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Quality Comparison of Commercial Silicon-on-Insulator Wafers by Photoluminescence

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1. Introduction

It is now generally recognized that the use of ultrathin silicon-on-insulator (SOI) wafers is requisite to realize higher speed and lower power consumption CMOS devices. The quality of SOI wafers has been improved greatly during the past several years. However, analysis of the electronic properties of ultrathin SOI wafers around 100 nm in thickness is quite difficult because of the overwhelming effects of the adjacent surface and interface and of the overlapping of the signal from the substrate. Ultraviolet (UV) light creates a breakthrough in the characterization of SOI wafers. The penetration depth of the UV light is just 5-10 nm, and the excited carriers are confined in the top Si layer because of the presence of the buried oxide (BOX) layer which acts as the diffusion barrier. We have focused on the characteristic photoluminescence (PL) from the condensed phase of the excited carriers, known as electron-hole droplet (EHD) at cryogenic temperature, and have shown the effectiveness of PL spectroscopy, decay and mapping for the diagnostic characterization of the SOI wafers [1]. In this paper the author compares the quality of commercial state-of-the-art SOI wafers using the PL technique.

2. Experimental Technique

SOI wafers for the comparative study were obtained from commercial sources: SIMOX wafers from suppliers A and B, Unibond® wafers from suppliers C and D, and ELTRAN® wafers from supplier E. All the wafers were 200 mm in diameter and were made in the year 2002. Two sets of wafers were obtained from the respective suppliers: 150-200 nm thick and 60-100 nm thick wafers for partially and fully depleted device applications, respectively. We also measured "old" SOI wafers fabricated a few years ago for comparison.

PL spectroscopy was performed at 4.2-300 K under various cw laser excitations ranging from deep UV (266 nm) to near infrared (1064 nm). A combination of PL observed from both sides of the wafer under various excitations with different penetration depths allowed us to extract information on the top Si layer, on the Si layer below the buried oxide layer, and on the substrate. The intensity mapping of specific spectral components was done at room temperature on a full wafer, and microscopic mapping of a particular region of interest was also performed under a resolution as high as 1 μm [2]. Decay time of the EHD luminescence from SOI wafers at 4.2 K was measured under a pulsed UV laser (266 nm) excitation.

3. Results and Discussion

PL spectra of the "old" and state-of-the-art Unibond wafers under UV excitation are shown in Fig. 1(a) and (b), respectively. The main peak at 1.08 eV is due to the condensate luminescence from the top Si layer. The substantial difference between the two spectra is the deep-level emission at 0.8 eV. The 0.8 eV band was reported to be associated with oxygen precipitates, which indicated the presence of the precipitates in the top Si layer in the "old" Unibond wafer. This was confirmed by transmission electron microscopy. Similar deep-level emissions were also observed in some "old" SIMOX and ELTRAN wafers, although the peak position varied depending on the samples and their origins are yet unidentified. These deep-level emissions were greatly reduced in the state-of-the-art SOI wafers, as in Fig. 1(b).

Carrier lifetimes are commonly used as a quality control measure in bulk Si substrates. However, the lifetime measurements in SOI wafers are problematic, because the carrier recombination is dominated almost entirely by the surface and interface which makes the lifetime very short, even shorter than the system response in our case. We turned our attention to the EHD lifetime, since the slow velocity of the EHD resulted in only moderate surface and interface effects. We demonstrated the quantitative correlation between the EHD lifetime and the interface trap density in Fig. 2 [3]. The EHD lifetime of the "old" SOI wafers with the l60-l80 nm thick top Si

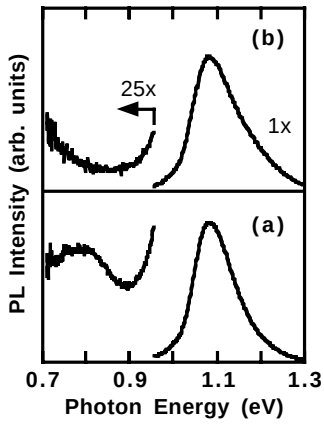

Fig. 1 PL spectra from top Si layers of Unibond wafers at room temperature. Wafers were fabricated in the year (a) 1999 and (b) 2002.

layer was scattered in the range 40-150 ns. The lifetime of the state-of-the-art SOI wafers converged in the narrower and higher range of 130-160 ns, similar to the value of high-quality bulk Si.

Mappings of the band-edge emission from the state-of-the-art 200 mm SOI wafers are shown in Fig. 3, where upper figures are PL on the top Si layers obtained under UV excitation and lower figures that on the substrates under visible excitation. The deep-level emission was below our detection limit in the top Si layer of all the wafers. Uniformity of the PL intensity on the wafer was considerably improved compared with the "old" wafers. However, characteristic nonuniform patterns peculiar to respective fabrication methods and suppliers were still observed as shown. We also discovered a micron-sized irregularity in the top Si layer of some SOI wafers, as shown in Fig. 4. We are now investigating the origins of the wafer nonuniformity and micron-sized irregularity.

3. Conclusions

We characterized the electronic properties of the state-of-the-art 200 mm SOI wafers by the PL method. Deep-level emission was below our detection limit and the EHD lifetime approached the value of bulk Si. However, characteristic nonuniform patterns peculiar to the fabrication methods and suppliers were still observable. We also discovered a micron-sized irregularity in some SOI wafers.

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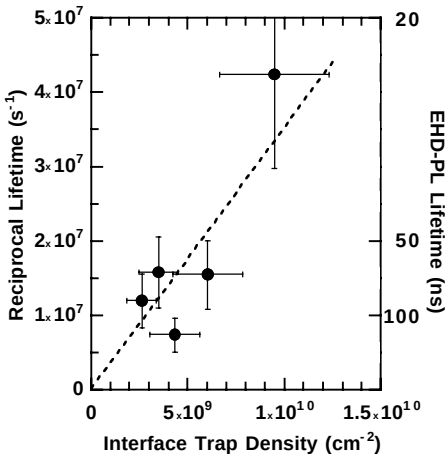

Fig. 2 Correlation between the EHD lifetime and interface trap density (Ref. 3).

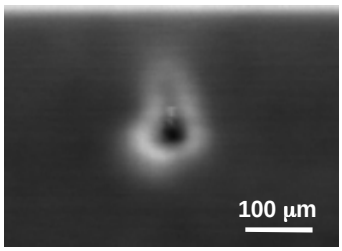

Fig. 4 Microscopic PL mapping on the dark spot in Fig. 3(c).

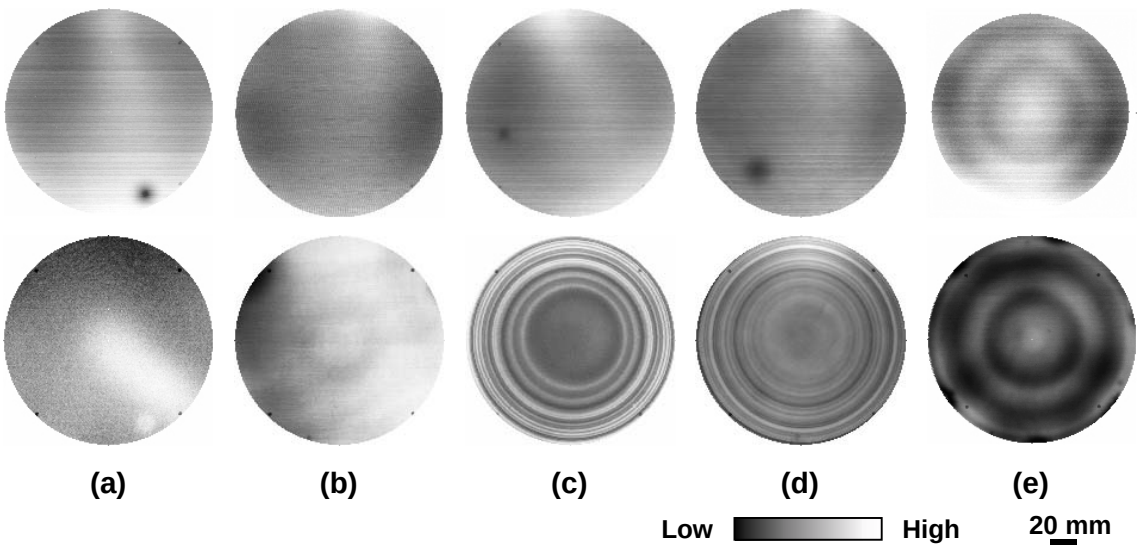

Fig. 3 PL mapping on (a) SIMOX-A, (b) SIMOX-B, (c) Unibond-C, (d) Unibond-D and (e) ELTRAN-E wafers with t_{SOI} = 150-200 nm at room temperature. Upper and lower figures are on the top Si layers and substrates, respectively.