X-Ray Production Using Stacked Pyroelectric Crystals

Andrew Kovanen, Yaron Danon, Don Gillich

Rensselaer Polytechnic Institute, Department of Mechanical, Aerospace, and Nuclear Engineering, 3021 Tibbits Ave., Troy, NY, 12180, kovana@rpi.edu

INTRODUCTION

Recent research showed that two pyroelectric crystals spaced apart with opposite z-faces across from each other produced x-rays with an endpoint energy approximately double that of a single crystal.[1] This research was an attempt to achieve similar gains by stacking $LiTaO_3$ crystals. This research also investigates how different materials between crystals affect x-ray endpoint energy.

THEORY

A single crystal with a target can be modeled as a system of two capacitors in parallel with both the crystal and the gap between the crystal and the target acting as capacitors.[2] For a multiple crystal system, the crystals are treated as capacitors in series with the equivalent capacitance of the crystals being in parallel with the gap capacitance. Figure 1 depicts a single and multiple crystal system.

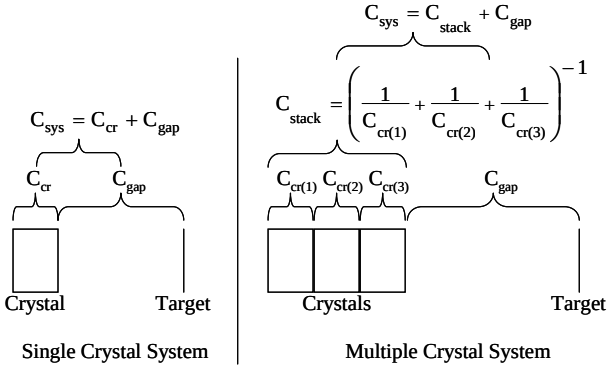

Figure 1 – Modeling single and multiple crystal systems as capacitors

The accelerating potential, φ, created by a pyroelectric crystal and target is given by[1]

$$\varphi = \frac{\gamma \cdot A \cdot \Delta T}{C_{sys}} \qquad (1)$$

where γ is the pyroelectric coefficient of the crystal, A is the area of the z-face, ΔT is the change in temperature, and C_{sys} is the system capacitance as depicted in Figure 1. The crystal capacitance C_{cr} is given by[1]

$$C_{cr} = \varepsilon_{cr} \cdot \varepsilon_o \cdot A / d \qquad (2)$$

where ε_{cr} is the relative permittivity of the crystal, ε_o is the permittivity of free space, A is the area of the z-face, and d is the thickness of the crystal. The gap capacitance (C_{gap}) can be calculated from equation 2 by removing the ε_{cr} term.

Modeling the experimental setup with equations 1 and 2 predicts potentials of 182 kV for 1 crystal, 362 kV for two crystals, and 536 kV for three crystals. Interestingly, modeling multiple crystals as capacitors in series is mathematically equivalent to using one crystal of the same total thickness. It was previously shown[3] that for one crystal the x-ray endpoint energy correlates with the crystal thickness.

DESCRIPTION OF THE ACTUAL WORK

A thermoelectric heater was mounted on a heat sink inside a vacuum chamber along with an 18 mm wide, 0.5 mm thick copper target oriented at a 45º angle. One, two, and three 5 mm long, 5 mm wide, 4 mm thick $LiTaO_3$ crystals were mounted to the thermoelectric heater with a thin layer of electrically conductive silver epoxy. The crystals were oriented such that the positive z-faces pointed down while the negative z-faces pointed up, resulting in electron emission during cooling. The vacuum chamber pressure was approximately 10^{-5} mbar during experiments.

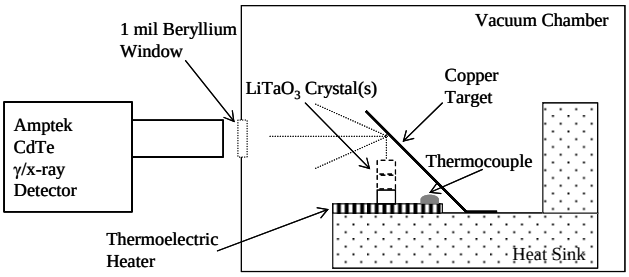

Figure 2 – Experimental setup

The crystal stack was heated to approximately 143 ºC and allowed to cool to 45 ºC through radiative heat transfer. An Amptek XR-100T-CdTe, cadmium telluride (CdTe) semiconductor detector was used to monitor x-ray emission.

The experimental setup was also used to test two crystals with different materials interfacing between them.

The interface materials tested were 1 mm thick Teflon, 1 mm thick JB Weld, and a thin layer of silver epoxy.

RESULTS

Figure 3 depicts the x-ray emission during cooling from a two crystal system with Teflon, JB Weld, and silver epoxy interfacing between the crystals as well as the x-ray emission during cooling from the two and three crystal systems with silver epoxy interfacing between the crystals. The x-ray emission of a single crystal is provided for reference.

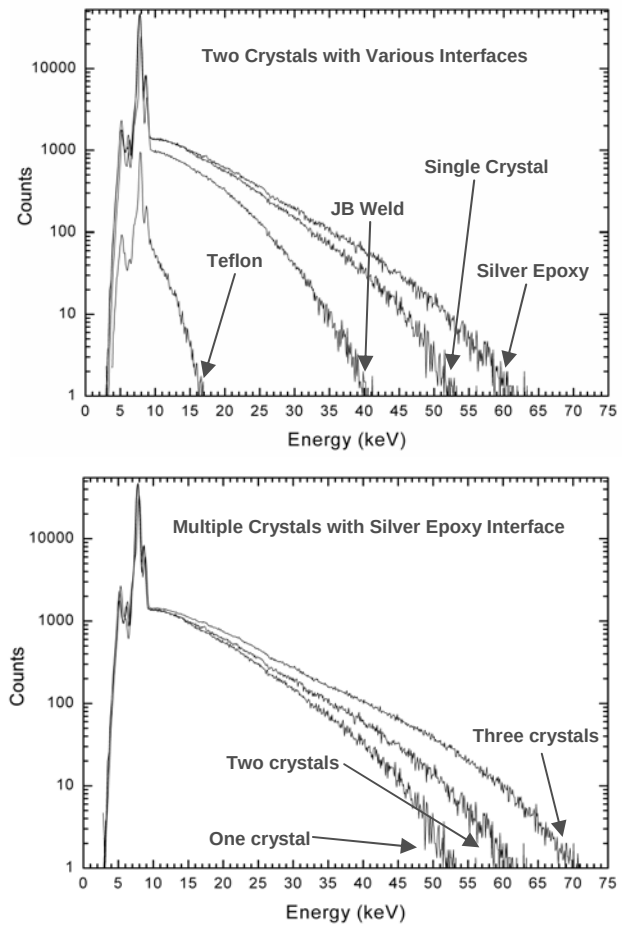

Figure 3 – X-ray emission during cooling, (top) varying the dielectric between the crystals, (bottom) varying the number of crystals

The maximum x-ray endpoint energy for two and three crystal systems using silver epoxy is 60 keV and 70 keV respectively which is greater than the 52 keV from a single crystal system. The maximum x-ray endpoint energy for two crystal systems using Teflon, JB Weld, and silver epoxy is 16 keV, 40 keV, and 60 keV respectively. In general, multiple crystal systems generate higher x-ray endpoint energies than single crystal systems and using electrically conductive materials between crystals results in higher x-ray endpoint energies as compared to using electrically insulating materials.

CONCLUSIONS

The stacking of pyroelectric crystals does increase x-ray endpoint energy, but not to the degree predicted by theory. A possible explanation for this is parasitic capacitance. Introducing a parasitic capacitance of approximately 6 pF into the total system capacitance would bring the theoretical predictions to within 7% of observed results. Another factor contributing to the discrepancy between theory and observation is the slow nature of crystal cooling. Radiative cooling in this experimental setup took a long time, sometimes up to 15 minutes to cool from 143 ºC to 45 ºC. Slower cooling gives accumulated charge more time to migrate away from the z-face. Better thermal management of crystal stacks is perhaps the best way to increase x-ray endpoint energy.

Placing materials of higher relative permittivity between two crystals resulted in lower x-ray endpoint energies. A possible explanation for this observation is that the material between the crystals changed how the crystals interact as capacitors. More work is needed to determine how to better model the crystal stack as a system of capacitors.

ACKNOWLEDGMENTS

This work was supported by DHS cooperative agreement number 2007-DN-077-ER0003.

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