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홈구조 실리콘 접합 경계면에서의 Void 제거를 위한 실리콘 직접접합 방법

The Removal Of Voids In The Grooved Interfacial Region Of Silicon Structures Obtained With Direct Bonding Technique

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Abstract

Structures obtained with a direct bonding of two FZ silicon wafers joined in such a way that a smooth surface of one wafer was attached to the grooved surface of the other were studied. A square net of grooves was made with a conventional photo lithography process. After high temperature annealing the appearance of voids and the rearrangement of structural defects were observed with X-ray diffraction topography techniques. It was shown that the formation of void free grooved boundaries was feasible. In the cases when particulate contamination was prevented, the voids appeared in the grooved structures could be eliminated with annealing. Since it was found that the flattening was accompaniedwith plastic deformation, this deformation was suggested to be intensively involved in the process of void removal. A model was proposed explaining the interaction between the structural defects resulted in "a dissolution" of cavities. The described processes may occur in grooved as well as in smooth structures, but there are the former that allow to manage air traps and undesirable excess of dislocation density. Grooves can be paths for air leave. According to the established mechanisms, if not outgone, the dislocations form local defect arrangements at the grooves permitting the substantial reduction in defect density over the remainder of the interfacial area.

Key words: Gate-Commutated Thyristor(GCT), turn-off, diode, lifetime control

1. Introduction[1]

The formation of voids in structures fabricated with Silicon Direct Bonding (SDB) technique has been investigated in detail by many authors [1-4]. As a result, the voids or local lack of bonding have been categorized as extrinsic and intrinsic ones. The basic difference between them depends on how they behave during high temperature annealing. When the nature of extrinsic voids was established, a variety of tools allowing to cope with dust particles, contamination and surface roughness were reported. Among them the procedure of bringing the wafers into contact below a water surface was proposed by Parkes *et al.*[5] and Wilson [6]. As for roughness and damage, different types of commercially available silicon wafers were subjected to a careful examination with highly sensitive optic, X-ray and STM techniques. Though unflatness was finally detected as an unremovable feature of wafer surfaces [4], a continuous bonding was routinely achieved, except of one condition. It was shown

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that when contact waves were originated from two or more points simultaneously, air was trapped in pockets. Such an air pockets caused an unremovable lack of bonding at lower (100~800℃) as well as higher (1000℃) temperatures. In contrast to extrinsic voids whose nature was almost unanimously recognized, intrinsic ones were interpreted due to at least two different models. It was demonstrated that these voids could be completely eliminated with annealing, no matter what reason led to their formation, either interfacial water or hydrocarbon absorption [2- 3].

Though it was admitted that the mechanical properties of the interface (elastic and plastic deformation, mass-transfer phenomena, external pressure) were responsible for bonding strengthening [4], rebonding [7], bonding energy value [8] etc., they were not so thoroughly described as the chemical ones.

In this paper our attention is restricted by an observation of voids in the grooved structures. In order to prevent particulate contamination and to avoid surface roughness and damage all traditionally required conditions were more or less fulfilled. It could be seen that the origination and removal of air pockets in these structures depended on the role of grooves.

2. Experiments

Commercially available mirror-polished FZ silicon wafers of (111) orientation and 7.5~10Ωcm resistivity were used as a starting material. On the surface of one wafer of each pare a square net of grooves was prepared with a conventional photolithography technique. The grooved pattern was made as follows: 50µm width, 200µm space and 0.3-5µm depth (Fig. 1).

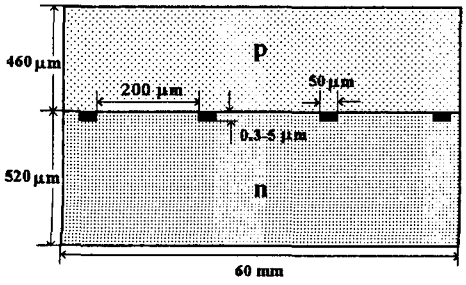

Fig. 1. The scheme of the bonded structure with a grooved interfacial region. When two-dimensionally displayed, the pattern looks like a square net of grooves

Before bonding the wafers were treated with a standard RCA cleaning [14] and rinsing in deionized (DI) water with 18MΩcm resistivity. An intimate contact between grooved and smooth surfaces was realized below a DI water surface, and face-to-face pairs were subjected to a subsequent spin drying. Dried pairs were kept in air at 95℃ under the pressure $0.1N/mm^2$ for 4h. High temperature annealing included two steps: 1000℃ (1h) and 1150℃ (2h).

Since the wafers were brought in contact in the water, their best crystallographic fit was scarcely attainable. The bonded structures thus contained two more or less rotationally misoriented wafers. Starting wafers were checked with a highly sensitive X-ray topographic technique [15] whose multi crystal arrangement included: (i) two perfect silicon crystals served as monochromators; they were cut in such a way that their angles of incidence for 111 reflections were not larger that 1°; when used in parallel setting, they allowed to obtain spatially spread but highly parallel X-ray beam; (ii) a studied crystal fixed in Bragg or Laue geometry; (iii) crystal-analyser used in Laue geometry. After bonding the structures were studied with Lang or Berg-Barrett-Newkirk technique.

3. X-ray topographic observation of voids in the grooved structures

Grooved bonding structures containing differently rotated wafers were studied after high temperature annealing. During the experiments continuous grooved surfaces were detected regularly. Thus it was confirmed that the formation of void free grooved boundaries was feasible and comparatively easily attainable. In those cases when the voids appeared in the studied structures, X-ray topographic observations allowed to conclude:

- Lack of bonding areas looked like circle- or wave-like outlined images wherein the reflections of smooth wafers a grooved pattern contrast has vanished;

- inside these areas local dislocation sources were observed (Fig. 2a);
- the sources possessed triangle or higher symmetry;
- after annealing the grooves acquired a specific contrast understandable as that of dislocation bundles at the grooves.

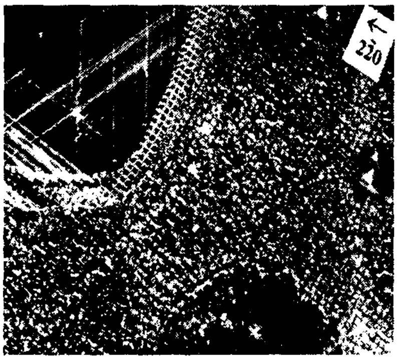

Fig. 2a. X-ray topograph showing macro-voids in the grooved structure. Dislocation sources are well seen

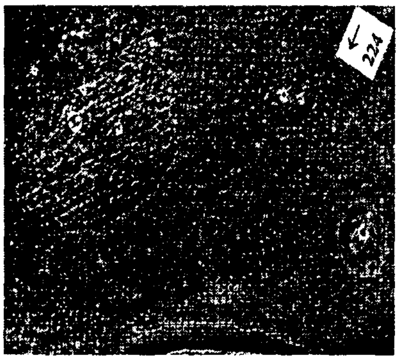

Fig. 2b. The topograph demonstrating the partial removal of the voids results due to the annealing at 1150℃, 2h.

When the structures were additionally annealed, the voids completely or partially eliminated. Large wave-like outlined areas were flattened only partially. In case of smoothen the contrast of local dislocation sources vanished, and the places of former void locations could be identified due to: (i) a weak contrast contour whose color corresponded to the local excess of dislocations (Fig. 2b); (ii) the outlined contour plus large amount of irregular distributed dislocations inside; (iii) the contour plus a small bubble showing the place where the local source had been producing the dislocations. Sometimes twice repeated additional annealing (1150℃, 2 h) resulted in the rearrangement of dislocations followed by the decrease in their mean density. The small voids had also disappeared. But in the other cases this process remained incomplete in the sense that a partially flatten void was "replaced" by a damaged area with residual discontacts and high density of crystalline defects.

4. Discussion and Summary

A model explaining void removal accompanied with plastic deformation and occurring at the grooved surfaces can be presented as follows. When two improper mating wafers lay on the top of each other, their weight plus atmospheric pressure are nonuniformly distributed over the interface. Each locally unbonded area can be presented as a sequence of contacts. During high temperature annealing these local contacts can act as indenters provoking origination of lattice dislocations. Fig. 3 schematically shows the place where the propagation of a contact wave failed. The indenter is depicted as a source, and an associated with this source defect arrangement includes: (i) prismatic loops; (ii) gliding dislocation loops; (iii) vacancies originated at the free surfaces. The other types of sources producing the same structural defects and not shown in Fig. 3 can be expected to locate inside the grooves. The admission for these latter sources to exist follows from the fact that the grooves are filled with air. Though it is hard to say whether the pressure of this air is sufficient or not, the plastic deformation under this pressure seems feasible. In such a case an unignorable slight roughness in the grooves may play the role of indenters.

Returning to the experimental observations it is worthwhile to note that, when compared with the obtained topographs, the diagram in Fig. 3 shows an agreement, but only partial. The experimentally observed local defect structures in the topographs are formed by gliding loops. Their symmetry is caused by an octahedral shape of set of possible glide planes which in a diamond structure are {111} ones. Observed triangle symmetry of local contacts corresponds to three inclined glide planes.

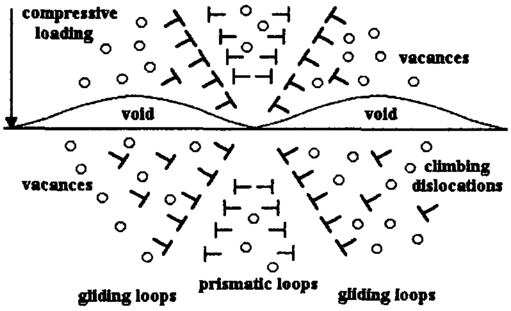

Fig. 3. The diagram showing a local lack of bonding. The structural defects appeared under nonuniformly disributed wafer weight are schematically presented.

All structural defects presented in Fig. 3 are involved in the process of void removal. The basic point of their interaction is a vacancy diffusion towards the regions compressed by dislocations. Achieving the dislocations, the vacancies are absorbed which leads to a dislocation climb.

We considered the directly bonded silicon structures whose interfacial region was observed to contain structural defects. Samples with grooved interfaces were studied, and it was confirmed that the formation of void free grooved boundaries was feasible. Nevertheless, when appeared, voids in grooved structures could be eliminated by annealing. A model was proposed which involved an intensive plastic deformation in the process of void removal. It was suggested that in the places where bonding failed, vacancies were able to originate at the free surfaces of voids. Bulk vacancy diffusion towards the dislocations facilitated their movement and a subsequent escape. This process of "dissolution" of cavities was occurring in the collaboration with a growing bonding intimacy which was presented as a mutual impression of the wafers under a compressive loading.

References

[1] R.Stengl, K.-Y.Ahn and U.Gsele, *Jpn. J. Appl. Phys.*, 27, L2364 (1988).

[2] T.Abe, T.Takei, A.Uchiyma, K.Yoshizawa and Y.Nakazato, *Jpn. J. Appl. Phys.*, 29, L2311 (1990).

[3] K.Mitani, V.Lehnmann, R.Stengl, D.Feijoo, U. Gsele and H.Z.Massoud, *Jpn. J. Appl. Phys.*, 30, 615 (1991).

[4] M.Horiuchi and S.Aoki, *J.Electrochem.Soc.*, 139, 2589 (1992).

[5] C.Parkes, E.Murray, H.S.Gamble, B.M.Armstrong,\ S.J.N.Mitchell and G.A.Armstrong, Ext.Abst. 1991\ Electrochem. Soc. Fall Mtg., Vol. 91-2, Phoenix, p.724 (1991).

[6] R.Wilson, H.S.Gamble and S.J.N.Mitchell, Ext.Abst. 1991 Electrochem. Soc. Fall Mtg., Vol. 91-2, Phoenix, p.742 (1991).

[7] R.Stengl, T.Tan and U.Gsele, *Jpn. J. Appl. Phys.*, 28, 1735 (1989).

[8] W.P.Maszara. G.Goetz, A.Caviglia and J.B.McKitterick, *J. Appl. Phys.*, 64, 4943 (1988).

[9] Q.-Y. Tong, H.-Z. Zhang and M.Quing, *Elect. Letters*, 27, 288 (1991).

[10] I.V.Grekhov, T.S.Argunova, M.Yu.Gutkin, L.S. Kostina and T.V.Kudryavtzeva, Collected Abst. 18-th International Conference on Defects in Semiconductors, Sendai, Japan, July 23-28, Abstr. No 402,(1995).

[11] E.D.Kim, N.K.Kim, S.C.Kim, I.V.Grekhov, T.S.Argunova, L.S.Kostina and T.V.Kudryavtzeva, *Elect. Letters*, Vol. 31, No. 23, pp. 2047-2049 (1995)

[12] E.D.Kim, S.C.Kim, J.M.Park, I.V.Grekhov, T.S.Argunova, L.S.Kostina and T.V. Kudryavtzeva, *J.Electrochem.Soc., Vol. 144, pp. 622-627 (1997)*

[13] T.S.Argunova, M.Yu.Gutkin, I.V.Grekhov, L.S. Kostina, T.V.Kudryavtzeva and E.D.Kim, *J. Appl. Phys., Vol. 37(12A) (1998)*

[14] W.Kern and D.A.Puotinen, *RCA Rev.*, 31, 187 (1970).

[15] V.N.Ingal and E.A.Beliaevskaya, *J. Phys. D: Appl. Phys.*, 28, 2314, (1995).