LOW TEMPERATURE Si LAYER TRANSFER BY MECHANICAL ION-CUT

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INTRODUCTION

Recent development in layer transfer processes for multi-material integration relies greatly on the "paste-and-cut" approach. Exemplified in both thermal ion-cut[1], mechanical ion-cut[2], and ELTRAN®[3] processes for SOI wafers, as well as laser liftoff transfer of GaN onto Si[4], the "paste-and-cut" approach consists of (1) bonding of two materials units and (2) separating the bonded system along a prescribed layer other than the bonded interface.

In this paper, we present a general concept for layer transfer in terms of mechanical strength of the bonding interface (γ_{bond}) and the cutting interface (γ_{cut}). For large-area layer transfer, $\gamma_{bond} > \gamma_{cut}$ is a necessary condition. This concept has been verified using mechanical ion-cut of Si consisting of direct wafer bonding and edge-initiated crack propagation.

EXPERIMENTAL AND RESULTS

Two types of bonding pairs were prepared. The first set consisted of Si-Si and Si-SiO_2 bonded pairs for the measurement of bonding interface strength. Two blank Si wafers were directly bonded to another Si wafer and an oxidized Si wafer (SiO_2), respectively. Prior to bonding, the wafers were cleaned in piranha (H_2SO_4 and H_2O_2), rinsed in DI water, and exposed to oxygen plasma. Bonded wafers were annealed at temperatures up to 300 ^oC and diced in a double-cantilever beam (DCB) shape. The effective surface energies at the bonding interface (γ_{bond}) were determined by the crack opening method. In this method, the measured equilibrium crack extension is directly related to the surface energy of crack propagation interface (γ_{bond} in this case) and represents resistance to mechanical separation, interchangeably, interface strength. Annealing of the Si-Si and Si-SiO_2 pairs at 105 and 200 ^oC, respectively, yielded bonding interface strength exceeding the bulk Si fracture strength ($\gamma_{bulk\ Si}$).

A second sets of bonded pairs consisted of implanted donor wafers and receptor wafers. Si (100) wafers implanted with a hydrogen dose of $8x10^{16}$ /cm^2 at a beam energy of 28 keV were used as the donor wafers. The donor wafers were directly bonded to both Si and oxidized Si receptor wafers at room temperature. The donor-receptor bonded pairs were subject to post-bond annealing in the same temperature range as the blank bonded pairs. After sufficient annealing, crack initiation by razor blade insertion from one edge of the implanted Si-Si and Si-SiO_2 pairs resulted in separation at the implanted region, resulting in layer transfer. By measuring the crack extension, the strength of the implanted layer (γ_{cut}) was determined. The measured strengths of the bonding interface and the implanted layer are presented in Fig. 1.

Three types of separation surfaces resulted upon initiating a crack from the implanted pairs. After annealing of implanted Si-Si and Si-SiO_2 bonded pairs at 105 and 200 ^oC, respectively, mechanically initiated crack propagated mostly through the implant interface with partial derailing to the bonding interface. As a result, partial transfer was observed (Mode II). After annealing above these temperatures, full transfer (Mode III) resulted and below these temperatures, no transfer (Mode I) resulted. The three separation modes are schematically illustrated in Fig. 2(a) and presented with the real images of separated surfaces resulting from the Si-SiO_2 pair in Fig. 2(b).

The roughness of the mechanically separated Si surfaces was comparable to thermally separated Si surface (at 400 ^oC) as measured in RMS roughness below 4nm.

CONCLUSION

In summary, partial Si transfer (Mode II) was observed when the donor-receptor pair was annealed at temperature as low as 105^oC. Si implanted with hydrogen ions of the conditions used for this work is known to create a mechanically weakened layer near the projected range (Rp)[5]. Our ERD, RBS channeling analyses, and reported FTIR study indicate that the chemical state, the concentration of H, and detectable lattice damage remain steady after annealing below 200 ^oC[6]. Hence, layer transfer by mechanical ion-cut below 200^oC is not caused by H_2 gas evolution but by crack propagation through the mechanically weakened layer near the peak H concentration depth.

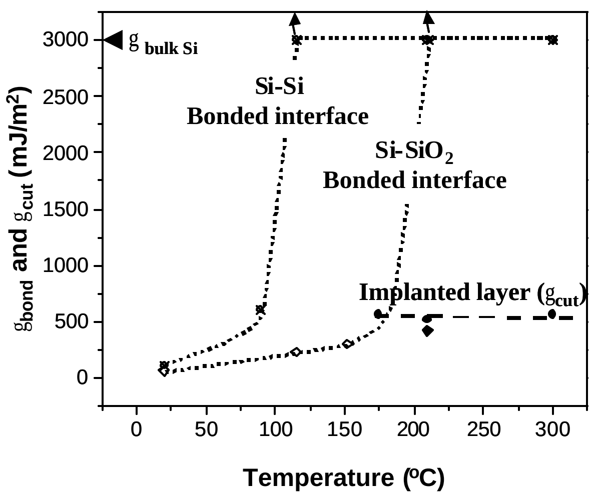

Figure 1. Measured strengths at the bonding interface and at the implanted layer for Si-Si and Si-SiO2 pairs.

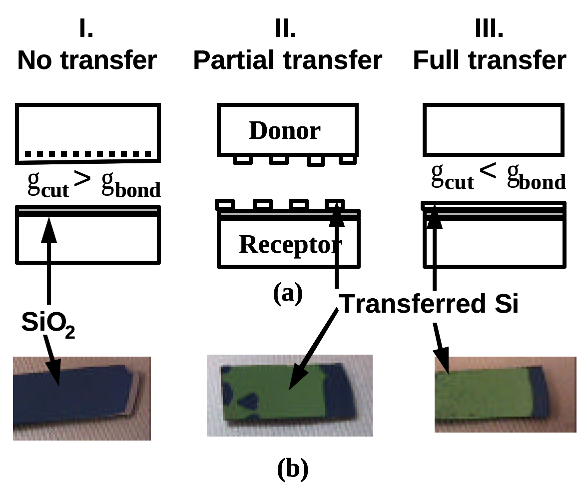

Figure 2. Schematic illustration of (a) three separation modes for implanted Si-SiO_2 pair and (b) the images of observed surfaces.

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