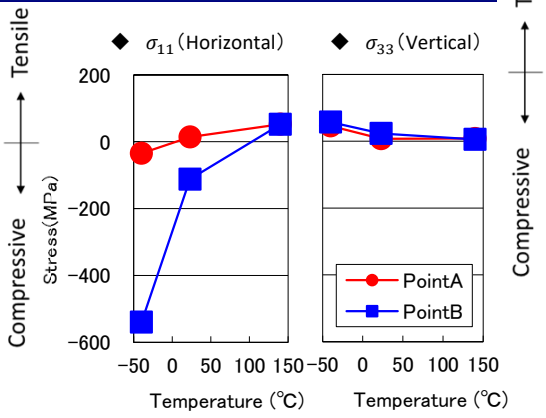


Mold resin was removed in Sample2.
Cu plate was removed in Sample3.



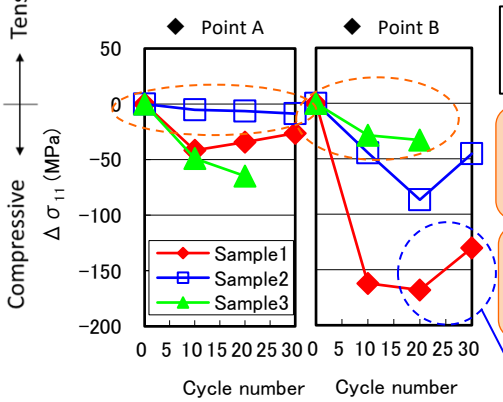
Optical microscopic image of the cross section of the SiC MOSFET.

3. Temperature-dependent stress evaluation of SiC MOSFETs



The horizontal stress was largely changed by the temperature. This tendency was remarkably observed at Point B which is located near the solder.

4. Stress change before and after the thermal cycle

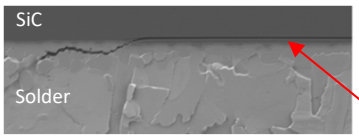


Temperature-controlled heating and cooling stage was used.
Cycle range: -40 ℃ ⇔ 140 ℃

The horizontal stress at PointA in Sample 2 showed no significant change. This result indicates that the stress at Point A is mainly resulted from the mold resin.

The stress change of Sample 3 was smallest at Point B. This result indicates that the stress at Point B is mainly resulted from the solder and Cu plate.

The crack was generated near the interface between the SiC and the solder after 30 cycles. The stress relaxation was occurred by this crack.



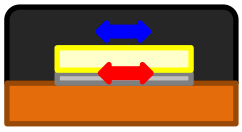
SEM image near the interface between the SiC and the solder after 30 cycles.

5. The degradation process of the device through the thermal cycles

- ✓ The stress in the package was changed through the thermal cycles.

➡ It indicates that the irreversible change was occurred by the temperature change in the package.

Examples of the irreversible change : Delamination, Degassing, Crack, etc.



Thermal stress can be occurred by the differences in CTEs.

- ➢ In the SiC MOSFET, the residual stress increased after the thermal cycles, especially near the solder. The crack was generated near the interface between the SiC and the solder and the stress relaxation was occurred by this crack.
- ➢ The mold resin affects to the stress at the edge of the chip.

Raman spectroscopy can measure the stress in devices and evaluate the degradation degree of the devices quantitatively.

*CTE : Coefficient of Thermal Expansion

[1] R. Sugie and T. Uchida., J. Appl. Phys. **122**, 195703 (2017).
[2] R. J. Briggs *et al.*, Phys. Rev. B **13**, 5518 (1976).

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