X-ray Generation Using Pyroelectric Crystals under UV Laser Irradiation

Hidenori Mimura [1,2], Tomoaki Masuzawa [1], Yoichiro Neo[1] Akifumi Koike[2] and Toru Aoki[1, 2]

mimura.hidenori@shizuoka.ac.jp
[1]Research Institute of Electronics, Shizuoka University, 3-5-1 Johoku Naka-ku, Hamamatsu, 432-8011
[2] ANSeen Inc. 3-1-7 Wajiyama Naka-ku Hamamatsu, 432-8003
Keywords: X-ray generation, pyroelectric crystal, UV laser, $LiNbO_3$

ABSTRACT

X-rays are generated by pulse UV laser (with a wavelength of 266 nm) irradiation on a $LiNbO_3$ crystal. The electrons produced from the $LiNbO_3$ crystal collide with a Cu target in vacuum, generating X-ray. The X-ray source requires no external voltage and no remarkable rise in temperature of the $LiNbO_3$ crystal is observed. When the pulse laser was turned off, the X-ray generation immediately stopped. The novel X-ray generation method offers safer radiotherapy than a conventional X-ray source with an external high voltage.

1 Introduction

Pyroelectric crystals such as lithium niobate ($LiNbO_3$) and lithium tantalite ($LiTaO_3$) have spontaneous polarization which varies with temperature. The surface polarization charge of the crystal is usually screened by the free charges that accumulate on the surface at equilibrium. The change in polarization of the crystal due to the temperature change generates a high electric field, resulting in emitting energetic electrons without external voltage when the crystals are heated or cooled. X-ray sources have been reported as applications of the electron emission from pyroelectric crystals [1-4]. One of the X-ray sources using a pyroelectric crystal excited by a Peltier device is commercialized. The use of a Peltier device, however, has problems. It requires an electric wire, and the response is slow due to its heat capacity, thus downsizing is difficult. To remove a Peltier device, Nakahama et al. irradiated a contentious infrared laser (CW Nd:YLF) on the graphite layer coated on the crystal [5]. However, in X-ray sources using an IR laser, the response is also slow, because it takes a time that the temperature of the crystal rises up. In this paper, we excited a $LiNbO_3$ crystal with pulse UV laser light (the wavelength of 266 nm) in the vacuum.

2 Experiments

Figure1 shows the experimental setup of the X-ray source using pyroelectric crystals under UV laser irradiation. We used a Nd:YAG laser operating at a wave length of 266 nm, a repetition rate of 10 Hz, a power of 400 mW, a pulse width of 10 ns and a beam diameter of 5 mm. The absorption coefficient of $LiNbO_3$ at 266 nm is of the 10^4 cm^{-1} order. We used a cylindrical $LiNbO_3$ pyroelectric crystal with a thickness of 4 mm and a diameter of 10 mm. A quartz glass of 2.3 mm in thickness was attached to the UV laser irradiation side of the pyroelectric crystal to reduce the laser irradiation damage on the pyroelectric crystal, and a stainless-steel tube was attached to the opposite side of the quartz glass. The target metal was a Cu film of 10 μm in thickness and a polyimide film of 75 μm in thickness was bonded to the Cu target on the atmosphere side. The gap distance between the crystal surface and Cu target was 6 mm. The pressure inside the vacuum chamber was set to 0.3 Pa. Temporal changes in X-ray count was measured by a GM counter tube, and an X-ray energy spectrum and a dose rate were measured by an EMF123 X-Ray spectrometer and an EMF521 electrometer, respectively. They were set at a position about 5 mm from the polyimide film. We also measured the current flowing in the Cu target and the temperature of the $LiNbO_3$ crystal with a thermocouple.

3 Results and Discussions

Figure 2 shows the X-ray spectrum generated by using a Cu target and a $LiNbO_3$ crystal excited by a pulse UV laser. The energy spectrum shows the Kα (8.0 keV) and Kβ (8.9 keV) characteristic X-ray peaks attributed to a Cu metal, and the bremsstrahlung X-rays can be observed in the higher energies up to 30 keV. This indicates that the electrons emitted from the $LiNbO_3$ crystal collide with the Cu target during the laser irradiation and that X-ray is generated from the Cu target.

Figure 3 shows the temporal response of the X-ray generation excited by 266 nm UV light. (a) and (b) indicate a dose rate and a total dose, respectively. When the laser is irradiated, X-ray generates and dose rate gradually increases. The maximum dose rate of about 3 mG/minute was obtained and total dose of 2mGy was obtained for 130 seconds. The X-ray generation increased at first and then gradually decreased even though the $LiNbO_3$ crystal was still excited by the pulse UV laser. This means that electron supply on the $LiNbO_3$ surface is slower than the electron emission from the $LiNbO_3$ surface.

Figure 4 shows the temporal change in temperature of the $LiNbO_3$ crystal during a pulse UV laser irradiation.

For pulse UV laser irradiation of about 9 min., the increase in temperature from room temperature was 4.3 K. To induce the emission of electrons from a $LiNbO_3$ crystal to generate X-rays, it is usually necessary to heat the $LiNbO_3$ crystal.[1-4] However, the rise in temperature of the $LiNbO_3$ crystal surface was not high in the X-ray generation by the UV laser irradiation, indicating that the X-ray generation by the UV laser irradiation on the $LiNbO_3$ crystal is safe for electronic brachytherapy.

4 Conclusions

We have successfully generated X-ray by irradiating a pulse UV laser (the wavelength of 266 nm) on a $LiNbO_3$ crystal. The X-ray spectrum indicates that the electrons are emitted from the $LiNbO_3$ crystal during the laser irradiation and that X-ray is generated by collision of the electrons with the Cu target in vacuum. The maximum dose rate was about 3 mGy/min. The X-ray source is a compact and does not require any external voltage. Temperature of the LiNbO3 crystal does not rise in during UV laser irradiation. This phenomenon might be novel one in X-ray generation using pyroelectric crystals.

References

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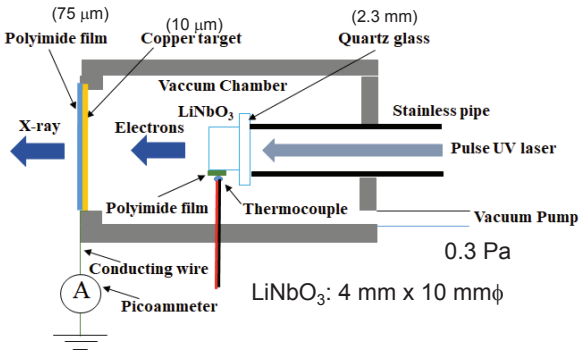

Fig. 1 Experimental setup of the X-ray source

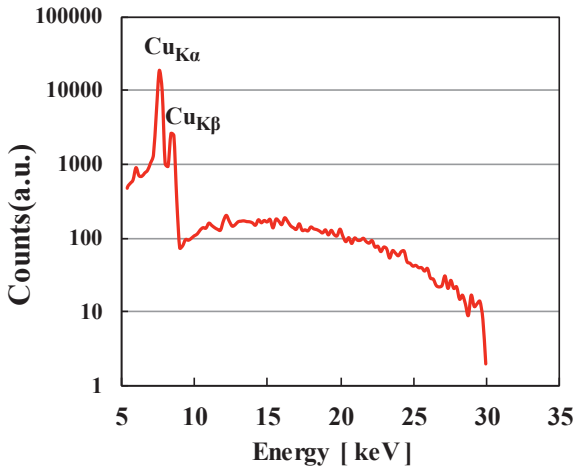

Fig. 2 X-ray spectrum generated by using a Cu target and a $LiNbO_3$ crystal excited by a pulse UV laser.

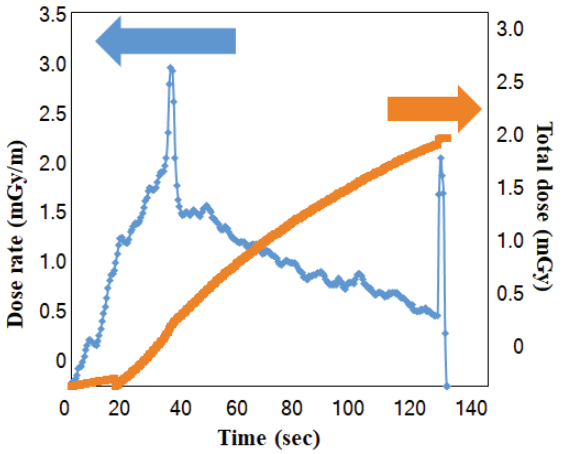

Fig. 3 Temporal response of the X-ray generation excited by 266 nm UV light. (a) and (b) indicate a dose rate and a total dose, respectively.

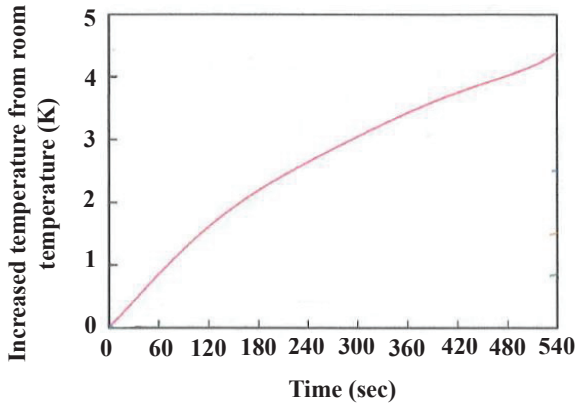

Fig. 4 Temporal change in temperature of the $LiNbO_3$ crystal during pulse UV laser irradiation.