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A LOCal Oxidation of SiC (LOCOSiC) Process for 4H-SiC Integrated Circuits

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***Abstract*—LOCal Oxidation of SiC (LOCOSiC) process on 4H-SiC is studied thoroughly. Through the optimization of pre-amorphization ion implantation and oxidation conditions, nearly ideal LOCOSiC isolation structure is confirmed by low leakage current of Schotttky barrier diode. This semi-recess isolation process promotes the progress of submicron SiC ICs.**

1. Introduction

The wide bandgap of SiC allows the power devices and integrated circuits to operate in harsh environment. Several SiC CMOS ICs have been demonstrated using 1.2 μm process [1, 2]. To scales down to sub-micron era, semi-recess isolation, similar to the local oxidation of Si (LOCOS), is required. LOCal Oxidation of SiC (LOCOSiC) has been studied for many years using pre-amorphization ion implantation (PAI) to enhance the oxidation rate of 3C- or 6H-SiC as substrate [3-5]. The recrystallization during oxidation leaves sever defects beneath the field oxide (FOX) so that the LOCOSiC process was considered impractical. Recently, it is reported that LOCOSiC process can be realized on 4H-SiC and improved gate oxide integrity has been demonstrated [6]. It seems that LOCOSiC is promising on 4H-SiC substrate.

2. PAI Species and Oxidation Temperature

Careful examination observes oxide notch at the bottom corner of the FOX edge (**Fig.1**). Plane view SEM inspection can observe a wide range oxide notch phenomenon (**Fig.2**) The oxide notch region has lots of generation-recombination centers which increases device leakage current as revealed by Schottky barrier diode (SBD) (**Fig.3**). It is suspected that the stress at the bottom corner of the amorphous region retards the oxidation rate so that the oxide notch is formed. Therefore, oxidation rate with difference PAI species and oxidation temperatures are studied.

Fig.4 shows the as-grown FOX thickness of the Ar-PAI and P-PAI samples oxidized at 1200 °C and 1300 °C. The PAI conditions are listed in Table-1. FOX thicker than 600 nm can be obtained. **Fig.5** shows the oxidation rate extracted from Fig.4. P-PAI exhibits higher oxidation rate than Ar-PAI. SIMS analysis indicates that P atoms remain in FOX and SiC substrate while Ar atoms diffuse out during oxidation (**Fig.6**). The high oxidation rate of the P-PAI sample is attributed to the existence of high concentration phosphorus. The oxidation rate of the PAI samples is higher than that of the crystalline 4H-SiC by 20~30 times at 1200 °C which implies oxidation mask is unnecessary.

FOX notch phenomenon with various PAI and oxidation conditions are inspected by plane view SEM after removing the FOX (**Fig.7**). Notch-free LOCOSiC can be realized by P-PAI + 1100 °C oxidation and Ar-PAI + 1200 °C oxidation.

3. Mechanism of Oxide Notch Formation

Microstructure of the partial oxidized Ar-PAI and P-PAI samples are inspected by TEM in **Fig.8**. The Ar-PAI sample shows thinner oxide layer and more apparent recrystallization than the P-PAI sample. **Fig.9** shows the cross-sectional TEM micrographs of the samples after Ar-PAI with vertical PAI mask and sloped PAI mask. Sloped PAI mask results in sloped amorphous edge such that a smooth and notch-free LOCOSiC structure is obtained **(Fig.10)**.

According to the above analysis, the mechanism of the formation of oxide notch is proposed. During oxidation, the amorphous region is oxidized from top surface while the remaining part of the amorphous region is recrystallized gradually. Since 4H-SiC is not the most thermodynamically stable polytype, solid-phase epitaxial recrystallization does not occur. The unoxidized amorphous region becomes polycrystalline composing of tiny grains. The oxidation rate would be reduced gradually with the progress of recrystallization but it is still much higher than that of the crystalline 4H-SiC. The volume expansion produces large compressive stress near the bottom corner of the FOX edge so that the oxidation rate reduces and oxide notch forms. Oxidation at high temperature increases oxidation rate and reduces the hardness of the grown SiO_2, thus the corner stress is relaxed. Sloped amorphous region also relax the corner stress.

Fig.11 compares the leakage current of SBD with LOCOSiC isolation formed by Ar-PAI + 1100 and 1200 °C oxidation. The leakage current is greatly reduced by high temperature oxidation, which confirms the fix of oxide notch problem.

4. CONCLUSIONS

LOCOSiC process on 4H-SiC is developed successfully. With optimized PAI and oxidation processes, high quality LOCOSiC isolation structure is obtained. The low-leakage-current SBDs fabricated with fine-tuned LOCOSiC process confirms few defects around the isolation edge. These results suggest LOCOSiC is useful for sub-micrometer ICs on 4H-SiC.

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Table 1 Ion implantation conditions of pre-amorphization process. The lighter mass and high dose of P than Ar produces thicker amorphous layer.

Sample ID	Species	60 keV	120 keV	200 keV
Ar-PAI	Ar	$5.0\text{x}10^{14}$ cm^{-2}	$1.5\text{x}10^{15}$ cm^{-2}	$1.5\text{x}10^{15}$ cm^{-2}
P-PAI	P	$1.5\text{x}10^{15}$ cm^{-2}	$5.0\text{x}10^{15}$ cm^{-2}	$5.0\text{x}10^{15}$ cm^{-2}

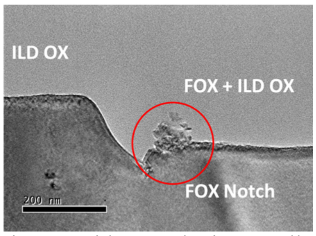

Fig.1 Oxide notch is usually observed at the bottom corner of the FOX edge. Ar-PAI with 1100 °C oxidation.

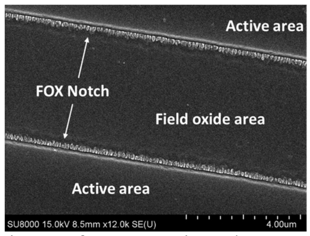

Fig.2 After removing the FOX, the tooth-like patterns along the FOX edge indicate notches in FOX. Ar-PAI with 1100 °C oxidation.

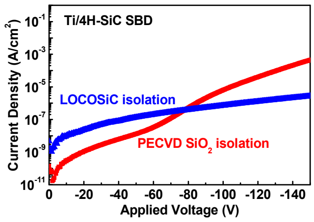

Fig.3 High leakage current at low reverse bias voltage reflects the oxide notch defects. LOCOSiC isolation suppresses leakage current at high voltage.

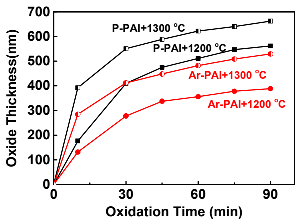

Fig.4 As-grown FOX thickness as a function of oxidation time. The thickness saturation is due to the consuming of the amorphous layer.

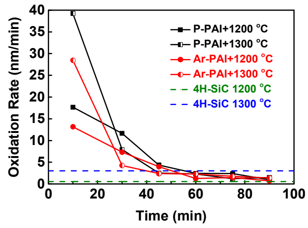

Fig.5 Oxidation rate as a function of oxidation time. Oxidation rate of crystalline 4H-SiC are also indicated as reference.

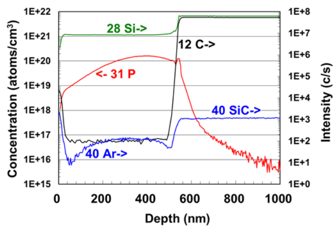

Fig.6 SIMS depth profile of P and Ar. P atoms remain in FOX and SiC. Ar atoms diffuse out of the sample.

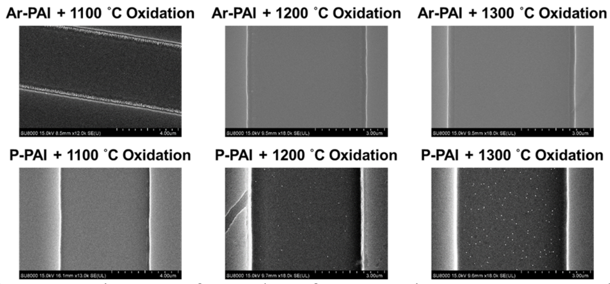

Fig.7 SEM images of samples after removing FOX. P-PAI with oxidation temperature higher than 1100 °C or Ar-PAI with oxidation temperature higher than 1200 °C resolves the oxide notch problem.

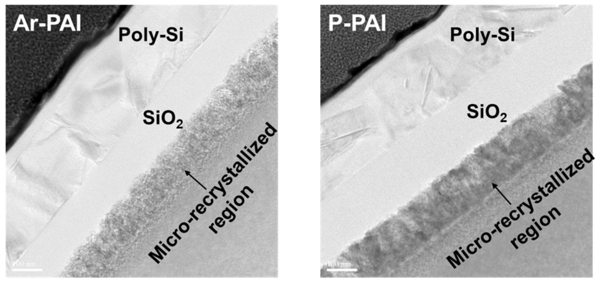

Fig.8 TEM images of partial oxidized Ar-PAI and P-PAI samples at 1200 °C for 10 min. P-PAI sample grows thicker SiO_2 and forms more defective recrystallized region than Ar-PAI sample.

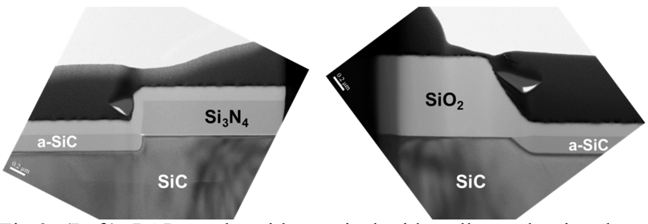

Fig.9 (Left) PAI mask with vertical sidewall results in sharp amorphous corner while (Right) PAI mask with sloped sidewall results in sloped amorphous corner. Sloped PAI mask can be formed by wet etching of SiO_2 layer or high temperature baked photo-resist.

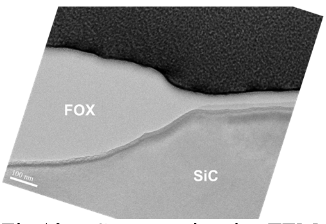

Fig.10 Cross-sectional TEM image shows notch-free FOX/SiC interface with Ar-PAI and 1100 °C oxidation.

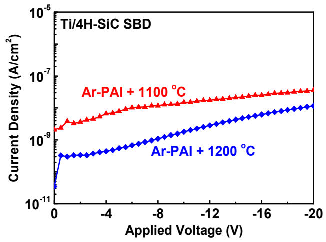

Fig.11 Leakage current of SBD at low reverse bias voltage. FOX grown at 1200 °C results in lower leakage current.