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Invited

Silicon Compliant Substrate for High-Quality Heteroepitaxial Growth

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1. Introduction

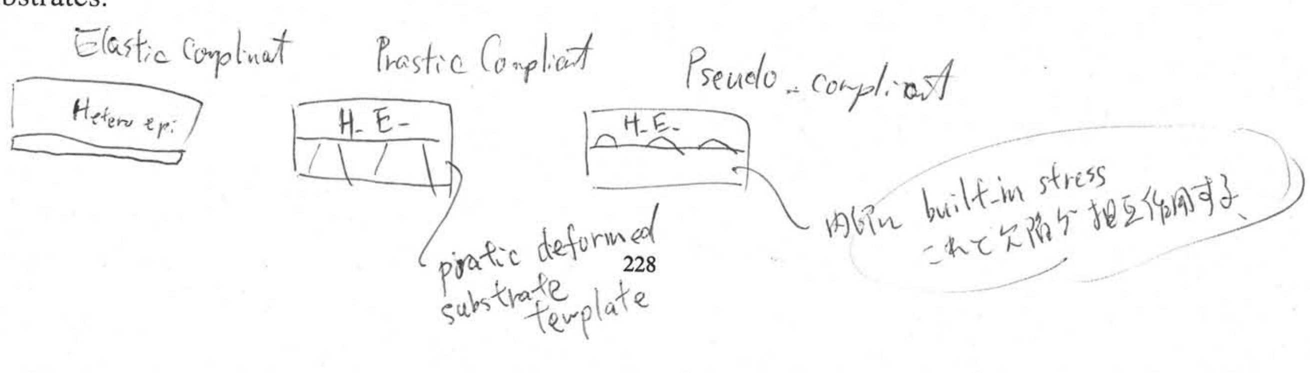
Recently, the concept of compliant substrates has been actively pursued and encouraging results have been demonstrated on III-V compound semiconductors [1,2]. It was found that bonding a thin GaAs layer to a bulk substrate with an intentionally introduced angular misalignment, namely a twist angle, this bonded thin layer may behave as a compliant substrate. When heteroepitaxial layers are grown on the bonded thin layer, this thin layer will be severely plastically deformed. This process can preserve the quality of the heteroepitaxial layer by confining dislocations in or very near to the plastically deformed thin layer. As a result, heteroepitaxial layers free of threading dislocations can be achieved even when their thickness is well above the critical thickness.

Although the concept of bonded compliant substrates has been demonstrated on GaAs, it is most desirable that the same concept can be demonstrated on Si. One technological challenge for making Si compliant substrates is the lack of ultra thin (in the order of 100Å) single crystal Si film on oxide for transfer to Si substrates using wafer bonding. The SOI wafers available today, produced from SIMOX, smart cut, or bonding and etch back process, do not produce a 100Å silicon layer, as needed for formation of twist-bonded compliant substrates. In addition, the chemically active silicon surface is subject to oxygen, carbon, and other contamination, causing an impurity rich bonding interface. Such a contaminated interface may disturb the compliance properties of the thin layer. This paper discusses our preliminary efforts in overcoming the above problems to fabricate twist-bonded Si compliant substrates. The effectiveness of the Si compliant substrates is then examined by growth of Ge layers on such substrates.

2. Fabrication of Si Compliant Substrates

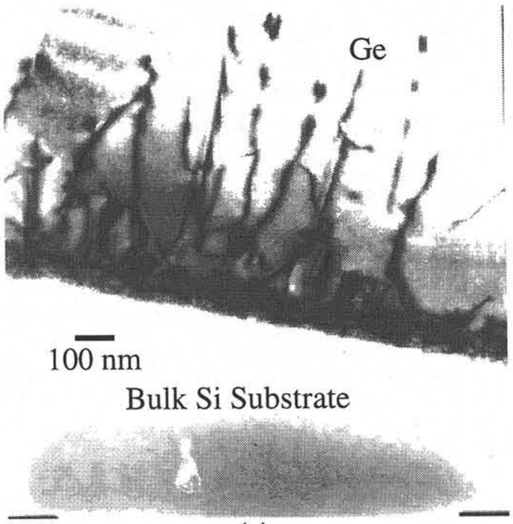
The substrate formation process is summarized below. The starting material is an SIMOX SOI sample comprising a 500Å Si layer and an embedded oxide layer. The SIMOX wafer and the Si substrate were bonded in high vacuum at around 1000 C with an angle. Before sample loading, the Si surfaces were hydrogen passivated by immersing the samples in HF solution. After bonding, the substrate of the SIMOX sample was first lapped and then etched by KOH at 60C. The KOH etch stopped at the oxide layer and the oxide was etched subsequently by BHF. The 500Å twist-bonded Si layer was further oxidized in an oxidation furnace until its thickness reaches about 100Å. Before epitaxial growth, the thermal oxide layer was etched and another volatile oxide layer was formed in the $HCl/H_2O_2/H_2O$ (3:1:1) solution. The formation of the volatile oxide consumes about 30 to 40 Å Si, leaving the final twist-bonded Si layer thickness to be 60 to 70 Å. This thickness was measured by cross sectional TEM.

Si compliant substrates have also been characterized by X-ray diffraction and EDX using scanning transmission electron microscopy (STEM). The X-ray linewidth for the bulk Si substrate, the SIMOX sample, and the twist-bonded Si compliant substrate are nearly the same (about 15 arc seconds). This indicates that no defects were introduced during the compliant substrate fabrication process. The EDX experiment using STEM allows us to identify the chemical species in a region of less than 20Å in diameter. It was found that the oxygen content at the bonded interface is essentially the same as the oxygen level in regions 20 Å above and below the bonding interface, all of which are near the instrument sensitivity limit (1%).

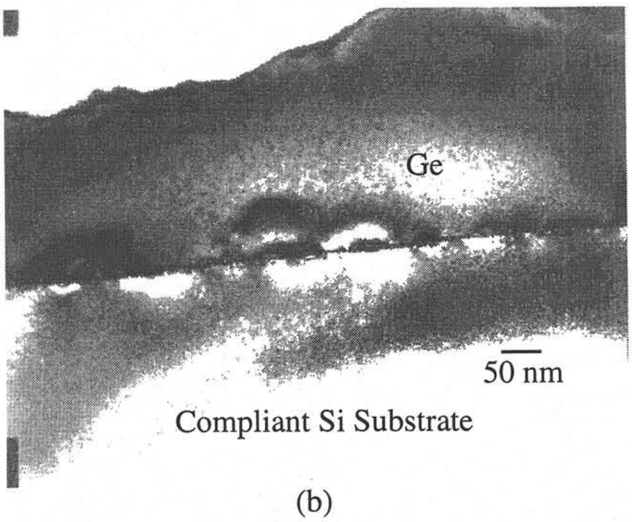


3. Ge Growth on Si Compliant Substrates

Preliminary heteroepitaxial growth experiment has been done on Si compliant substrates.



(a)



(b)

Fig. 1 Corss sectional TEM for Ge layers grown on (a) a conventional Si substrate and (b) a bonded Si compliant substrate. The Si template is about 10 nm thick bonded to a bulk Si wafer.

Figure 1 shows the cross sectional TEM for MBE grown Ge layers on Si bulk substrates and Si compliant substrates. Substrate compliance has resulted in a significant reduction in threading dislocation density. The etch pit density in the Ge layer was around 10^6 cm^{-2} for the compliant substrate sample and 10^8 cm^{-2} for the bulk substrate sample. Although the improvement of the material quality is substantial, the threading dislocation density is still too high for defect sensitive device applications. More research needs to be done to further improve the heteroepitaxial material quality.

viscosity

$$\tau = \frac{\alpha a^2}{M h_i h_2}$$ linear dimention

$\tau = 10^9$ second!

4. Conclusion

The field of compliant substrates is in its embryonic stage. Much research needs to be done and many hurdles are to be overcome. On the other hand, compliant substrates present an unmatched opportunity for the next major breakthrough in semiconductor technology. Only continuing research will be able to tell us how critical a role compliant substrates will play eventually in the broad area of semiconductors.

Acknowledgment

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References

1) F. E. Ejeckam, Y. H. Lo, S. Subramanian, H. Q. Hou, B. E. Hammons, *Appl. Phys. Lett.*, 70(13), p. 1685 (1997)

2) Z. H. Zhu, R. Zhou, F. E. Ejeckam, Z. Zhang, J. Zhang, J. Greenberg, Y. H. Lo, H. Q. Hou, B. E. Hammons, *Appl. Phys. Lett.*, 72(20), p. 2598 (1998)

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