

## Pretreatment Effects on Void Formation for Low Temperature Si-Si Bonded Wafers

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**Introduction:** Since 1980's silicon direct bonding (SDB) technologies have been introduced successfully into many device fabrications [1, 2]. Both high bonding strength and void-free are the main characteristics for high quality bonding wafer techniques. Low temperature wafer bonding techniques have been investigated these last years in the literature [3-8]. In [8] oxygen plasma and tetramethoxysilane (TMOS) pretreatments prior to wafer bonding at low temperature have been considered and compared about the resulting surface energy. In [4, 6] special cares for reducing the void formation during annealing of SDB have been considered in the case of O<sub>2</sub>-plasma activation. Based on the experimental results reported in [9], it appears that the importance of void formation is not only linked to the annealing temperature but also the annealing time. Therefore, both the low temperature and long time storage/annealing are very important trials for electronics long-term reliability.

**Objectives:** In this study, we carried out two kinds of activation methods of the wafer surfaces prior to wafer bonding: O<sub>2</sub>-plasma and warm nitric acid. We compared the bonding strength and void formation for both surface pretreatments versus annealing time (long period of time) and temperature (below 400°C).

**Approach:** Several samples for both pretreatments have been bonded and annealed at 120°C or 400°C for 70, 120, 220 hours. The bonding strength (surface energy  $\gamma$ ) for all samples has been extracted thanks to a steady-state measurement technique [10] based on the well-known crack opening method, the cracking length being measured with an infrared imaging system.

**Results:** For the activated pair by *warm nitric acid* treatment, we found that the size of the completely trapped bubbles occurring at the prebonding stage increased after annealing of 70 hours ( $\gamma = 1.2 \text{ J/m}^2$ ) while partial trapped bubbles (edge of the bonded Si pair) were slightly decreased (Fig. 1). The increase of completely trapped voids size can be explained by the product polymerizing in hydrophilic wafer low temperature bonding [9]. The completely trapped voids seem to almost vanish if we extend the annealing time up to 120 hours (Fig. 2) ( $\gamma = 1.45 \text{ J/m}^2$ ). The completed void close to the bonded wafer rim has disappeared thoroughly after annealing at 120°C for 220 hours (Fig. 3). No new bubbles were generated even if the bonded wafers were heated at 400°C for 100 hours (Fig. 3c).

For the *O<sub>2</sub>-plasma activation*, no bubble occurred after annealing of 70 hours at 120°C ( $\gamma = 1.34 \text{ J/m}^2$ ) as also demonstrated in [4], but a great number of scattered small bubbles appeared after 220 hours of annealing at the same temperature (Fig. 4) and even more for annealing at higher temperature (400°C) and appeared sooner (Fig. 5).

**Conclusion:** High bonding strength can be obtained with O<sub>2</sub>-plasma surface activation prior to SDB but voids occur even at low temperature when the annealing time or the exposure to this temperature is longer than approximately 200 hours. It means that depending on the use of Si-Si bonded wafers afterwards this wafer bonding technique

can be considered or not. However, bonded wafers activated by means of warm nitric acid present minimum voids even after a long annealing period and are also characterized by a high bonding strength which is compatible with main post-processes in microelectronics and packaging specifications.

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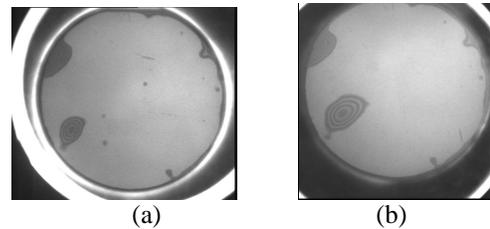


Fig.1. The bonded wafers before annealing (a) and after annealing at 120°C for 70 hours (b).

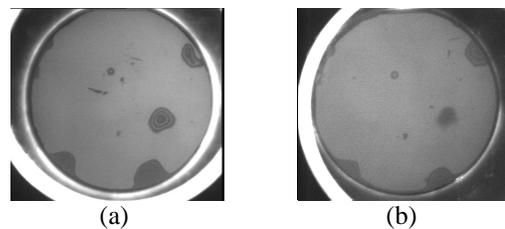


Fig. 2. The bonded wafer before annealing (a) and after annealing at 120°C for 120 hours (b).

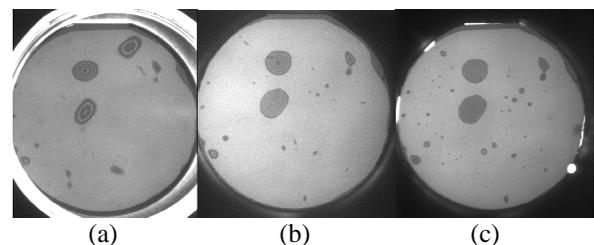


Fig. 3. Bonded wafer before annealing (a), after annealing at 120°C for 220 hours (b), and after an additional annealing at 400°C for 100 hours (c).

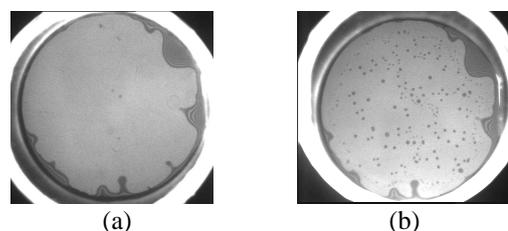


Fig. 4. Bonded wafers activated by O<sub>2</sub>-plasma before (a) and after annealing at 120°C for 220 hours.

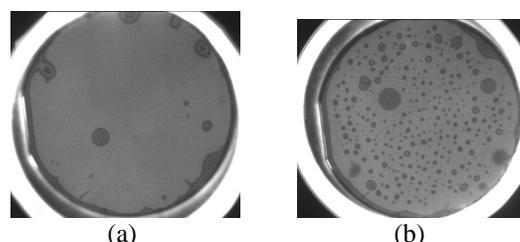


Fig. 5. O<sub>2</sub>-plasma before (a) and after (b) annealing at 400°C for 70 hours.