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Fabrication and characteristics of Germanium-on-Insulator

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1. Introduction

In the past few years, there is much interest in new materials such as strained silicon or strained SiGe due to their improved carrier mobilities. Recently, pure germanium has been suggested as a replacement of silicon for sub-100nm transistors because of its superior hole and electron low field mobilities. Since germanium oxide is not stable, germanium MISFETs' feasibility is greatly enhanced by the advancement in high-k gate dielectrics. The smaller bandgap of germanium also facilitates power scaling and possibly alleviates source/drain parasitic resistance. However, the high dielectric constant of germanium may aggravate short channel effects. The cost, mechanical strength, and vulnerability to chemical solutions also post challenges to the acceptance of germanium in volume production. Germanium on insulator (GOI), on the other hand, retains the advantages of germanium and also mitigates these concerns. By adopting silicon as a handle wafer, most CMOS processes can be readily transferred. Good quality thermal silicon oxide also serves as an ideal buried oxide over a deposited oxide or other insulators. In this study, bare germanium on oxidized silicon is realized by wafer bonding and Smart-Cut^{TM} techniques. The characteristics of fabricated GOI will also be presented.

2. Experimental Procedures

All the experiments were performed on 4" n-type (4×10^{15} /cm^3 Sb) germanium wafers and 4" p-type silicon wafers with thermal oxide thickness ranging from 200 nm to 400 nm, all in (100) orientation. For blistering study comparison, p-type (100) and n-type (111) germanium wafers were also investigated. A hydrogen dose of 1×10^{17} /cm^2 was implanted in both the blistering and the splitting processes. Bonding of bare germanium and oxidized silicon was performed after proper wet cleaning. An ammonium hydroxide treatment prior to bonding was essential to obtain a hydrophilic surface for high bonding energy. Annealing and layer-splitting were carried out at 200°C. The split GOI wafers were then subjected to further annealing and polishing processes for crystallinity restoration and surface smoothness. A final germanium film thickness of 100 nm to 300 nm was achieved. XTEM, SIMS, XRD, and SRP were employed to characterize GOI film properties.

3. Results and Discussions

Hydrogen in germanium

Implanted hydrogen in (100) n-type germanium created micro-cracks on (100) and {111}-type planes. Unlike the silicon case, these two types of platelets were located in different region of damaged zones as shown in Fig. 1. The hydrogen peak, measured by SIMS, aligned to the positions of (100) cracks. These micro-cracks emerged and layer splitting took place with transferred layer thickness corresponding to the depth of the (100) cracks. The hydrogen, nevertheless, do not reside in these platelets permanently. From both blistering (Fig. 2) and layer splitting data, out-diffusion of hydrogen was inferred. It is believed that H_2 [1] instead of Ge-H is the energy stable specie in germanium which is prone to out-diffusion, and therefore a shelf time dependency was observed.

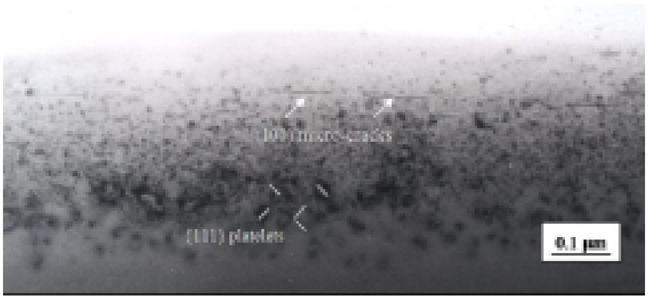

Fig. 1 XTEM of hydrogen as-implanted germanium sample.

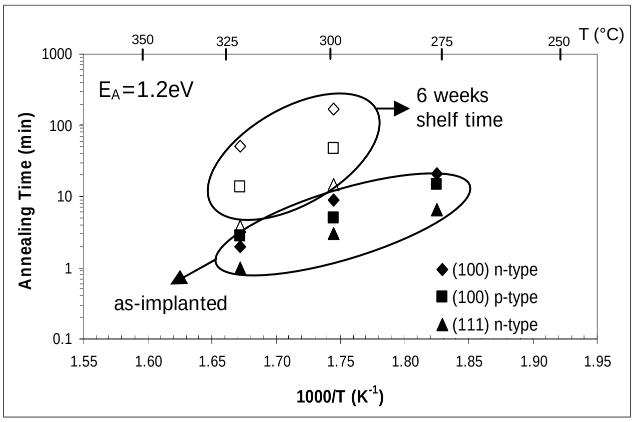

Fig. 2 Blistering data of various germanium samples. A shelf time dependency is explicitly observed.

Germanium on Insulator

One of the critical steps in the fabrication of GOI was the cleaning of germanium. Ammonium hydroxide treatment [2] was found to yield a hydrophilic surface, with surface roughness of 6.71 Å, compared to 5.8 Å of starting Ge wafer. A bonding energy of 800 mJ/m^2 could be achieved after 200°C annealing for 100 hours. This bonding energy was sufficient for Smart-Cut^{TM} process. A successfully transferred germanium on oxidized silicon wafer is shown in Fig. 3. The XTEM (Fig. 4) reveals voids at the bonding interface concave into germanium film, and may affect electrical performance of fully-depleted MOSFETs. With elaborated designs, interface voids concave into buried oxide rather than the GOI film may be feasible, and this condition is still under verification.

Fig. 3 Transferred germanium on oxidized silicon right afte Smart-Cut^{TM}.

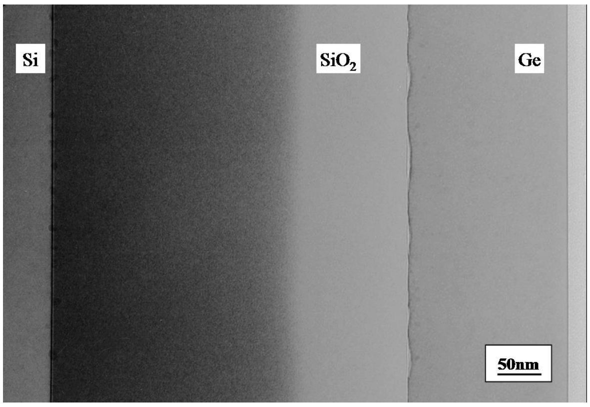

Fig. 4 XTEM of GOI with 172 nm Ge on top of 390 nm SiO_2. The contrast change within oxide layer is due to different specimen thickness.

Germanium on Insulator Characteristics

A basic electrical study of transferred germanium film was performed with SIMS, hot-probe, and SRP measurements. SIMS results showed a residual hydrogen concentration in the orders of 1×10^{19} /cm^3 in the film. Roughly 0.3 percent of them is electrically active and act as acceptors. It is known that incorporated hydrogen in forms of V_2H has acceptor energy level of 0.08eV above valence band in germanium [3], and may account for high concentration of p-type dopants.

Due to the difficulty of dopant activation in germanium, this high level of acceptor concentration increases concerns on the subsequent device design and fabrication. It is therefore important to investigate dopant activation in both bulk Ge and GOI. By optimizing implantation and annealing conditions, high concentration of both n-type and p-type dopants were achieved at relatively low annealing temperatures. More interestingly, p-type dopant in GOI yielded an electrically active concentration of 6×10^{20} /cm^3, which is higher than achievable in bulk Ge (Fig. 5), and is the highest number ever being reported. This improvement is not attributed to the higher-than-set process temperatures of the germanium film due to the thermal isolation of buried oxide, since high temperature annealing of bulk germanium would not yield comparable activation as in the GOI case. On the other hand, n-type dopant yielded a carrier concentration of 5×10^{19} /cm^3 in GOI and of 1×10^{20} /cm^3 in bulk Ge, which are also sufficient for device fabrication requirements. The discrepancy of activation between bulk Ge and GOI is hypothesized that incorporated hydrogen may involve in the activation process, and more detailed investigation is still on going.

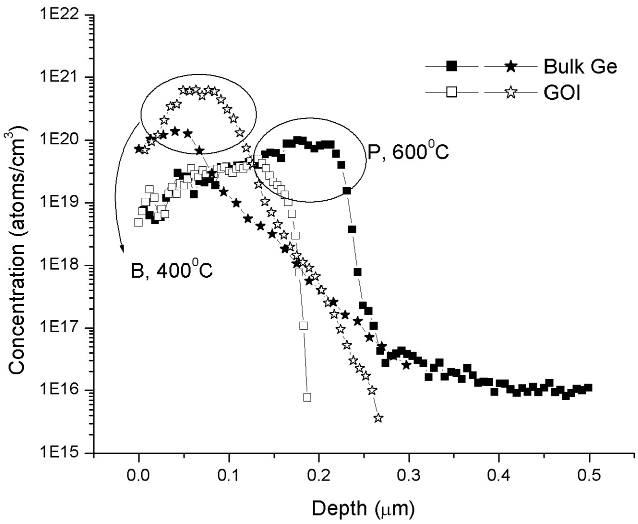

Fig. 5 Activated n-type and p-type dopants in bulk Ge and GOI.

3. Conclusions

Fabrication of germanium-on-insulator is demonstrated. A shelf-time dependency was observed in both blistering and layer splitting processes. The transferred germanium film showed high p-type dopant concentration. Nevertheless, activation of boron and phosphorous dopants could be successfully achieved. The hydrogen characteristics in germanium are believed to be responsible for these phenomena.

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References

[1] S. M. Myers, *Physical Review B.* **51**, 15 (1995) 9714.
[2] Y.-L. Chao, Q.-Y. Tong, T.-H. Lee, R. Scholz, M. Reiche, J. C. S. Woo, U. Gösele, submitted to *Electrochemical and Solid-State Letters*.
[3] S. J. Pearton, *Hydrogen in Crystalline Semiconductors* (1992).