Relationship between X-ray Intensity and Electric Bias on Al_2O_3 Surface during Low Energy Ga^+ Irradiation

Jiancun Rao*, Minghui Song, Renchao Che, Masaki Takeguchi and Kazuo Furuya

High Voltage Electron Microscopy Station, National Institute for Materials Science, Tsukuba 305-0003, Japan

Low-energy characteristic X-ray emission is detected during bombardment of positive low energy ions onto insulator materials. The phenomenon is considered to be related to surface charge-up. To study further the mechanism, the characteristic X-rays was studied during 30 keV Ga^+ ions bombardment onto Al_2O_3 monocrystalline specimens applied with a direct current (DC) bias in the present work. The applied DC voltage builds an electric field parallel to the surface of the specimen. The results show that the characteristic X-rays of O- $\text{K}\alpha$ and Al- $\text{K}\alpha$ increased with the increasing of the applied DC voltages.

(Received October 14, 2005; Accepted January 24, 2006; Published March 15, 2006)

Keywords: X-ray emission, insulator, direct current bias, ion irradiation

1. Introduction

Some insulating samples under ion beam bombardment show important charging effects: a large bremsstrahlung background in the X-ray spectra and enhancement of characteristic X-ray yields of component elements.¹⁻⁹⁾ When these insulating samples were bombarded by ion beams, such as protons and alpha particles, they produce a very large bremsstrahlung background in the X-ray spectra. Also, the yields of the X-ray lines of component elements are largely enhanced in comparison with those obtained from the same elemental concentrations in conductive samples or samples simultaneously neutralised by an electron gun. There is compelling evidence connecting the enhancement with the charging up of the samples and some researchers attributed the effect to accelerated electrons as the cause of the X-ray yield enhancement.

Recently, low energy characteristic X-ray emission is observed by our group under bombardment by positive slow ions onto insulating materials. However, the mechanism that leads to the charging of the samples, with consequent buildup of high potentials, is unknown. Theory or models concerning the charging and breakdown of insulating samples bombarded by ion beams are scarce. There is a study of the charging process by He^+ ion beams¹⁰⁾ and another¹¹⁾ relative to the charging by some keV electron bombardment and subsequent surface breakdown. It is considered that some ideas of that model can be applied to the charging up of insulators under proton bombardment. The evidence both from our previous work and from the reports was brought to confirm that the charging process is responsible for the X-ray yield enhancement in some insulating samples under slow ion bombardment. In the present work, the influence of electric field on the characteristic X-ray yield was studied. And it is concluded that DC bias has influence on low energy characteristic X-ray emission from insulator targets under ion bombardment.

2. Experimental

Pure Cu film was deposited as electrodes on one polished clean side of Al_2O_3 monocrystalline substrate with the normal of $(1\bar{1}02)$. The electrodes were 2.0 mm apart from each other. The substrate size is 7×3 mm (long $\times$ wide). The thickness of Al_2O_3 substrate is 0.2 mm while that of Cu electrode films of 2 μm . The DC voltage was applied to generate an electric field on the polished surface of Al_2O_3 monocrystalline substrate through the deposited Cu electrodes by a special specimen holder. The EDS spectra were detected by EX-94013JNU Ultra Nine 30 detector based on JED-2300 analysis system with energy resolution of 138 eV (JEOL Co., Japan). The collecting live-time was set as 1200 s. The EDS were collected from the center part of the Al_2O_3 area in the electric field built up by different DC bias (0, 100 and 200 V) under the ion bombardment in the vacuum of about 2×10^{-4} Pa at room temperature.

30 keV Ga^+ was used as the incident ion source. The ion current was measured as about 0.5 nA and beam size about 70 nm in diameter by a special Faraday cup.

Figure 1 gives the diagram of the sample and the circuit for measuring both the characteristic X-ray and sample current. The sample is normal to the incident ion beam.

3. Results and Discussion

Low energy characteristic X-ray emission is detected under bombardment of positive slow ions onto Al_2O_3 monocrystalline.

Figure 2 shows the relationship between low energy characteristic X-ray emission and electric field under low energy ion bombardment. The X-ray counts [Fig. 2(a)] and peak accumulation [Fig. 2(b)] of O- $\text{K}\alpha$ and Al- $\text{K}\alpha$ lines increase with the increasing of direct current voltages. Fig. 2(a) gives the EDS spectra in energy range from 0.1 to 2.0 keV from the Al_2O_3 specimens with different DC bias (0, 100 and 200 V) under 30 keV Ga^+ ion bombardment. The X-ray counts were normalized to $\times 10^9$ counts per Coulomb ions. Figure 2(b) gives the total counts of O- $\text{K}\alpha$ and Al- $\text{K}\alpha$ peaks, respectively, under different DC voltages. The peak accumulation was summed in the range from 0.40 to

*Corresponding author,
E-mail: jcr Rao@hit.edu.cn, RAO.Jiancun@nims.go.jp

Fig. 1 Top (a) and side (b) views of the sample and the circuit for measuring both the characteristic X-ray and sample current. The sample is normal to the incident ion beam. The sample was earthed and hung in the vacuum without any back support.

0.65 keV for O-K α and from 1.35 to 1.64 keV for Al-K α with background extracted. It shows clearly that the total counts increased as the increasing of the DC voltages applied to the surface of Al₂O₃ substrate under ion bombardment.

The X-ray emission from the insulating materials is related with electrical charge build-up and discharge on the surface due to the incident ions.¹⁻⁹ The applied DC bias has obvious effect on the X-ray emission. The possible mechanism can be understood as following. The applied DC bias built up an electric field on the surface of the bombarded insulator by low energy charged incident ions. On the other hand, charging-up took place on the surface of the samples. There is interaction to some extent between the surface charge-up and the built-up electric field, which consequently will enhance the yield of characteristic X-ray.

The interaction for ion bombarding on surface of bulk materials is dominated by the role of the potential energy carried by the incident ion beam toward the surface while the influence of the kinetic projectile energy remains much less important.¹⁻⁹ The interaction at and below the surface is quite different for metal and insulator surfaces because of comparably much lower electron density and higher electron binding energy of the latter. It is critical to note however, that the sample was earthed and hung in the vacuum without any back support.

This abnormal X-ray emission could obviously not be explained with the binary elastic collision mechanism, both from the target dependence and the value of transferable energy in the collision of low energy ion irradiation. It is also not probable to be considered as due to the quasi-molecule mechanism, which has been accepted as a model to explain X-ray emission during low energy heavy ions collisions,¹² considering that the X-ray could be induced from insulating samples but not from conducting ones.

X-ray may be directly stimulated by electrons. If all the

Fig. 2 Relationship between low energy characteristic X-ray emission and electric field under 30 keV Ga⁺ bombardment. The X-ray counts (a) and peak accumulation (b) of O-K α and Al-K α lines increase with the increasing of the applied direct current voltages. The peak accumulation was summed in the range from 0.10 to 0.65 keV for O-K α and from 1.35 to 1.64 keV for Al-K α with background extracted.

electrons are with the same energy, the influence of DC bias on O-K α and Al-K α should be the same. On the other hand, if the electrons have an energy distribution, low energy electron should be more influenced by DC bias, therefore low energy X-ray emission should be more influenced by DC bias. The present results imply that electrons have an energy distribution.

As mentioned above, the influence of electric field on the low energy characteristic X-ray yield is obvious though the DC bias used in the present work is not very high. Unfortunately, our experimental results are the indirect observation of this interaction process, and there are some factors affecting the surface charging. Much work remains to be done before a theoretical description of the interaction of slow ions bombarding on the insulator surface. To this goal, the experiment can be improved by the following aspects: collecting more data from different kinds of insulator, much higher DC bias and optimum detect parameters.

4. Summary

The electric field has evident influence on emission of low energy characteristic X-rays of constitute elements from the Al₂O₃ monocrystalline under bombardment of 30 keV Ga⁺ ions. The X-ray counts of O-K α and Al-K α peaks increase with the increasing of the applied direct current voltages.

REFERENCES

- 1) M. Peisach, A. E. Pillay and C. A. Pineda: Nucl. Instrum. Methods B **75** (1993) 14–16.
- 2) M. Peisach, C. A. Pineda, A. E. Pillay and K. A. Springhorn: Nucl. Instrum. Methods B **94** (1994) 540–544.
- 3) R. C. M. Mboweni, C. A. Pineda, M. Peisach and A. E. Pillay: Nucl. Instrum. Methods B **85** (1994) 138–141.
- 4) A. E. Pillay and M. Peisach: J. Radioan. Nucl. Chem. Lett. **188** (1994) 453–462.
- 5) H. Hamanaka, K. Hasegawa and K. Maeda: Nucl. Instrum. Methods B **109–110** (1996) 203–205.
- 6) J. Kawai, K. Maeda, N. Sakauchi and I. Konishi: Nucl. Instrum. Methods B **109–110** (1996) 206–208.
- 7) Z. Szoekfalvi-Nagy, I. Demeter, K. Hollos-Nagy and I. Kovacs: Nucl. Instrum. Methods B **109–110** (1996) 59–62.
- 8) A. P. Jesus, M. A. Reis and L. C. Alves: Nucl. Instrum. Methods B **136–138** (1998) 837–840.
- 9) A. P. Jesus, M. A. Reis and L. C. Alves: Nucl. Instrum. Methods B **161–163** (2000) 120–124.
- 10) J. D. Meyer and D. E. Arafah: Nucl. Instrum. Methods B **50** (1990) 109–113.
- 11) G. Blaise and C. Le Gressus: J. Appl. Phys. **69** (1991) 6334–6339.
- 12) U. Fano and W. Lichten: Phys. Rev. Lett. **14** (1962) 627–629.