

Pyroelectric Electron Acceleration: Improvements and Future Applications

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INTRODUCTION

Among the many uses of radiation in industry is the need for a non-destructive method of materials analysis and imaging. Portable systems are particularly useful, since they can be carried on-site to analyze a material, whether it is a bridge member or the skin of an aircraft wing. While isotopic sources can be manufactured to provide a wide range of source yield and energy, they require bulky shielding, even when not in use, thus detracting from their portability. Pyroelectric electron sources (first used by Rosenblum et al¹.) and pyroelectric x-ray sources (pioneered by James Brownridge²), offer an alternative: an x-ray or electron source which can be turned off when not in use, and though low in yield, can be manufactured to fit into a pocket and run on a nine-volt battery, as demonstrated by Amptek's Cool-X x-ray device³.

When heated or cooled, pyroelectric crystals exhibit a change in polarization, resulting in a potential sufficient to eject electrons from the crystal surface and accelerate them to energies of above 100 keV, in a beam which changes in energy but is monoenergetic at a given point in time. Pyroelectric crystals can be heated with only a few watts of power, and so they offer an opportunity to create ultra-portable x-ray and electron sources. Since the emitted electrons create ion pairs in the fill gas, the electric field of the crystal also creates a beam of accelerated ions in a direction opposite to the electron beam.

Since RPI began to investigate the generation of x-rays with pyroelectric crystals, significant progress has been made in terms of source strength and characterization. This report summarizes our results, with emphasis on our threefold increase in maximum x-ray energy to a present-day maximum of ~150 keV, our direct measurement of electron energy, the first independent verification of Brownridge's observation of positive ion production⁴, and our doubling of x-ray energy by using two crystals in series instead of a single crystal. The possibility of creating a pyroelectric neutron source will also be discussed.

DESCRIPTION OF THE ACTUAL WORK

The pyroelectric crystals used in our experiments were lithium tantalate [LiTaO₃] and lithium niobate [LiNbO₃]. These crystals had a cross sectional area of 5 mm x 5 mm perpendicular to the z-axis (the axis of

polarization). They ranged in length from 1 mm to 20 mm. The crystals were epoxied to a heating resistor, with either the +z or -z surface of the crystal facing away from the resistor.

Our experiments were performed in a vacuum chamber, typically at ~1mTorr. In order to measure electron energy, a crystal for which the -z surface was exposed was aimed toward a collimated surface barrier detector. Each crystal was heated to ~150°C and allowed to cool through radiative heat transfer. Spectra were taken every five seconds or so. These spectra were compared to find the maximum electron energy for a given crystal size. For the positive ion measurements, a similar experiment was performed, except the collimator aperture was widened, and crystals with the +z surface exposed were heated to ~150°C and then cooled. Finally, for the comparison of x-ray energy with a one- versus two-crystal system, a crystal with the +z surface exposed was oriented to face a crystal with the -z surface exposed. For the two-crystal system test, they were heated in series to 150°C and then cooled, at which time a spectrum was recorded using a CdTe detector. For the one-crystal system tests, the heating resistor for one crystal was disconnected, and the same heating cycle was repeated.

RESULTS

We had previously published results showing that the x-ray endpoint energy from a pyroelectric generator can be doubled by using a two-crystal system⁵. Since then, our maximum achievable energy from a two-crystal system has increased from 50 keV to over 150 keV. We show electron spectra measured with a surface barrier detector in which we demonstrate that the electrons from a pyroelectric system are monoenergetic, with an energy that changes with crystal temperature, as shown in Figure 1. Finally, we offer the first separate verification of Brownridge's observation of the acceleration of positive ions by pyroelectric crystals, by recording spectra of monoenergetic particles with time-variant energy which travel in a direction opposite to the electron motion under the influence of the pyroelectric crystal's electric field. We observed positive ions with energies of up to 97 keV.

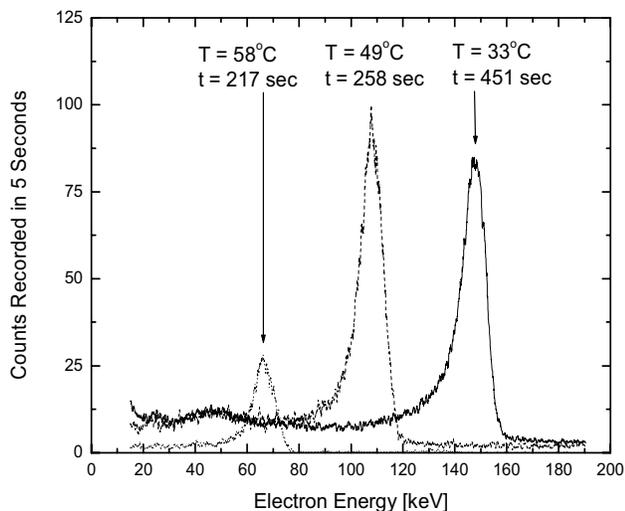


Fig. 1. Electron energy shift during crystal cooling

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