Evaluation of Mechanical Backside Damage of Silicon Wafer by Minority Carrier Recombination Lifetime and Photo-Acoustic Displacement Method

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Abstract

We investigated the effect of mechanical backside damage in Czochralski silicon wafer. The intensity of mechanical damage were evaluated by minority carrier recombination lifetime by a laser excitation/microwave reflection photoconductance decay method, photo-acoustic displacement method, X-ray section topography, and wet oxidation/preferential etch methods. The data indicate that the higher the mechanical damage intensity, the lower the minority carrier lifetime, and the photo-acoustic displacement values are also increased proportionally.

1. Introduction

It has been reported [1,2] that laser excitation / microwave reflection photoconductance decay (μ-PCD) method is a noncontact, nondestructive, and high throughput technique with higher sensitivity than secondary ion mass spectroscopy and total reflection X-ray fluorescence spectrometry in metal contamination monitoring point of view. Also it is commonly recognized that minority carrier lifetime measured by μ-PCD method is very sensitive to crystallographic defects which can act as trap centers.[3]

In silicon wafer industry, mechanical damage method, which provides dislocation and/or stacking fault nuclei [4,5] on wafer backside, is one of the extensively used extrinsic gettering techniques [6] since it is simple and less costly.

In this work, a systematic experimental investigation on the effect of mechanical backside damage in Czochralski (CZ) silicon wafers was executed using by minority carrier recombination lifetime by μ-PCD method, photo-acoustic displacement method (PAD), X-ray section topography, and wet oxidation/preferential etch methods.

2. Experimental

The starting materials in this study were p-type (boron-doped, 9-20 Ω · cm) CZ silicon wafers, with 200 mm diameter (100), single-side polished, and 725 ㎛ thick.

The oxygen concentration measured with Bio-RAD QS-300 FTIR according to the New ASTM procedure (ASTM F121-81 [7]) was 13.3 ~ 16.6 ppma, whereas the carbon level was less than 0.05 ppma which is lelow the detection limit of FTIR.

The wafers were heat treated at 700℃ for 10 min in N_2 ambient for oxygen donor annihilation [8] and each cleaved into quarter pieces. One piece from each wafer was not mechanically damaged. This piece is designated as reference to distinguish it from the second, the third and the fourth pieces, designated grade 1, grade 2, and grade 3, whose backsides were mechanically damaged with three kinds of grades as shown in table 1, respectively, using liquid honing method .

Table 1. Liquid honing process parameters

Parameter Grade	Air Pressure* (kgf/cm^2)	Conveyer Speed* (mm/sec)	No. of Nozzle*
1	1	12.3	1
2	4.3	12.3	1
3	5.7	10	2

(* : normalized value)

After liquid honing process, the samples were cleaned by RCA cleaning method and then subjected to surface passivation treatments, such as HF dipping for 10 min using high purity 49% HF chemical of semiconductor grade and dry oxidation at 1000℃ for 40 min (growth of about 400Å thick oxide layer), to minimize the surface recombination velocity for lifetime measurements. [9]

The minority carrier recombination lifetime for the samples were performed at room temperature with μ-PCD lifetime measurement system (SEMILAB WT-85X). The decay of excess minority carriers generated by irradiation with a pulsed laser beam (pulse width : 200 nsec, wavelength : 904 nm) impinged onto the polished surface is observed by monitoring the time decay of the microwave (10 GHz) reflection power since the conductivity decreases with the recombination of excited carriers and accordingly the microwave reflection power decays.

The stresses on as-received wafers caused by mechanical damage were evaluated by employing PAD method (PA 300 model) and X-ray topography system (Bede L6). In order to reveal the defects generated as a result of relieving the stresses caused by liquid honing method, the samples were oxidized at 1100℃ for 60 min in wet oxygen ambient and then inspected under the optical microscope after Wright etch [10] for 1 min.

3. Results and discussion

(1) Relationship between mechanical damage intensity and lifetime - Figs. 1 shows minority carrier recombination lifetime data measured with μ-PCD technique in nondamaged ("Reference") and backside mechanically damaged silicon wafers. These data clearly show that the higher the mechanical damage intensity, the lower the minority carrier lifetime. It is well known that the actual penetration depth of laser beam (904 nm wavelength) into silicon crystal bulk is less than 30 ㎛. [11]

However, as shown in Fig. 1 it is obvious that electrons and holes excited by laser beam are propagated up to wafer backside, consequently affecting the minority carrier recombination lifetime value. Judging from this, it is suggested that nondamaged wafers be used to obtain correct data for contamination and defect monitoring during device processing.

(2) Characterization of Stresses - To evaluate the stresses caused by liquid honing method, we have performed PAD and X-ray section topography analyses. Fig. 2 shows PAD values are increased proportionally by the mechanical damage intensity. This technique is based on the sensitive measurements of the surface displacement due to the absorption of laser-light energy. The PAD simply depends upon the ratio of the thermal expansion coefficient to the thermal conductivity (κ) for a homogeneous sample. κ is strongly dependent on the crystal structure. Since lattice defects cause κ to decrease, we expect PAD to increase with the amount and extent of defects present in materials. It is of course true that change in κ is determined by the total amount of defects within the range of interaction of the thermal wave. [12]

Fig. 3 displays the stresses revealed by X-ray section topography technique with (440) reflection and Mo Kα_1. The Pendellösung fringes indicate high perfection of CZ silicon wafers used for this study. These data clearly indicate that the stresses due to even Grade 1 of liquid honing method are propagated from mechanically damaged points on backside toward front surface to the extent of almost whole wafer thickness.

The defects generated during wet oxidation at 1100℃ for 60 min as a result of relieving the stresses caused by liquid honing method are as follows ; that is, Grade 1 is 2×10^5 ea/cm^2, Grade 2 is 4×10^6 ea/cm^2, Grade 3 is 6×10^6 ea/cm^2 each. Note that the harder the mechanical damage intensity, the higher the oxidation induced stacking fault (OISF) density. It can be deduced that OISF test method may be a useful way to distinguish mechanical damage grades.

4. Conclusion

The stresses caused by mechanical damage and their effects were evaluated by minority carrier recombination lifetime by laser excitation/microwave reflection photoconductance decay method and photo-acoustic displacement method, X-ray section topography, and wet oxidation/preferential etch methods. As we can see the Fig. 4, the results indicate that :

(1) The higher the mechanical damage intensity, the lower the minority carrier recombination lifetime, and

(2) The photo-acoustic displacement values are also increased proportionally.

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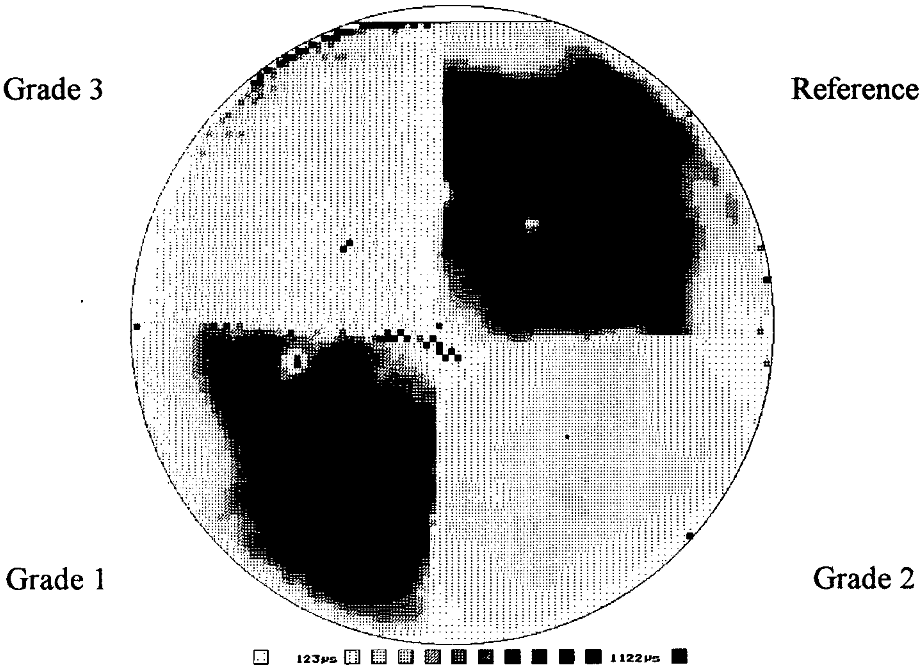
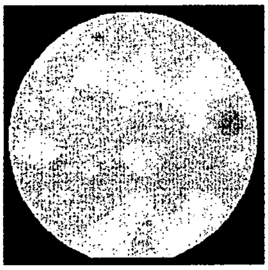
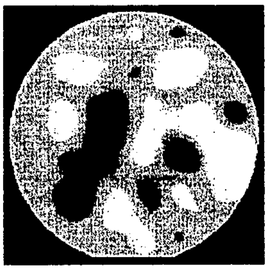


Reference	Grade 1	Grade 2	Grade 3
894.4	846	233.1	158.8

[μs]

Fig. 1. Lifetime Mapping and Average Values

			
Reference	**Grade 1**	**Grade 2**	**Grade 3**
118.0	**128.2**	**317.6**	**535.8**

[×0.1 pm]

Fig.2. PAD Mapping and Average values

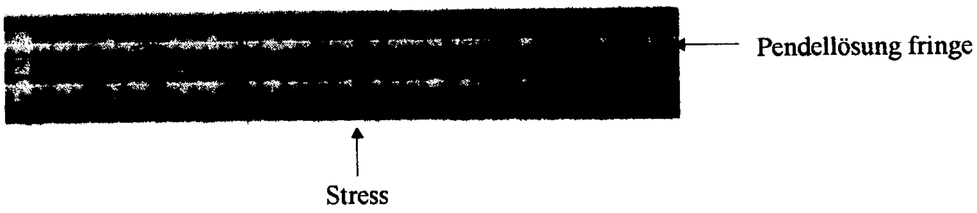


Fig. 3. The stresses revealed by X-ray section topograph [(440) reflection, Mo $K\alpha_1$]

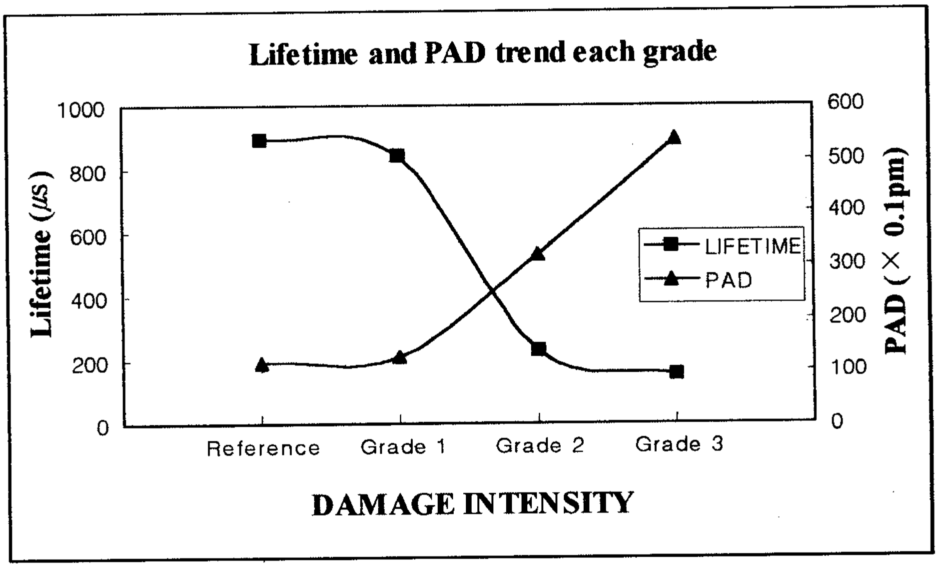


Fig. 4 Lifetime and PAD trend each grade