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기계적 손상에 의한 실리콘 웨이퍼의 반송자 수명과 표면 거칠기와의 관계

논 문
12-1-4

Relationships between Carrier Lifetime and Surface Roughness in Silicon Wafer by Mechanical Damage

최치영*, 조상희*
(Chi-Young Choi and Sang-Hee Cho)

Abstract

We investigated the effect of mechanical back side damage in viewpoint of electrical and surface morphological characteristics in Czochralski silicon wafer. The intensity of mechanical damage was evaluated by minority carrier recombination lifetime by laser excitation/microwave reflection photoconductance decay technique, atomic force microscope, optical microscope, wet oxidation/ preferential etching methods. The data indicate that the higher the mechanical damage degree, the lower the minority carrier lifetime, and surface roughness, damage depth and density of oxidation induced stacking fault increased proportionally.

Key Words(중요용어) : Mechanical damage(기계적 손상), Silicon wafer(실리콘 웨이퍼), Minority carrier recombination lifetime(소수 반송자 재결합 수명), Atomic force microscope(원자간 힘 현미경), Optical microscope(광학 현미경), Surface roughness(표면 거칠기), Damage depth(결함 깊이), Oxidation induced stacking fault(산화 유기 적층결함)

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 from the metal contamination monitoring point of view. Also it is commonly recognized that minority carrier lifetime measured by the μ-PCD technique is very sensitive to crystallographic defects which can act as trap centers.[3]

Conventional cross-sectional transmission electron microscopy (TEM) and scanning electron microscopy (SEM) have been usually used to evaluate nanometer order three-dimensional (3D) metrology. These methods, however, are destructive and they require a long sample preparation time. Recently, nanometer-scale material characterization has become necessary in silicon technology. Hence, various characterization techniques which allow nanometer-scale investigation have been developed. Scanning probe microscope (SPM) such as the scanning tunneling microscpoe (STM)[4], atomic force microscope (AFM)[5], and others, are some of the most powerful characterization techniques. In fact, AFM and STM are now extensively used for the evaluation of surface micro roughness of silicon wafers on an atomic scale with nanometer-scale lateral resolution.

This apparatus features (1) high resolution 2~3 Å in lateral, and 0.1 Å in vertical direction

* : 경북대학교 무기재료공학과
(대구 북구 산격동 1370, 702-701, Fax:053-950-5645
E-mail : j8860@chollian.net
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respectively; (2) three-dimensional observation in sample surface; (3) measurement of dielectric or semiconductor material as well as conducting material, and of diverse environment -air, liquid, vacuum etc.; (4) analysis of electrical, optic, physical characteristic of sample.[6] Surface roughness values ranges below 1 ㎛ up to several ㎚ order. Besides AFM, stylus, optical microscope, electron microscope etc. can be used as the measurement method of roughness. In case of exhibiting the roughness values quantitatively, root-mean-square roughness (Rrms), roughness average(Ra), and roughness peak to valley (Rp-v) are generally adopted as parameter.[7]

In silicon wafer industry, the mechanical damage method, which provides dislocation and/or stacking fault nuclei[8,9] on wafer back side, is one of the extensively used extrinsic gettering techniques[10] since it is simple and less costly.

We focused on analysis of mechanical damage degree in as-received wafer. In this work, electrical and surface morphological evaluations on the effect of mechanical damage on back side in Czochralski (CZ) silicon wafers were executed by μ-PCD technique, atomic force microscope, optical microscope, and wet oxidation/preferential etching methods.

2. Experimental

The starting materials in this study were p-type (boron-doped, 9-20 Ω · cm) CZ silicon wafers, with 200 mm diameters (100), single-side polished, and 725 ㎛ thick. The oxygen concentration measured with a Bio-RAD QS-300 FTIR according to the New ASTM procedure (ASTM F121-81)[11] was 13.3~16.6 ppma, whereas the carbon level was less than 0.05 ppma which is below the detection limit of FTIR.

The wafers were heat treated at 700℃ for 10 min in N_2 ambient for oxygen donor annihilation[12] and each cleaved into quarter pieces. One piece from each wafer was not mechanically damaged. It was designated as the "reference" to be distinguished from the second, the third and the fourth pieces, and the other three were also designated as grade 1, grade 2, and grade 3, whose back sides were mechanically damaged with three kinds of grades as shown in Table Ⅰ, respectively, by using liquid honing method (in Fig.1).

Table Ⅰ. Liquid honing process parameters.
표 Ⅰ. Liquid honing 공정 파라미터.

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)

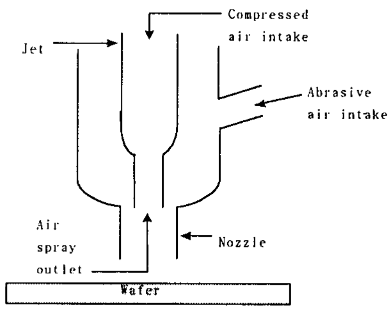


Fig. 1. Schematic of liquid honing method.
그림 1. Liquid honing 방법의 모식도.

After the liquid honing process, each of the samples was prepared for lifetime measurements through standard cleaning procedure and subjected to surface passivation treatments, such as HF dipping for 10 min by high purity 49% HF chemical of semiconductor grade, followed by dry oxidation at 1000 ℃ for 40 min (growth of about a 400 Å thick oxide layer) to minimize surface recombination velocity.[13] The laser excitation/microwave reflection photoconductance decay (μ-PCD) lifetime measurements for the samples were performed at room temperature using a WT-85 lifetime scanner system (SEMILAB). The silicon wafer was positioned on a wafer mounting stage driven by computer-controlled motors to provide the x-y mapping capability over the wafer surface. A pulsed laser diode with wavelength of 904 ㎚ and 200 ㎱ pulse width was applied for the excitation of the excess carriers. The light source was concentrated at a spot of ~1 mm^2. A microwave system operating at a frequency of 10.3 GHz was used for the detection of the conductivity decay curve from which the time constant (lifetime) of the recombination process could be calculated.

The surface roughness was also measured by using AFM (Autoprobe M5 : Park Scientific Instruments) in as-received wafer. Particularly, M5 system of contact mode was used to measure the damage depth and surface morphlogy. It takes not much time to measure with this method, and the method is brief and helpful to measure flat surface. We could obtain the surface morphology and surface roughness — R_{rms}, R_a, and $R_{p\text{-}v}$ with it. We also could measure the samples of reference, grade 1, 2, and 3 on the same conditions, that is, scan area, data point, scan rate, servo gain, and set point are 10 ×10 ㎛, 256×256 pixel, 1 line per sec, 1, and 10.8 nN respectively.

In order to reveal the defects generated as a result of relieving the stresses caused by the liquid honing method, the samples were oxidized at 1100℃ for 60 min in wet oxygen ambient, and then damage depth and surface density were inspected under the optical microscope after Wright etching[14] for 1 min.

3. Results and discussion

(1) Minority carrier recombination lifetime -

Figure 2(a) shows minority carrier recombination lifetime data measured by μ-PCD technique in nondamaged ("reference") and mechanically damaged back side of silicon wafers. Figure 2(b) clearly shows that the higher the mechanical damage degree, 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 ㎛.[15]

However, as shown in Fig. 2, it is obvious that electrons and holes excited by laser beam are propagated up to wafer back side, consequently affecting the minority carrier recombination lifetime value. Judging from this, we can suggest that nondamaged wafers be used to obtain correct data for contamination and defect monitoring during device processing.

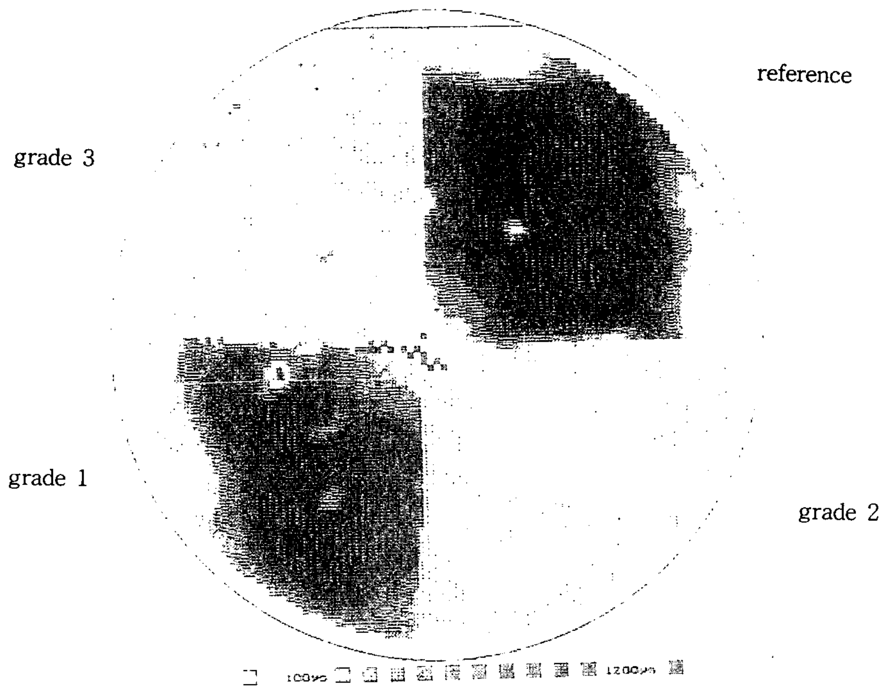
(2) Surface micro-roughness-

We have performed AFM to evaluate the surface roughness caused by the liquid honing method. Figures 3(a)-3(d) show the AFM image on the front side of the as-received samples for reference, grade 1, 2, and 3 with the stresses caused by liquid honing method. Although the imge of each samples is micronic area of 10×10 μm, it can be observed that the pit number increase as the damage degree increases. As the damage degree of grade 1 sample is softer than the grades 2 and 3 sample, the pit number of reference and grade 1 sample are nearly same as zero. Because the depth and the size of individual pit for the damage degree are generated randomly, the relationships between damage degree and pit depth, size could not be found. The roughness data in the selected area are estimated. They increased remarkably from reference to grade 3 sample, that is, from 2.1 to 31 Å in R_{rms}, 1.6 to 81 in R_a, 29 to 612 Å in $R_{p\text{-}v}$, respectively, and they are listed in Table Ⅱ. These roughness values of R_{rms}, R_a, and $R_{p\text{-}v}$ are correlated damage degree. Note that the harder the mechanical damage degree, the higher the roughness values. It can be deduced that surface roughness would be a useful way to distinguish mechanical damage degree.

(3) Damage depth and density of OSF-

To evaluate the damage depth and surface defect density caused by the liquid honing method, we have performed optical microscope, wet oxidation /preferential etching method. The samples were wet oxidized at 1100 ℃ for 60 min as a result of relieving the stresses caused by liquid honing method, and then HF dipping, Wright etching, and rinsing were followed in turn. Figures 4(a)-4(d) show the damage depth of oxidation induced stacking fault (OSF) on 11° 32′ bevel polished surface by optical microscope for reference, grade 1, 2, and 3. The data as follows; reference, grades 1, 2, and 3 are 0, 2.78, 2.82, 3.18 ㎛, respectively. As the mechanical damage degree increased, so did the damage depth.

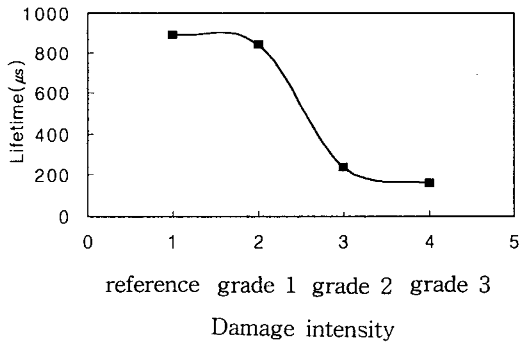
On the other hand, observing the surface of



reference	grade 1	grade 2	grade 3
894.4	846	233.1	158.8

[μs]

(a) Lifetime mapping data and average values



(b) Trend of average lifetime values

Fig. 2. Relationship between mechanical damage degree and minority carrier recombination lifetime measured by μ-PCD technique.
(a) Lifetime mapping data and average values and
(b) Trend of average lifetime values.

그림 2. μ-PCD 기술로 측정된 소수 반송자 재결합수명과 기계적인 손상 세기와의 상관관계.
(a) Lifetime 도해 데이타와 평균값 그리고
(b) 평균 lifetime값의 경향.

Table Ⅱ. Roughness values for reference, grade 1, 2, and 3 of as-received wafer.
표 Ⅱ. 받은 상태 웨이퍼에서의 reference, grade 1, 2, 3에 대한 거칠기 값.

sample	reference	grade 1	grade 2	grade 3
R_{rms}	2.1	2.2	15	31
R_a	1.6	1.6	3.5	8.1
R_{p-v}	29	67	832	612

[unit : Å]

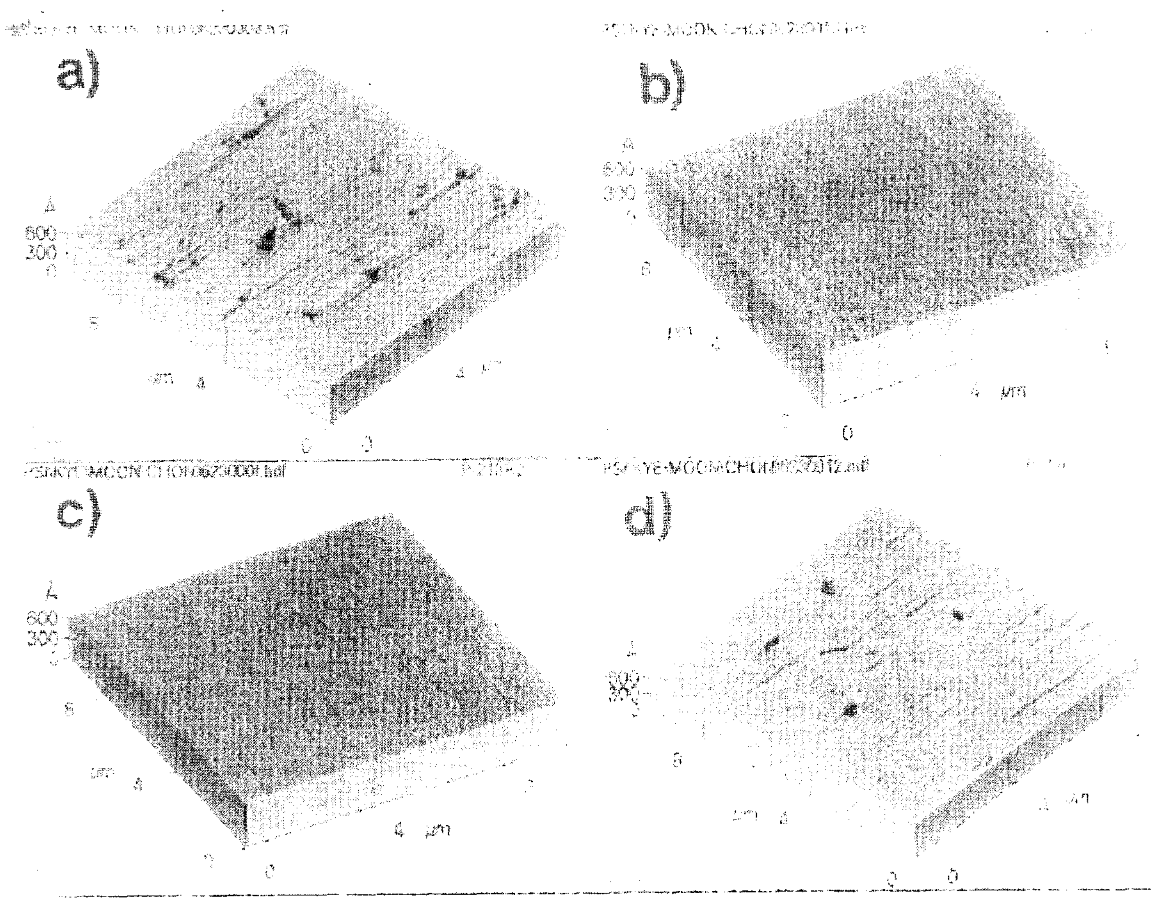


Fig. 3. AFM image for as-received wafer, (a) grade 3, (b) reference, (c) grade 1, and (d) grade 2.
그림 3. 받은 상태에서의 원자간 힘 현미경 영상, (a) grade 3, (b) reference, (c) grade 1, and (d) grade 2.

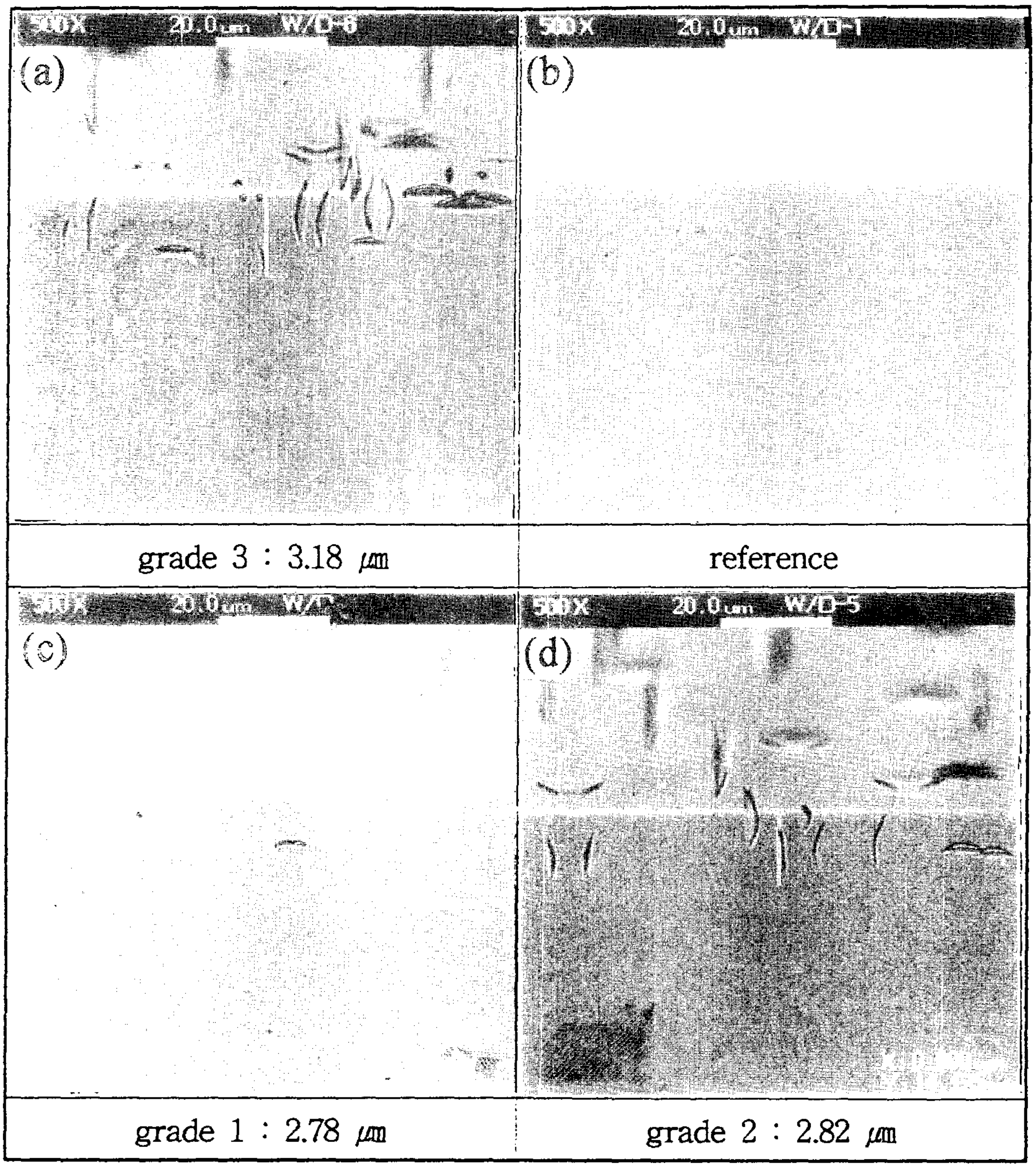


Fig. 4. Damage depth of OSF on 11° 32′ bevel polished surface, for the (a) grade 3, (b) reference, (c) grade 1, and (d) grade 2.

그림 4. 산화유기 적층결함의 11° 32′ 경사 연마 면에서의 결함 깊이, (a) grade 3, (b) reference, (c) grade 1, and (d) grade 2.

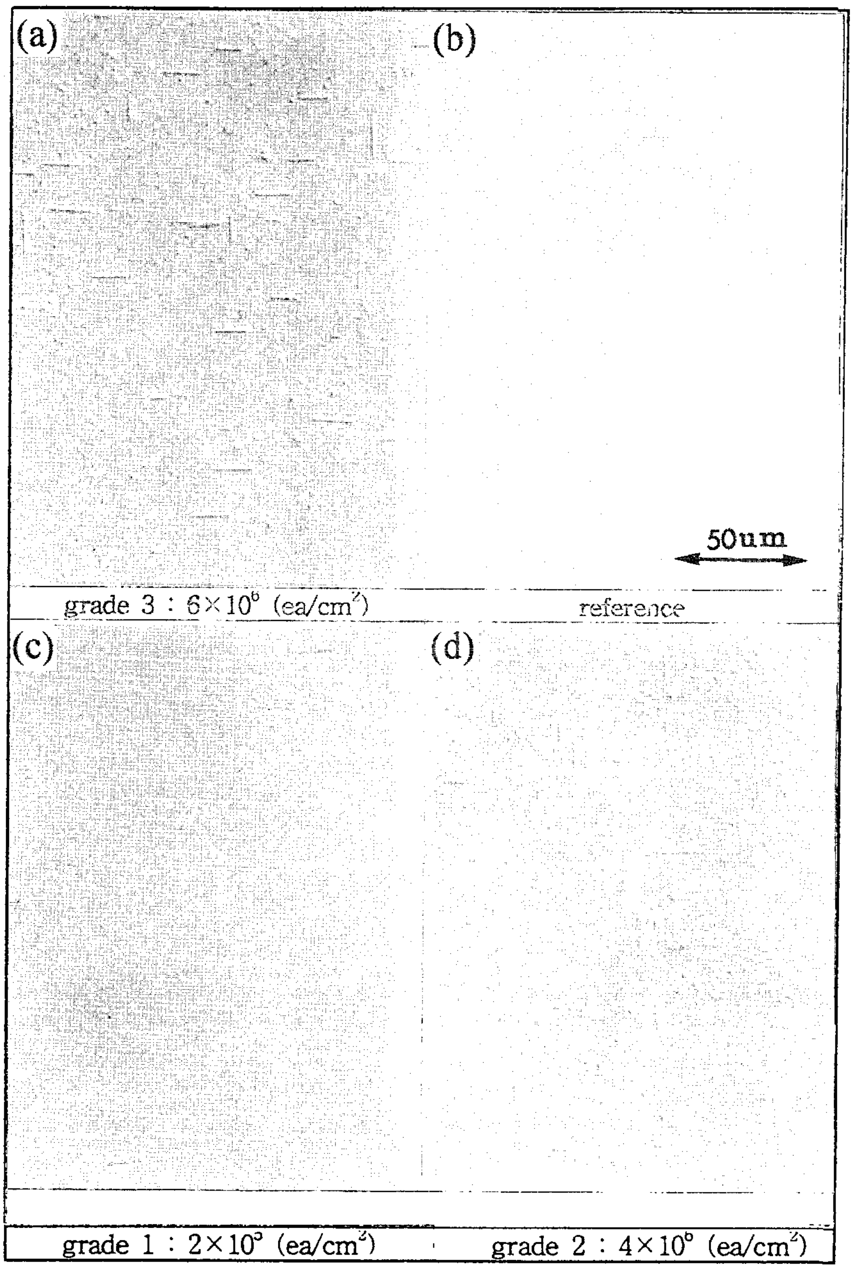


Fig. 5. Oxidation induced stacking faults for the (a) grade 3, (b) reference, (c) grade 1, and (d) grade 2 generated during wet oxidation at 1100℃ for 60 min.

그림 5. 1100℃에서 60 분간 습식 산화 과정시 발생된 (a) grade 3, (b) reference, (c) grade 1, and (d) grade 2에 대한 산화 유기 적층 결함.

samples, the OSF density are 2×10^5, 4×10^6, and 6×10^6 ea/cm^2 for the grades 1, 2, and 3, respectively. As the sample goes to a higher grade of damage, the OSF density increases.

The optical microscopy images of the sample surfaces are shown in Fig. 5. It can be concluded that damage depth and density would be a useful way to distinguish mechanical damage degree.

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(μ-PCD) technique, atomic force microscope(AFM), optical microscope, wet oxidation/preferential etching methods.
The results indicate that :
(1) The higher the mechanical damage degree, the lower the minority carrier recombination lifetime, as the lifetime of the reference sample is 894.4 μs and it decreased dramatically to 158.8 μs in grade 3.
(2) As the mechanical damage degree increased, the data increased remarkably from reference to grade 3 sample, that is, 2.1 to 31 Å in R_{rms}, 1.6 to 81 Å in R_a, 29 to 612 Å in R_{p-v}, respectively.
(3) The damage depth of 0, 2.78, 2.82, and 3.18 μm for reference, grades 1, 2, and 3 samples increased proportionally to mechanical damage degree.
(4) The difference in OSF density was clearly distinguishable by showing the higher OSF density of 0, 2×10^5, 4×10^6, and 6×10^6 ea/cm^2 as the mechanical damage degree goes higher from the reference to grades 1, 2, and 3.

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