Al イオン打込みによる p 型ウェル上に形成した 4H-SiC(0001)NMOSFET 特性の機械的歪みによる異常な変化

Mechanical-stress-induced anomalous change of electrical characteristics of 4H-SiC (0001) NMOSFET fabricated on Al-implanted p-type well

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[Introduction] The strained-Si technologies have been widely employed for the enhancement of CMOS performances [1-2]. For SiC, it has been theoretically calculated that both compressive and tensile strain will lead to a reduction of the energy gap [3], predicting a potential of strain engineering in SiC-based devices. However, the relationship between strain and electrical performance in SiC-based MOSFET has not been systematically studied yet. In this research, we investigate on the impact of mechanical stress on the electrical characteristics of 4H-SiC (0001) MOSFET fabricated on Al-implanted p-type well.

[Experiments] Effects of mechanical stress on the electrical characteristics was studied for NMOSFETs fabricated on Al-implanted p-type well (peak concentration ~4×10^{17}cm^{-3}) on n-type 4H-SiC (0001) wafer. The channel direction of the device was <11-20>. The SiO_2 gate dielectric was formed by CVD after the formation of interface layer by thermal oxidation, followed by NO-annealing at 1300°C. n^+-poly-Si was used as gate. To apply mechanical stress on the sample, four-points bending tool was employed where two plates were placed above and under the chip. The plates are with either circular ridge or parallel ridges, applying biaxial or uniaxial stress on the sample, respectively. To estimate the strain caused in the stress test, we refer to the stress-displacement relationship provided by previous research [4].

[Results & Discussions] Field-effect mobilities (μ_{FE}) of NMOSFETs, while applied with or without uniaxial mechanical stress along channel direction <11-20>, are shown in Fig. 1. Observing significant change in peak mobility when mechanical stress was applied, we refer compressive stress as negative value and tensile stress as positive value, and describe μ_{FE} as a function of applied mechanical stress in Fig. 2. For uniaxial stress applied along <11-20>, μ_{FE} increased monotonically while tensile stress increased, and decreased monotonically while compressive stress increased. On the other hand, for biaxial stress, μ_{FE} tended to increase when compressive stress was applied. Note that we applied only a small mechanical stress, in the order of tens of MPa. Compared to previous researches on p-type epitaxial layer (p-epi layer) channel [5], the observed change of mobility in this study seems multiple times higher. Moreover, the uniaxial stress-induced effect on μ_{FE} seems opposite to the previous report on p-epi layer channel [5]. Though the origin of such anomalous phenomenon and the discrepancy from the previous report is still not clear, we assume that it is related to the ion-implantation-induced significant strain in the channel region, which exists even without applying mechanical stress. In addition to the mobility change in Fig. 1, it should be noted that significant change in threshold voltage (V_{th}) was observed while applying mechanical stress. As shown in Fig. 3, both compressive and tensile stress can induce change in V_{th}, though tensile stress leads to larger shift in V_{th}. Considering that such anomalous change of V_{th} has not been reported in classical study of mechanical stress effect on Si MOSFETs, this result may indicate a possibility that the band alignment at SiC/SiO_2 interface should be quite sensitive to the mechanical stress, or the amount of trapped charges at the interface should be quite sensitive to a small change of electric structure of SiC.

References [1] Y. Sun, S. E. Thompson, and T. Nishida. "Strain effect in semiconductors: theory and device applications", Springer Science & Business Media, 2009. [2] K. Uchida, et al. Tech. Digest. -Int. Electron Devices Meet., IEEE (2004). [3] F. M. Steel, et al. J. Appl. Phys., 114, 013702 (2013). [4] M. Chu, et al. J. Appl. Phys., 103, 113704 (2008). [5] W. Takeuchi, et al. International Conference on Solid State Devices and Materials, Nagoya, 2019.

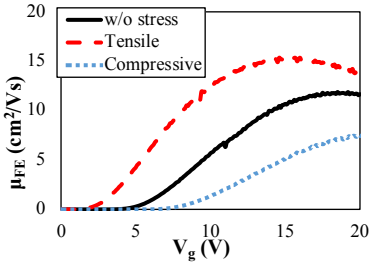

Fig. 1 Field-effect mobility μ_{FE} with tensile or compressive mechanical stress applied.

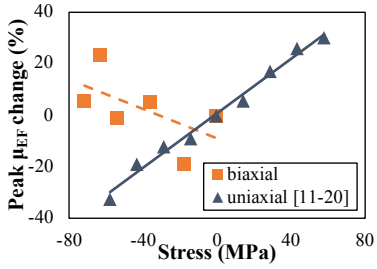

Fig. 2 Relationship of change in peak μ_{FE} with mechanical stress applied on NMOSFET.

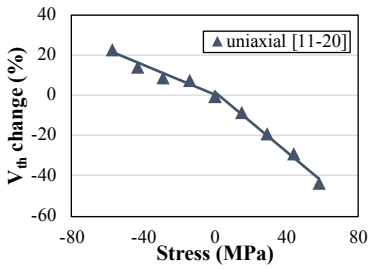

Fig. 3 Change in V_{th} as a function of mechanical stress applied on NMOSFET.