의학물리. 제5권 2호 1994

Defect center of Li^+ ion implanted Al_2O_3

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Abstract

The thermoluminescence(TL) glow curves and the optical absorption of Al_2O_3 irradiated with γ-ray, electron, and Li^+ ion followed by electron irradiation have been investigated to determine the relation of TL peak to its defect type. The TL glow curve of Al_2O_3 irradiated with γ-ray shows TL peaks at 380 K, 415 K, and 475 K. The UV photobleached TL glow curve of Al_2O_3 irradiated with γ-ray shows that the 380 K and 475 K TL peaks completely disappear while the 415 K TL peak still exists. The electron beam induced TL glow curve of Al_2O_3 after Li^+ ion implantation shows that the TL peak at 440 K is enhanced by a factor of 2 over the TL intensity of unimplanted Al_2O_3, while the TL peak at 380 K evidently disappears The implanted Li^+ ions are assumed to form singly charged interstitial cations and then recombine with electron trapped in F centers to produce F^+ centers. The 380 K and 475 K TL peaks are proposed to be associated with F center, while the 415 K and 440 K TL peak are connected with F^+ center.

Introduction

A thermoluminescence (TL) of pure and impurity doped Al_2O_3 has been widely studied during the last several years[1, 2]. Rescently, the high dielectric strength of this material cause it to be used as an insulator and its high melting point and low atomic number make it a good candidate for the first wall of proposed fusion reactors. The electronic structure of Al_2O_3 is of interest because the material is used as a substrate in the fabrication of silicon on sapphire microelectric devices[3, 4]. Moreover, the sensitivity of impurity doped Al_2O_3 to ionizing radiation is many times higher than that of TLD-100, and there have been many studied on the effects of impurities and defects on the TL characteristics[5-7]. Defects have been studied by techniques[8] such as thermoluminescence, optical absorption, electron spin resonance (ESR), ionic thermocurrent (ITC), and so on.

Defects in the Al_2O_3 structure are produced in the growth process or by the bombardments of energetic particles. Defect type of Al_2O_3 have F, F^+, V, and V_{OH} center in general[9]. An F center is an oxygen vacancy with two electrons, and an F^+ center is an oxygen vacancy with one electron, a V center is an alumimum vacancy with three holes localized on adjacent oxygen ions, and a V_{OH} cener is a V center with an next OH. When an insulator or semiconductor is heated after being irradiated with some kind of radiation (X-ray, γ-ray, UV light, particle beam, and so on) at a low temperature, the irradiated sample emits thermally stimulated luminescence[10] which is related to the defects. Based on the chracteristics of TL, defect effects on the TL glow curve of Al_2O_3 can be investigated. In spite of extensive studies on the TL glow curve of $Al_2 O_3$ irradiated with various radiations, there have been very few studies on the TL characteristics of Al_2O_3 irradiated with γ-ray, electron, and alkaline metal ions.

In the present paper, TL glow curve, optical absorption, UV photobleaching from γ-ray irradiated Al_2O_3, and electron beam induced TL glow curve from alkaline metal ion implanted and unimplated Al_2O_3 are studied.

Experiment

A schematic diagram of the experimental equipment is given in Fig. 1. The chamber was specially designed and constructed in order to measure the TL and thermally stimulated electron emission (TSEE) following ion implantation and electron irradiation without destroying the good vacuum condition. The chamber was evacuated to $2x10^{-7}$ torr by an oil diffusion pump with a LN_2 trap, and quartz window was attached to irradiate X-ray or UV light and to detect TL with a photomuliplier (PM) tube.

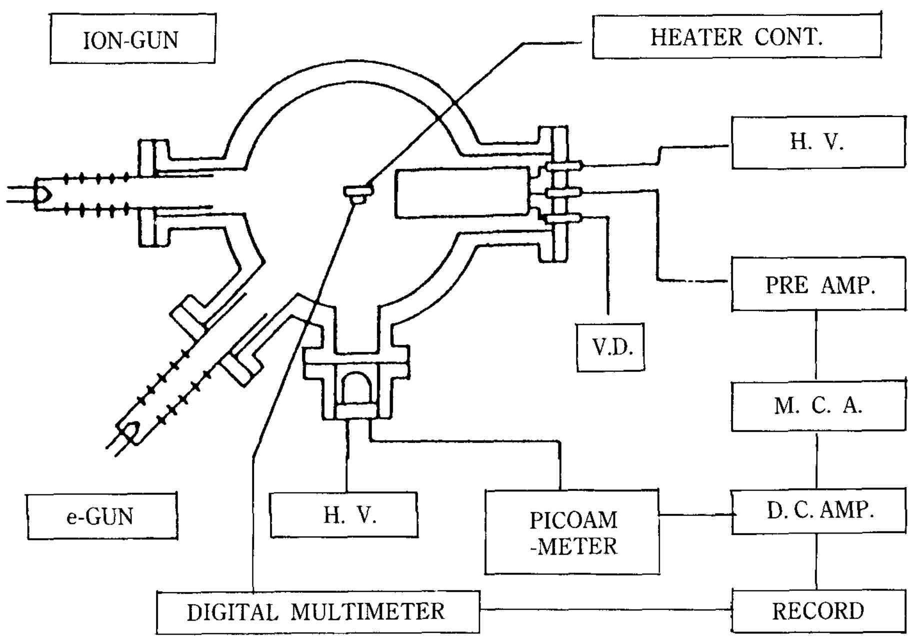

Fig 1. Schematic diagram of the experimental apparatus for measuring TL and TSEE.

The diameter of Al_2O_3 (ESPI, K−277) was 10 mm and thickness was 1mm. Before irradiation γ-ray, UV light, electron, and alkaline metal ion, the Al_2O_3 were annealed at 800 ℃ for 1 hour in order to drive out trapped carriers already existing inside Al_2O_3. Implantation of alkaline metal ions into Al_2O_3 were carried out with a small accelerator having magnetic mass analyser. The Li^+ ion source was the thermionic emission type, and the β-eucryptite[11] was used as a source material for Li^+, which was synthesized by heating stoichiometric composition of Li_2CO_3, SiO_2, and $2Al_2O_3$. The diameter of the Li^+ ion beam was controlled by varying the voltage on the electrostatic quadrupole lens and ion beam was swept so as to implant ions onto the whole surface of the sample. The Li^+ current density is o.5 $\mu A\ cm^{-2}$ during implantation. The electron gun was also designed and constructed for this study. The diameter of the electron beam could be controlled by varying the voltage on the einzel lens. The dose of electron irradiation was equal to that of Li^+ ions implanted into Al_2O_3.

γ-ray and UV irradiation, Li^+ ion implantation and electron irradiation were performed at room temperature. TL was detected by a PM tube (Hamamatsu, R955) mounted at the observation window. The anode current from the PM tube was measured with an electrometer (Takeda Riken, TR−8651) and displayed on the Y axis of an X−Y recorder (Yokogawa, 3077). The temperature of Al_2O_3 was measured with a copper-constantan thermocouple attached to the Al_2O_3 surface. The electromotive force (EMF) form thermocouple was connected to the X−axis of X−Y recorder through a digital multimeter (Fluke, 8842A). Irradiation of γ-ray was performed using ^{60}Co gamma ray unit (Picker, C-9) at a dose rate of 0.028 Gy s^{-1}. Optical absorption measurements were carried out with a spectrophotometer (Shimatsu UV−240), and UV irradiation was provided by a mercury lamp.

Result and Discussion

A TL glow curve form γ-ray irradiated Al_2O_3 heated at a rate of 0.1 K s^{-1} is shown in Fig. 2. The TL glow curve have a prominent peak at 380 K and two peaks located at 415 K and 475 K. Kawamura and Royce[12] obtained the 380 K and 440 K TL peak in thermally stimulated current (TSC) from X-ray irradiated Al_2O_3 and suggested that the defect center associated with 380 K and 440 K TL peak were V center and electron trap, respectively. Cooke et al.[13] suggested that the TL glow peak at 440 K was attributed to the thermal annealing of V^{-}_{OH} center and Fullerton and Moran[14] reported that the defect center attributed to the 440 K TL peak had a large capture cross-section for electron similar to the F^+ center. Thus the defect centers contributed to the TL glow peaks at 380 K and 440 K were differently suggested according to researchers. But overwhelming evidence had shown that F, F^+, and V center exist in Al_2O_3 and that the F and F^+ centers are responsible for the electron traps[9]. The optical absorption bands at 6.1 eV and 4.4 eV had been found to be associated with F and F^+ center, respectively[15]. We observed the optical absorption bands in pure, γ-ray irradiated, and electron irradiated Al_2O_3. The solid curve in Fig. 3 shows the optical absorption spectrum of pure Al_2O_3 measured at room temperature. The pure Al_2O_3 have only 6.1 eV absorption band, which means that Al_2O_3 used in this study have already F centers. The dash-dotted curve in Fig. 3 shows the optical absorption of Al_2O_3 irradiated with γ-ray. The optical absorption is abruptly increased at 6.1 eV band and the TL glow curve of γ-ray irradiated Al_2O_3 have a prominent TL glow peak at 380 K as shown in Fig. 2, which means that the 380 K TL peak is related to the 6.1 eV band. We suggest that the γ-ray irradiated Al_2O_3 have mainly F center and the 380 K TL peak is associated with F center. The dotted curve in Fig. 2 shows the photobleached TL glow curve of Al_2O_3 resulting form γ-ray irradiation followed by UV light for 10 minutes. Fig. 2 shows that the 380 K and 475 K TL peak completely disappear and the 415 K TL peak do not vanish even though its intensity is significantly reduced. Therefore we suggest that the 380 K and 475 K TL peak, which are faded away by UV photobleaching, are associated with F center and the remaining 415 K TL peak is connected with F^+ center.

The electron beam excited TL glow curve of Al_2O_3 after Li^+ ion implantation were studied to reconfirm the relations of the TL glow peaks to its defect type besides the optical absorption and UV photobleaching. The dotted curve in Fig. 3 shows the optical absorption of 1 keV electron irradiated Al_2O_3 with a dose of $8x10^{14}$ cm^{-2}. This spectrum shows a peak at 6.1 eV band, which means that electron irradiated Al_2O_3 have also F center. Lee and Crawford[16] studied the F center in Al_2O_3 and found that F center can be converted to F^+ center ; that is, the thermally released holes recombine with F center and produce F^+ center. We assume that the F centers convert to F^+ centers due to ionization during electron irradiation and the F^+ centers are converted into the excited F centers by combination of the thermally released electron during TL measurements. This excited defect centers produce a TL glow peaks. The TL glow curve from the 1 keV electron irradiated Al_2O_3 with the dose of $8x10^{14}$ cm^{-2} is shown as the solid curve in Fig. 4. The TL glow peaks occur at 440 K and three shoulders at 380 K, 415 K, and 460 K.

In order to study a defect centers contributed with TL glow peaks, the electron beam induced TL glow curve of Al_2O_3 after Li^+ ion implantation were performed. We suggest that Li^+ ion will produce singly charged interstitial cations and then recombine with F centers like holes to produce F^+ centers. Therefore the TL peak associated with F centers would disappear, while the TL peak associated with F^+ centers would be enhanced. The dotted curve in Fig. 4 shows the TL glow curve from Al_2O_3 resulting from 5 keV Li^+ ion implantation with a dose of $8x10^{14}$ cm^{-2} followed by 1 keV electron irradiation with same dose of Li^+ ion, which shows only the TL glow peak at 440 K. The TL peak at 440 K is enhanced by a factor of 2 over the TL intensity of unimplanted sample, while the TL peak at 380 K evidently disappears in the TL curve after Li^+ ion implantation. From the optical absorption of electron irradiated Al_2O_3 and the electron beam excited TL glow curves of Al_2O_3 after Li^+ ion implantation, we propose that the 380 K TL peak is found to be associated with F center and the 440 K TL peak to be connected with F^{+} center.

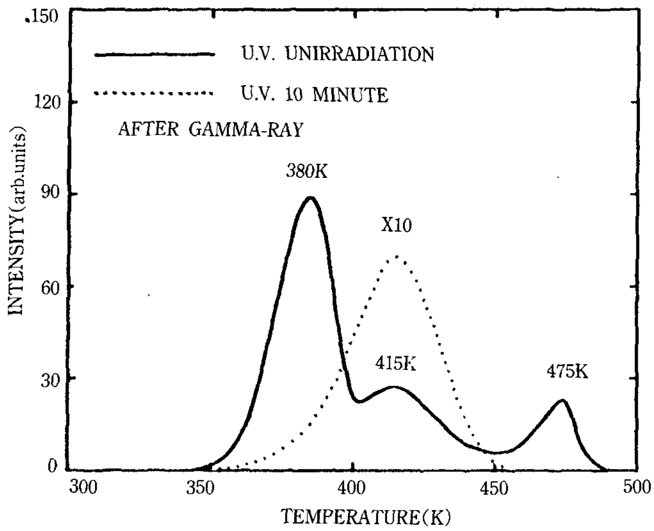

Fig 2. Solid line shows the TL glow curve from ^{60}Co gamma ray with 100 Gy irradiated Al_2O_3 heated at a rate 0.1 K s^{-1} and have a prominent peak at 380 K and two peaks at 415 K and 475 K. Dot curve is photobleached TL glow curve of Al_2O_3 resulting from gamma ray irradiation followed by UV light for 10 minute, and shows that the 380 K and 475 K TL peak completely disappear and the 415 K TL peak do not vanish even though its intensity is reduced.

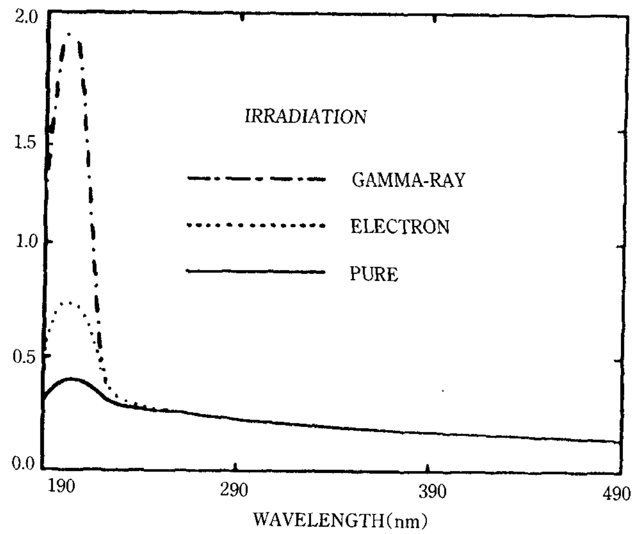

Fig 3. The dash-dotted curve is the optical absorption spectra from Al_2O_3 irradiated with 100 Gy of ^{60}Co gamma ray and the curve is abruptly increased at 6.1 eV band. The solid and dot curve are pure and 1 keV electron with 8×10^{14} cm^{-2} irradiated Al_2O_3, repectively.

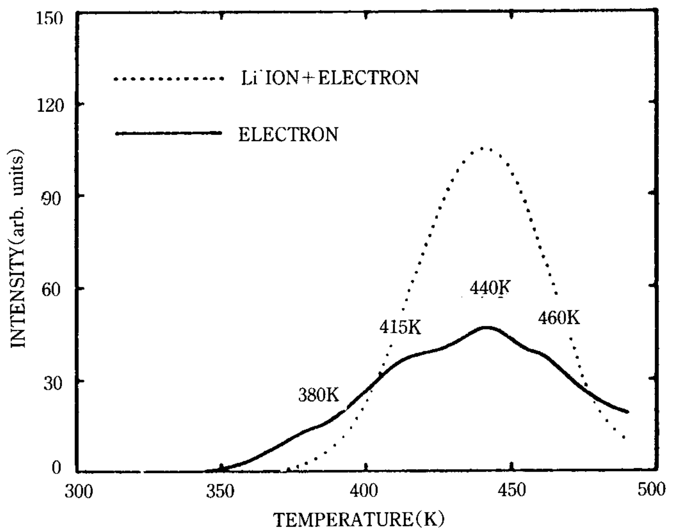

Fig 4. The TL glow curve of Al_2O_3 irradiated with 1 keV electron with a dose of $8x10^{14}$ cm^{-2} is shown as solid curve. The dot curve is the TL glow curve of Al_2O_3 resulting from 4 keV Li^{+} ion implantation with a dose of $8x10^{14}$ cm^{-2} followed by 1 keV electron irradiation with same dose of Li^{+} ion. The TL peak at 440 K is enhanced by a factor of 2 over the TL intensity of unimplanted sample, while the TL peak at 380 K evidently disappears.

Conclusion

The TL glow curve, optical absorption, UV photobleaching from γ-ray irradiated Al_2O_3, and electron beam induced TL glow curve from alkaline metal ion implanted and unimplated Al_2O_3 have been studied.

The TL glow curve of Al_2O_3 irradiated with γ-ray have a prominent peak at 380 K and two peaks at 415 K and 475 K. The optical absorption of Al_2O_3 irradiated with γ-ray is abruptly increased at 6.1 eV band which is associated with F center. The photobleached TL glow curve of Al_2O_3 resulting from γ-ray irradiation followed by UV light shows that the 380 K and 475 K TL peaks completely disappear and the 415 K TL peak is in existence. The 380 K and 475 K TL peaks are suggested to be associated with F center, while the 415 K TL peak connected with F^{+} center.

The electron beam induced TL glow curve of Al_2O_3 after Li^{+} ion implantation have been investigated to reconfirm the relation of the TL glow peak to its defect type. It has been found that the TL peak at 440 K is enhanced by a factor of 2 over the TL intensity of unimplanted sample, while the TL peak at 380 K evidently disappears in the TL curve after Li^{+} ion implantation. Li^{+} ions are assumed to form singly charged interstitial cations during or after implantation and then recombine with electron trapped in F centers to produce F^{+} centers. The disappeared 380 K TL peak is assumed to be associated with F centers which has a large electron capture cross-section and the enhanced 440 K TL peak to be associated with F^{+} center.

From the unphotobleached and photobleached TL glow curves of Al_2O_3 resulting from γ-ray irradiation followed by UV light, and the electron beam excited TL glow curves of Li^+ ion unimplanted and implanted Al_2O_3, the 380 K and 475 K TL peak are proposed to be associated with F centers, while the 415 K and 440 K TL peak to be associated with F^+ centers. More work is necessary tȯ separate the complicated TL glow curve to determine the relation of the 460 K TL peak to its defect type.

Acknowlegement

This paper was supported by NON DIRECTED RESEARCH FUND, Korea Research Foundation, 1993.

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Li^+ 이온 주입된 Al_2O_3의 결함 특성

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초 록

본 연구에서는 감마선 조사, 전자선 조사방법에 의한 전자만의 주입 및 이온 주입 후 전자선 조사 방법으로 전자들이 주입된 α-Al_2O_3의 열자극 발광(Thermoluminescence : TL)에 관련된 결함 형태를 조사하였다. 감마선 조사된 α-Al_2O_3의 열자극 발광 곡선은 380K, 415K, 440K, 460K 및 475K에서 TL peak가 나타났다. 광흡수 스펙트럼과 자외선 photobleaching 결과로부터 감마선 조사된 α-Al_2O_3의 380K와 475K TL peak는 F center에, 415K TL peak는 F^+center에 기인함을 알았다. 전자선 조사방법에 의하여 전자 주입된 α-Al_2O_3의 열자극 발광 곡선은 380K, 415K, 440K 및 460K TL peak를 가졌고, Li^+ 이온 주입 후 전자선 조사방법으로 전자들이 주입된 α-Al_2O_3는 440K에서 TL peak가 나타났다. 전자선 조사방법에 의한 전자만의 주입과 Li^+ 이온 주입 후 전자선 조사방법으로 전자들이 주입된 α-Al_2O_3의 열자극 발광 특성은 380K TL peak는 F center에, 440K TL peak는 F^+ center에 기인함을 보였다.