INVESTIGATION OF X-RAY EMISSION FROM PYROELECTRIC CRYSTAL

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ABSTRACT
Time dependence of X-ray emission from a pyroelectric crystal (LiTaO₃) was measured with a digital oscilloscope used as a DSP (digital signal processor). At the same time, we examined an electron irradiation area using a fluorescent plate. When the cooling rate of a LiTaO₃ crystal was over 0.3 K/s, X-ray emission continued for less than 15 seconds. X-ray emission stopped by a discharge between the surface of LiTaO₃ and an electron target. On the other hand, when the cooling rate was below 0.3 K/s, X-ray emission continued for over 220 seconds.

INTRODUCTION
When the surface of a pyroelectric crystal such as lithium tantalate (LiTaO₃) or lithium niobate (LiNbO₃) is charged by changing its temperature under vacuum conditions, an electric field is produced. Brownridge (1992) first invented a pyroelectric X-ray generator using a cesium nitrate (CsNO₃) single crystal. Currently, Amptek Inc. has commercialized a portable X-ray generator using a pyroelectric crystal. The pyroelectric crystal technology has also been applied to other apparatus such as electron and ion beams (Rosenblum et al., 1974; Brownridge and Shafroth, 2001), as an ion source for mass spectrometry (Neidholdt and Beauchamp, 2007), and an electron source for an electron probe X-ray microanalyzer (EPMA) (Imashuku et al., 2011). X-ray emission using a pyroelectric crystal is, however, unstable. Yamaoka et al. (2012) revealed that X-rays from a pyroelectric crystal were emitted by two different processes; an electric discharge around z-plane of a pyroelectric crystal and bombardment of suspended electrons on a target material. We also confirmed these processes (Ohira et al., 2014). In the present study, we investigated these two processes by examining the time dependence of emitted X-ray intensity with change of crystal temperature using a Geiger-Müller counter and digital oscilloscope as a digital signal processor (DSP). At the same time, we examined the electron irradiation area using a fluorescent plate.

EXPERIMENTAL
The apparatus in the present study is shown in Figure 1. A single crystal of LiTaO₃ was used as an electron source. The size of the LiTaO₃ crystal was 6 mm × 6 mm in the x-y plane and 5 mm in the z-axis. The +z surface was attached onto a Peltier device with silver paste. A
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titanium plate coated with Cu and Al doped ZnS was used as a fluorescent plate. The size of the fluorescent plate was 15 mm × 10 mm. The distance between the –z surface and the center of the fluorescent plate was 10 mm. The +z surface of the LiTaO3 crystal and the fluorescent plate were both grounded. The temperature of the LiTaO3 crystal was measured with a thermocouple attached 1 mm above the +z plane. X-ray intensities were measured with a Geiger-Müller counter connected to a digital oscilloscope. The details of the measurement are described in the Appendix. The Geiger-Müller counter was 80 mm away from the center of the fluorescent plate. Pressure of the chamber was kept at 1 Pa. The LiTaO3 crystal was first heated at 340 K. Then, the LiTaO3 crystal was cooled to room temperature.

RESULTS AND DISCUSSION

Time dependence of X-ray emission intensity and temperature of the LiTaO3 crystal is shown in Figure 2. From t = 10 to 65 s, X-ray emission was observed three times (t = 15 ~ 20, 27 ~ 34, 44 ~ 64 s). No X-rays were emitted in between these periods of X-ray emissions. For each of these three X-ray emissions, X-rays stopped after the highest intensity was observed. Figure 3 shows photographs of the fluorescent plate at t = 32 (a), 33 (b), 35 s (c). At t = 32 s, the luminescence of the fluorescent plate was weak. At t = 33 s, the fluorescent plate illuminated strongly. Considering that X-ray emission stopped after strong luminescence, it is probable that this strong luminescence was caused by a discharge between the surface of the LiTaO3 crystal and the fluorescent plate. The discharge neutralized the charge on the surface of the LiTaO3 crystal and then X-ray emission stopped. From t = 80 to 300 s, X-rays were emitted continuously with intensity less than 20 cps. The X-ray intensity from t = 80 to 300 s was 19 times lower than that from t = 10 to 65 s. Short-lasting X-ray emissions such as those measured from t = 10 to 65 s were observed at the beginning of cooling when the cooling rate was over 0.3 K/s. Long-lasting X-ray emission such as that measured from t = 80 to 300 s was observed when the cooling rate was less than 0.3 K/s. From the results, it is shown that we can obtain relatively stable X-ray emission at a cooling rate less than 0.3 K/s.
Figure 4 shows time dependence of X-ray intensity when the cooling rate of LiTaO$_3$ crystal was 0.09 K/s. Long-lasting X-ray emissions were observed only twice ($t = 92 \sim 135, 165 \sim 267$ s). Both X-ray emissions stopped with discharge. As temperature of the LiTaO$_3$ crystal decreased, an electrical potential difference between the surface of the LiTaO$_3$ crystal and the target (fluorescent plate) became larger. As a result, X-ray intensity increased because the amount of suspended electrons with energy enough to generate X-rays increased. Then, the electron potential difference became large enough for a discharge to occur. The cooling rate of LiTaO$_3$ crystal has to be less than 0.09 K/s to prevent the discharge.

Figure 2. Time dependence of X-ray intensity and temperature of LiTaO$_3$ crystal.

Figure 3. Photograph of fluorescent plate at (a) $t = 32$ s, (b) $t = 33$ s, (c) $t = 35$ s.
CONCLUSION
The time dependence of X-ray emission intensity and temperature of a pyroelectric LiTaO₃ crystal was measured. A discharge was observed between the surface of the LiTaO₃ crystal and a fluorescent plate at the moment when X-ray emission stopped. It was found that a longer lasting emission could be obtained by controlling the cooling rate of the pyroelectric crystal below 0.3 K/s.

APPENDIX
TIME DEPENDENCE MEASUREMENT WITH DIGITAL OSCILLOSCOPE
When we use digital oscilloscopes as analog-digital converters (ADCs) and connect them to X-ray detectors, we can obtain voltage signals from the detectors. We can process the signals with various parameters. The Geiger-Müller tube (model LND712, LND, Inc.) was used in the present study. 500 V bias voltage was applied to the Geiger-Müller tube. Figure 5 shows voltage signals read out with a digital oscilloscope (Picoscope 2202, Pico Technology Ltd.). When an X-ray photon entered into the Geiger-Müller tube, one voltage pulse was produced as output. We designed an electric circuit of the Geiger-Müller counter to output 3 V for each pulse. Undershoot in each pulse was observed. We did not eliminate the undershoots by improving the electric circuit because undershoots do not have an influence on the statistical processing in the present study. The voltage signals obtained from the digital oscilloscopes were saved in a CSV format. The result of X-ray intensity was obtained by counting the number of pulses.
Figure 5. Row data of a digital oscilloscope connected to a Geiger-Müller counter in Figure 1. (A) $t = 17$ s, (B) $t = 63$ s.

REFERENCES