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Oxygen Precipitates and Related Defects in SOI Substrate Fabricated by Wafer Bonding and H^+ Splitting

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1. Introduction

An SOI wafer fabricated by wafer bonding and hydrogen splitting technique (UNIBOND®) is recognized as one of the most reliable substrates for future fine structure, low power devices. In the fabrication process, high dose H^+ are implanted into a surface oxidized Si wafer, and bonded with a supporting Si substrate. The bonded wafers are two-step annealed. The first annealing is at 400-600℃ to split the superficial Si layer at the H^+ implanted depth, and the second one is at 1100℃ to increase bonding strength. The SOI substrate has excellent film thickness uniformity, since the superficial Si thickness is determined by the implanted H^+ depth. The fabrication cost is potentially low, since the process is highly ULSI compatible in terms of the implantation and annealing, and the Si wafer after the surface splitting can be reused. The defect density in the SOI active layer, however, as evaluated by the four-step Secco etching technique, is still 10^3-10^4/cm^2, which is too high to provide reliable devices[1].

In this paper, we characterize the defects both in the superficial Si layer and in the supporting substrate by means of photoluminesence (PL) spectroscopy and transmission electron microscopy (TEM). The defect formation mechanism is also discussed based on the characterization.

2. Experiment

In the experiment, commercially available UNIBOND® wafers were evaluated by PL and TEM. For the PL characterization, both PL spectra and intensity-mapping images were obtained under the UV and visible laser light excitation that was used to evaluate, respectively, the superficial Si layer and supporting substrate. The small penetration depth of the UV light and the SOI structure for the confinement of the photo-excited carriers enabled us to analyze the superficial Si layer separately from the supporting substrate[2].

TEM samples were prepared through a combination of mechanical thinning and chemical etching. For the supporting substrate observation, the superficial Si and buried SiO_2 layers, respectively, were etched off first with a KOH solution and diluted HF etching. After then, the sample backside was mechanically polished and a final thinning was done by chemical etching using a $HF/HNO_3/H_2O$ solution from the backside. For the superficial Si layer observation, after the same mechanical and chemical thinning as for the supporting substrate, the buried SiO_2 was removed by the diluted HF etching. Several samples of each layer were observed by TEM bright-field, dark-field and weak-beam images at a 200 KV operating voltage.

3. Results and discussion

Figure 1 shows a PL mapping image of the band-edge emission taken from a quarter of the supporting substrate. Concentric rings were clearly observed, while no particular contrast was observed from the superficial Si layer. The concentric pattern observed in the supporting substrate is similar to the striation pattern, often observed in Czochralski grown Si substrates after oxygen precipitation annealing. This striation pattern usually reflects the inhomogeneous oxygen distribution in the Si substrate.

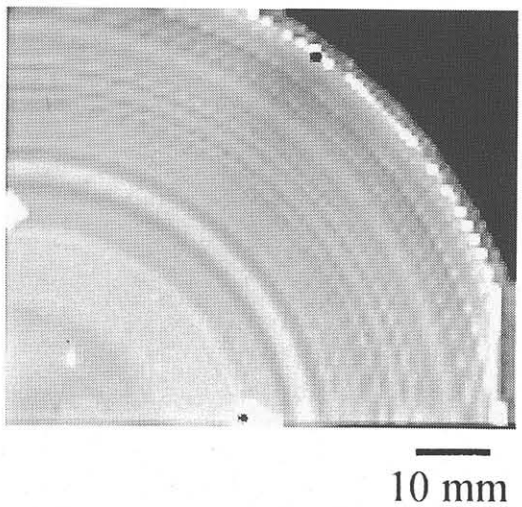

Fig. 1. PL mapping image of supporting substrate. Whiter gradation indicates higher intensity level.

Although no literature has referred to defects in the supporting substrate, we believe oxide precipitates exist in the substrate, possibly due to the two-step annealing in the SOI fabrication process which is similar to the well known heat treatment to promote oxygen precipitation. The first annealing at 400-600℃

is considered to be a nuclear formation process for the precipitation and the second one at 1100℃ is to promote growth of the precipitates. The appearance of the deep-level PL associated with oxide precipitates also suggests the oxide precipitation occurred in the supporting substrate.

Furthermore, the PL spectrum from the superficial Si layer also indicated deep-level emission due to oxide precipitates, although no clear contrast was observed in the PL mapping image. This suggests there was an uniform distribution of the oxide precipitates in the layer. The superficial Si layer in the SOI substrate was very thin, which may be why the precipitates had no striation pattern. The two-step annealing, however, was also applied to the superficial Si layer. Therefore, it is reasonable to believe precipitates existed in the layer.

To verify whether this was so, we carried out TEM observations for both the supporting substrate and the superficial Si layer. Figures 2 and 3 are TEM images taken from the supporting substrate and from the superficial Si layer, respectively. As can be clearly seen, the same kinds of defects were observed in both samples. The observed defects were precipitates (possibly oxide precipitates) in Figs. 2(a) and 3(a), dislocation clusters close to the precipitates (the dislocations might be punched out from the precipitate) in Figs. 2(b) and 3(b), and rod-like defects in Figs. 2(c) and 3(c). There were no defects observed only in the superficial Si layer. Moreover, we can not think of any other reason besides oxide precipitation for the defect formation in the supporting substrate, since H^+ is not implanted into the supporting substrate. Therefore, we believe most of the defects in the superficial Si layer are also caused by the oxide precipitation due to the two-step annealing in the SOI fabrication process. These results suggest that the defect density can be reduced by using Si substrate with a low oxygen concentration as a starting material for the superficial layer, or by changing the annealing sequence to suppress the oxide precipitation.

Acknowledgments

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References

1) M. Bruel *et al.*, Electrochem. Soc. Proc., Vol.97-23, 3 (1997).

2) M. Tajima *et al.*, Appl. Phys. Lett., **70**, 231 (1997).

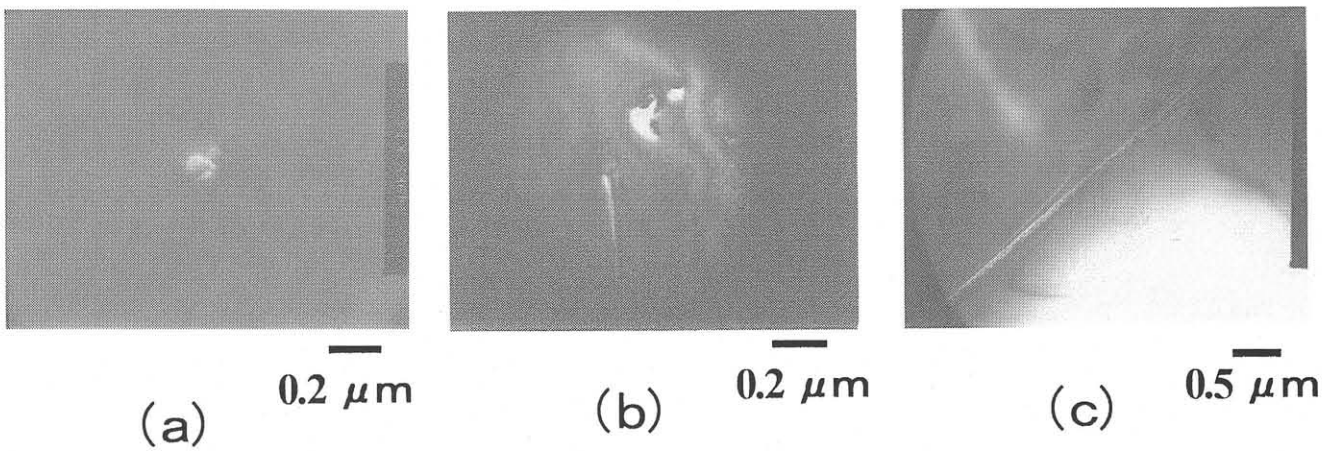

Fig. 2. Defects observed in the supporting substrate, (a) precipitate (dark-field image), (b) precipitate and related dislocations (weak-beam image), and (c) rod-like defect (weak-beam image).

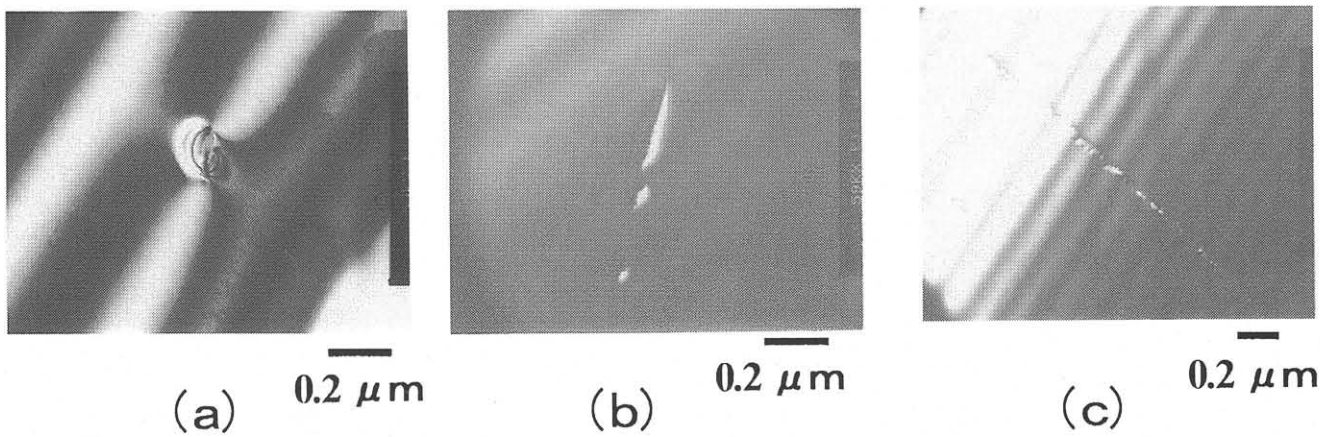

Fig. 3. Defects observed in the superficial Si layer, (a) precipitate (dark-field image), (b) precipitate and related dislocations (weak-beam image), and (c) rod-like defect (weak-beam image).