Superior Characteristics of Body Diode in DMOSFET Fabricated on 4H-SiC Bonded Substrate

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Objective

Our research has focused on the novel substrates "**Bonded substrate**" [1] [2]

➡ There are few studies that developed the devices on bonded substrate device, especially MOSFET

We **fabricated a DMOSFET on a bonded substrate** and **demonstrated its characteristics** comparing with that on a single-crystalline substrate for the first time

Previous Studies

- **Suppression of forward-bias degradation for PiN diodes (Fig. 1) [4]**
- **Simplified processing** of the backside metal [3]

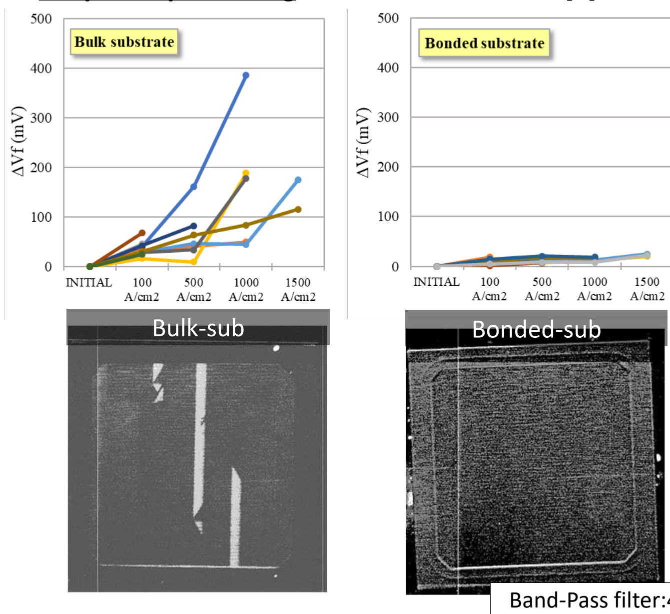
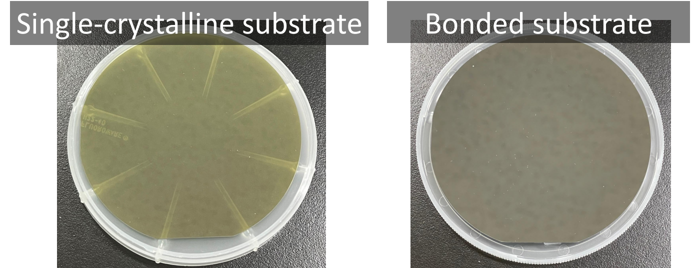


Fig. 1 ΔV_F of the PiN Diode and results after forward testing [4]

What is Bonded substrate?

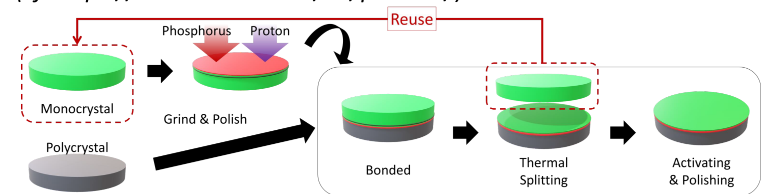
Structure

- A stacked substrate with two different SiC polytype using direct wafer bonding technologies



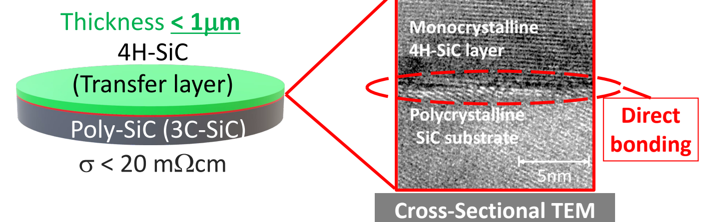
How is bonded substrate produced?

(cf. https://www.sicoxs.com/en/product/)



Features

- No unstable interlayer at the bonded interface
- Comprising of an **extremely thin** (submicrons) **monocrystal 4H-SiC layer bonded to a low resistivity polycrystal 3C-SiC substrate** (i.e. Untransparent)
- **Lower resistivity than Single-crystalline substrate**



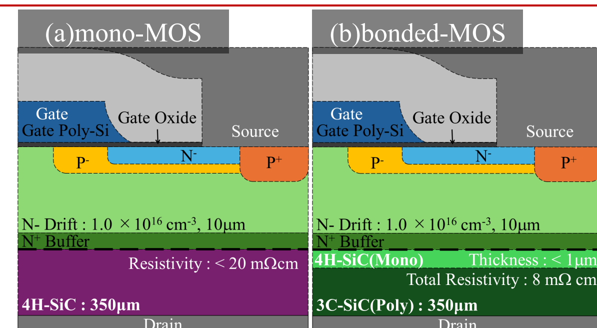
Experiments

DMOSFET fabrication

- 1.2 kV-class DMOSFETs were fabricated on a 4H-SiC Single-crystalline substrate (mono-MOS) and a SICOXS bonded substrate (bonded-MOS)
- The fabrication conditions and device structures, including the drift layer, were identical for mono-MOS and bonded-MOS

Measurement and characterization

- Static characteristics, Reverse-recovery characteristics of the body-diode
- Forward-current stress testing, High-temperature reliability testing



Results

Static characteristics of DMOSFET

Blocking characteristics (Fig. 2)

✓ There was no difference between the two DMOSFETs

I_D-V_D characteristics (Fig. 3)

✓ **Bonded-MOS has higher current than the mono-MOS on each temperature due to low resistivity polycrystal (2.1% higher at 175 °C)**

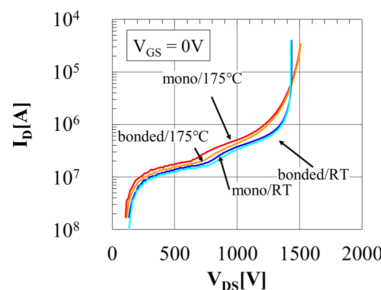


Fig. 2 Blocking characteristics

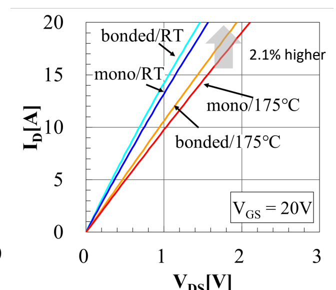


Fig. 3 I_D–V_D characteristics

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Static and dynamic characteristics of Body-diode

I_F-V_F characteristics (Fig. 3)

- Bonded-MOS has lower I_F than the mono-MOS at 175 °C

Reverse-recovery characteristics (Fig. 4)

- I_{RR} of the bonded-MOS was smaller than that of the mono-MOS at high temperature
- Reverse-recovery charge was approximately 30 % down at 175 °C (i.e., **suppressed recovery-loss**)

➡ Carrier lifetime was shortened in drift layer of the bonded-MOS

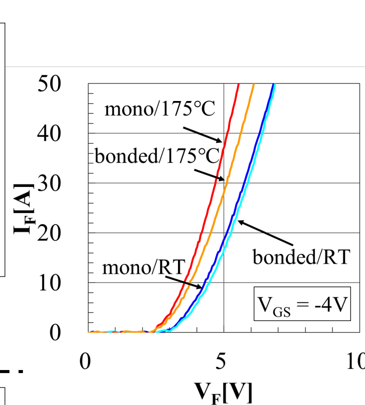

Fig. 3 Dependences of I_F–V_F characteristics

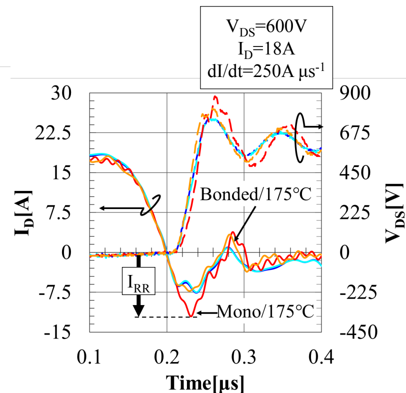

Fig. 4 Reverse recovery waveforms of the body diode

Forward-current stress testing (Fig. 5,6) & PL imaging results after the test (Fig. 7)

- The V_F almost did not change in the bonded-MOS
- Shockley-type stacking faults on the bonded-MOS were not observed at all (**No bipolar degradation**)
- This tendency is the same as that of a PiN diode fabricated on a bonded substrate[4]

➡ The author reported the characteristic was probably caused by proton implantation for fabricated process of bonded substrate [5] [6]

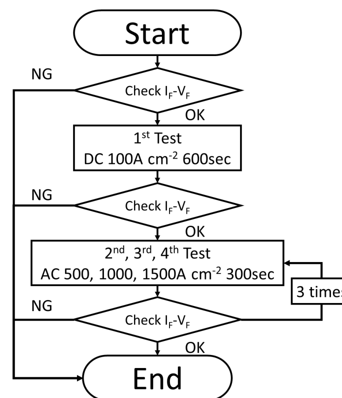

Fig. 5 Flowchart diagram of the forward-current stress test

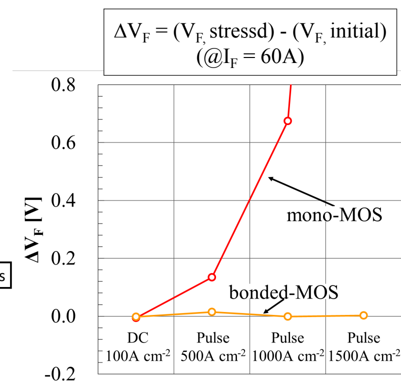

Fig. 6 ΔV_F of the body diode after forward testing

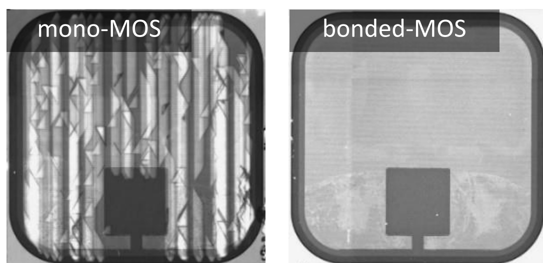

Fig.7 PL imaging results after the stress testing (Band-pass filter = 420nm)

High-Temperature Reliability

Test item	Test Condition	Duration	Number of samples
HTRB	T_a= 175°C V_R = 1200V	1000hr	8(each 4)
Burn-in	T_a = 175°C V_{GS} = +20/-10V	1000hr	6(each 3)
	T_a = 175°C V_{GS} = +22/-12V	1000hr	6(each 3)

Comparison of I-V characteristics of Mono-MOS and Bonded-MOS before and after the tests, **there were no significant differences**

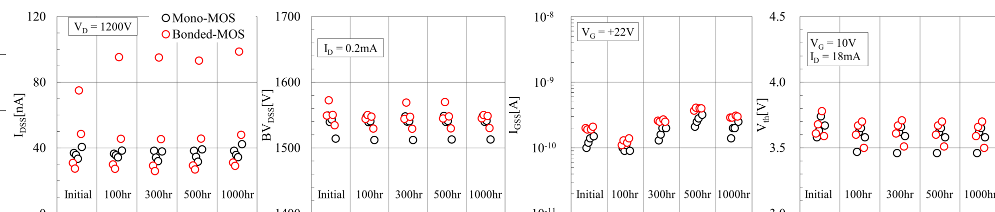

Fig.8 Each characteristics values (I_{DSS}, BV, I_{GSS}, V_{th}) after HTRB testing

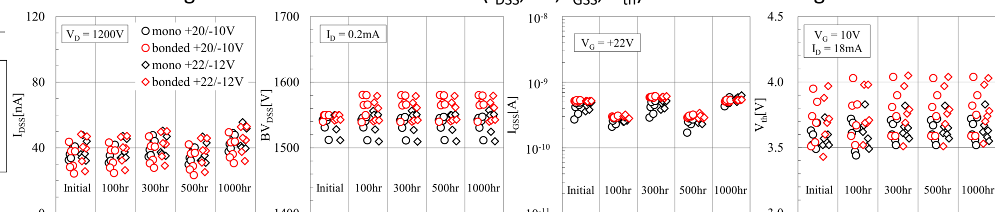

Fig.9 Each characteristics values (I_{DSS}, BV, I_{GSS}, V_{th}) after Burn-in testing

Conclusion

DMOSFET on bonded substrate shows:

- Lower on-resistance than that on Single-crystalline, despite of unchanging blocking ability
- Lower recovery-loss than that on Single-crystalline at high temperature
- Suppressed forward bias degradation
- No significant difference of reliability for standard use, comparing with that on Single-crystalline

Bonded substrate indicated superior potential to solve several issues on fabricated DMOSFET on monocrystalline substrate.

References

[1] S. Rouchier et al., Materials Science Forum 1062, p. 131, 2022
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[5] H. Uchida et al., Proceeding of ICSCRM, p. 209, 2023
[6] H. Uchida et al., Abstract of ICSCRM, 2024

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