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Silicon Wafer-Bonding Process Technology for SOI Structures

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The perfections of bonded interfaces with the sandwich structure of a SiO_2 layer are studied by the x-ray diffraction topography and the tensile testing. The tensile strengths of this structure were compared with that for two bare silicon wafers and two wafers with oxide coatings. It is discussed that a proper amount of H, OH and H_2O on wafers play an important role on the chemical bonding under 800C and an interaction between adjacent atoms and the deformation of SiO_2 layer are effective for tight bonding over 1000C.

1. INTRODUCTION

The use of SOI for device applications such as radiation hardening, high-density C-MOS or high voltage has been considered ideal from the viewpoint of performance. To obtain this structure both ZMR[1)] and SIMOX[2)] has been studied for the last 20 and 10 years, respectively. On the other hand, SOI structures made by wafer bonding[3.4)] provide an attractive alternative with the end product expected to be more perfect.

In this paper, three kinds of bonded structures (direct bonding Si/Si, both side oxide SiO_2/SiO_2 and one side oxide SiO_2/Si) are studied for the formation of voids which are unbonded area and the change of bonding strengths obtained with increasing temperatures.

2. EXPERIMENTS

Figure 1 shows schematically the wafer bonding process for bipolar devices made with the SOI structure as an example. The SiO_2/SiO_2 and Si/Si specimens are fabricated by whether both side wafers have oxide layers or not. The base wafer as denoted is brought in contact with the bonded wafer without the use of external pressure, AC voltage or adhesives. These are then annealed at various temperature for 2hrs. in a nitrogen ambient.

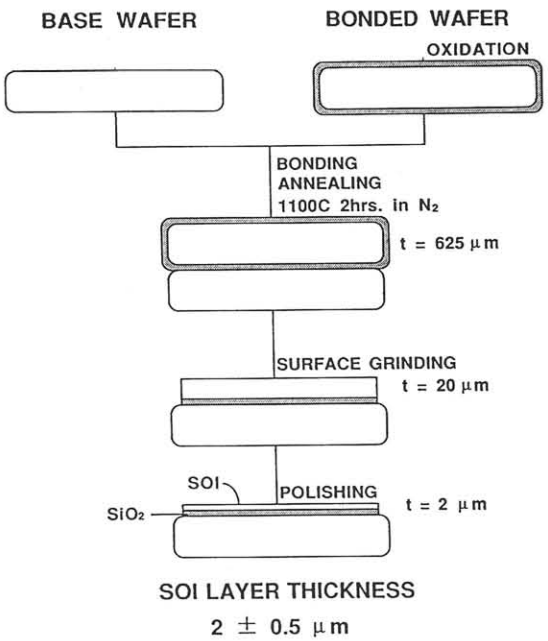


Fig. 1 Schematic of silicon wafer bonding process with SOI structure

The bonded wafer is thinned by surface grinding : first with a coarse grit and then with a much finer grit.

Finally the thickness of the bonded wafer is controlled to several microns using the conventional polishing.

The following two methods were used for the analysis of bonding perfections :

2.1 The x-ray diffraction topography

After adhering two wafers at room temperature the x-ray topographs were taken to confirm void-free and then taken again to see the voids formed by annealing. In order to *in-situ* observe the void formation in the bonding wafers inserted between two carbon-sheet-heaters, PbO vidicon camera which is highly sensitive for x-ray beam was used[5].

2.2. Strength testing for the bonded films

The bonded strengths of thin films were measured using a tensile tester (Sebastian V : Quad Group). A special adhesive which has the tensile strength of about 800kg/cm^2 was used for fixing between the film crystals and the jig of the tester. When the specimens are annealed at low temperature, the bonding strengths are so low that the thinning of the specimens is difficult.

Figure 2 shows the micro roughness of silicon surface used, which is measured by a scanning tunnel microscope (STM : Nanoscope II).

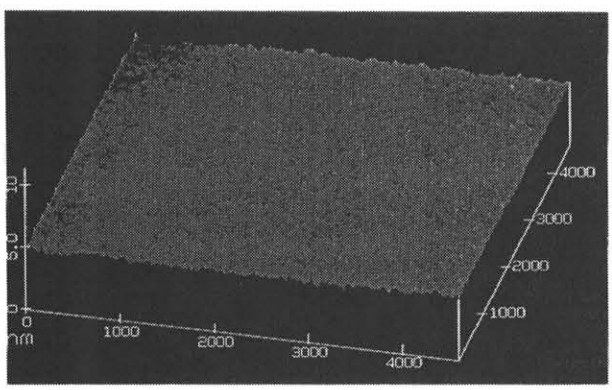
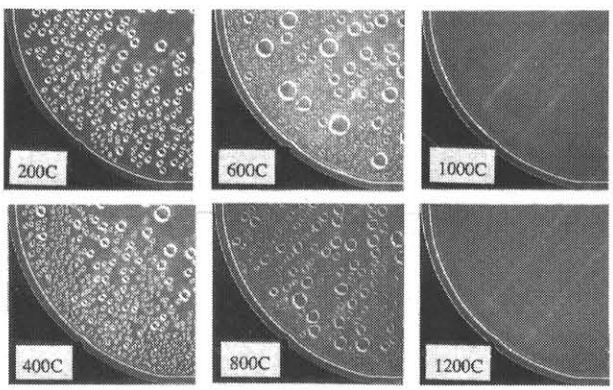


Fig. 2 Surface roughness of polished wafers for wafer bonding measured by STM (Nanoscope II)

3. RESULTS

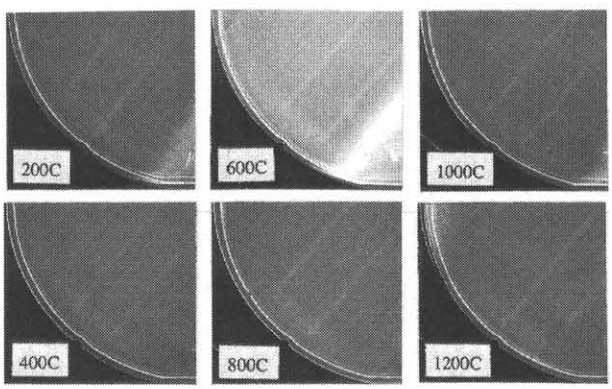
3.1. The void observed by the x-ray topography

Figure 3 is the x-ray topographs of the Si/Si and SiO_2/Si bonding wafers which were annealed with the various temperatures. Under 800C annealing, the voids are only formed in the former bonding structure. The latter bonding structure prevents to form the voids as well as the both side bonding wafers, which are not shown here. In Fig. 3(a), it is observed that the density and number of voids are maximum and both in Fig. 3(a) and (b), the x-ray intensity of the background is also maximum in the topographs at 600C.



Annealing period : 2hrs , Ambient : N_2, Wafer diameter : 100 mm

(a)



Annealing period : 2hrs , Ambient : N_2, Wafer diameter : 100 mm

(b)

Fig. 3 X-ray topographs of bonded wafers without SiO_2 layers (a) and with SiO_2 layers (b)

Although no change occurs by 100C, as shown in Fig. 4(a) which is a section topograph at the temperature of 103 ± 1C, the small voids are generated. The diameter and number of these voids increase with the annealing periods as shown in Fig. 4(b). It is noted that the voids generate during heating up but not cooling down.

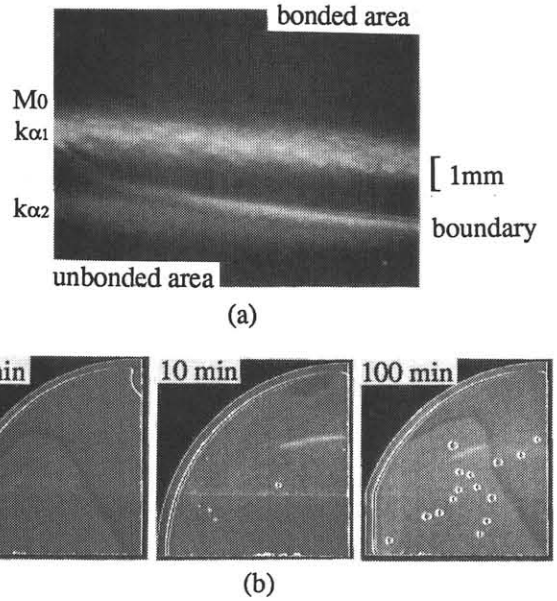


Fig. 4 *in situ* x-ray section topograph around 100C (a) x-ray topographs after cooling from 103 ± 1C (b)

3.2. Bonding strengths on the bonded structures

Table 1 shows the experimental results of bonding strength on the three kinds of interfaces. Although no significantly different results were observed at 1200C annealing due to the limitation of the upper strength of the adhesive, the most stable and strongest binding strength is obtained in the case of one oxide surface as considered here.The next strongest case is that of the bonding of two bare silicon surface but with some unstability and the worst case is for bonding two wafers with oxide coatings.

4. DISCUSSION

The reasons of void formation in the two bare silicon bonding wafers in the lower temperature range

ANNEALING TEMP.(C) in N_2	Si / BASE	SOI / BASE	SOI / BASE
800	UNSTABLE	WEAK	STABLE
1000	UNSTABLE	UNSTABLE	STABLE
1200	STABLE	STABLE	STABLE

Table 1 Bonding strengths of three kinds of interfaces depending on temperature

and the differences of bonding strengths depending on the bonding structures in the higher temperature range are described.

According to the results of the thermal desorption analysis[6], there are in large amount of H, OH and H_2O on the bare silicon surfaces and natural oxide, but very little on the thermal oxide surfaces. Figure 5 shows the schematic of the bonding interfaces based on the above informations.

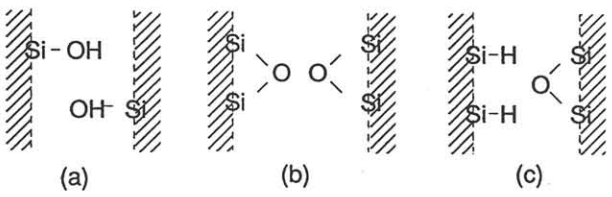


Fig. 5 Schematic of atomic configurations at bonding interfaces at low temperature (a) Si/Si. (b) SiO_2/SiO_2 and (b) Si/SiO_2 interface

In the two bare silicon interface, the strong hydrogen bonding takes place and excess OH and H_2O fill in hollows and dips as seen in Fig. 2.

These OH and H_2O are vaporized and as the result, voids made by water vapor are formed. Around 600C, according to the reaction,[7]

$$Si\text{-}OH + OH\text{-}Si \rightarrow H_2O + Si\text{-}O\text{-}Si$$

the dehydration is brought to stronger bonding, which maybe bring about the high contrast of x-ray topograph as seen in Fig. 3.

It is expected that in the case of one oxide surface the reason without voids is attributed to absorption of OH and H_2O into bulky oxide layers. In the lower temperature range, although relatively weak binding compared with the hydrogen bonding as seen in Fig. 5(c), the homogeneous binding is obtained due to void-free. Consequently, silicon and oxygen atoms can react easily each other and the most stable tight binding is obtainable at high temperature. Furthermore, as the extrinsic effects the oxide layer is expected to be able to deform to fit the grooves or hills and silicon atoms which are mobile[8] are also possible to planarize the uneven surfaces. On the other hand, in the case of the both side oxide coatings, two wafers are not closed enough for binding from the low temperature and this related in the weak or unstable binding.

SUMMARY

The perfections of bonded interfaces with the sandwich structure of a SiO_2 layer are studied by the x-ray diffraction topography and the tensile testing. The tensile strengths of this structure were compared with that for two bare silicon wafers and two wafers with oxide coatings. It is discussed that a proper amount of H, OH and H_2O on wafers play an important role on the chemical bonding under 800C and an interaction between adjacent atoms and the deformation of SiO_2 layer are effective for tight bonding over 1000C.

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