High Electron Mobility in Germanium Junctionless n-MOSFETs

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1. Introduction

Junction-less FET (JL-FET) [1] is gaining much attention for solving the problem of sharp doping profile formation and for improving the short-channel effects. Then, we have already demonstrated Ge p-channel JL-FET based on its high bulk mobility [2]. Meanwhile, it was be noted that the electron mobility in bulk n-Ge is one order higher than that in n-Si in heavily doped region \((N_D = 10^{18} \text{ cm}^{-3})\). In this work, we demonstrate n-channel JL-FET fabricated on GeOI substrate.

2. Device Fabrication

A heavily-doped 90nm-thick n-type GeOI wafer with 100-nm-thick buried SiO\(_2\) and intrinsic Si was used. From secondary ion mass spectroscopy (SIMS) analysis, the average doping concentration in initial GeOI wafer was around \(3 \times 10^{18} \text{ cm}^{-3}\). The device structure of JL-FET in this work is schematically described in Fig. 1. First, the mesa type Ge islands were defined by wet-etching. Next, Ge islands were thinned down to 15-32 nm by a careful wet-etching (\(\text{NH}_3\text{H}_2\text{O}_2\text{H}_2\text{O}\)) process only for the channel regions, and 80-nm-thick Ge was remained for the S/D regions to make electrical contacts better. After cleaning with methanol and HCl, 20nm-thick Y-GeO\(_2\) was deposited onto the Ge islands by rf-sputtering, followed by annealing at 550°C in O\(_2\) to passivate the surface defects. Prior to electrode formation, the sample was oxidized at low-temperature (400°C) to form the very thin GeO\(_x\) layer on S/D region, and then to weaken the Fermi-level pinning near the Ge valence band edge [3]. Finally, Al was deposited and patterned for S/D. Al was also deposited on the backside of Si as the back gate electrode. In the present work, four-point probe arrangement was prepared to subtract the parasitic resistance.

3. Results and Discussion

Fig. 2 shows transfer characteristics of Ge n-channel JL-FETs with various Ge thicknesses. The high on/off ratio of \(-10\) was achieved by thinning the thickness of Ge, so that the majority carriers in the channel were fully depleted. On the other hand, it should be noted that Ge/Al contacts at source and drain did not show the perfect ohmic characteristics in spite of the formation of pinning-relaxation layer. Therefore, we employed 4-probe measurement to estimate the channel mobility. Fig. 3 shows the field effect mobility of Ge n-channel JL-FETs. The mobility degradation with decreasing the Ge thickness was clearly observed. Meanwhile, it is worthy mentioning that the channel mobility of 32-nm-thick Ge JL-FET with subtracting the parasitic resistance is much higher than the bulk mobility in n-Si with the impurity concentration of \(1-5 \times 10^{18} \text{ cm}^{-3}\). However, the mobility in this work is lower than that in bulk n-Ge. To clarify its origin, Raman scattering measurement was carried out. FWHM of Raman peak at 300 cm\(^{-1}\) for the present GeOI was around 3.7 cm\(^{-1}\), while it was 3.3 cm\(^{-1}\) for the conventional Ge (100) substrate. Thus, it can be concluded that the crystallinity of the present GeOI is poor than that of conventional Ge substrate, and then that Ge n-channel JL-FET has higher potential.

4. Summary

We demonstrated the high electron mobility in Ge n-channel JL-FET for the first time. The best value of field effect mobility and on/off ratio were \(1000 \text{ cm}^2/\text{Vs}\) and \(10^8\), respectively. Although the S/D contact formation is a big issue to consider carefully, the channel mobility of Ge n-channel JL-FET is much higher than the bulk mobility of n-Si, which is the limitation of Si n-channel JL-FET.

REFERENCES


4-probe measurement was performed.