A Pyroelectric Crystal Particle Accelerator

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Recent demonstrations of D-D fusion induced by a pyroelectric crystal accelerator [1,2] have stimulated interest in the possibility of utilizing this novel technique for the development of a portable neutron generator. Such a device could employ the high electric field produced by heating or cooling a pyroelectric crystal under vacuum to dissociate and field ionize deuterium molecules, producing deuterons that are then accelerated by the electric field into a deuterated target at energies ~ 100 to 200 keV. At 100 keV, the D-D fusion cross section (16 mb) is sufficiently high that useful fluxes of 2.5 MeV neutrons conceivably could be produced via the $d(d,n)^3He$ reaction.

We have designed and constructed a pyroelectric crystal accelerator for the purpose of assessing the parameters that determine the energy and intensity of the particle beam. A photograph of the apparatus is shown in Fig. 1. The system consists of an inner chamber, containing the pyroelectric crystal and a remotely controlled target wheel, and an outer chamber containing a liquid nitrogen cooled "cold finger". The vacuum in the outer chamber is maintained by two 1000 L/s diffusion pumps and an automated gas control system enables delivery of gas to the inner chamber and regulation of its pressure via differential pumping. The pyroelectric crystal, a 10 mm x 20 mm-dia. cylinder of $LiTaO_3$, is attached to a copper block with epoxy. The copper block is connected to the cold finger by means of a ground strap. Two resistors, mounted on the copper block provide the ability to heat the crystal. A Li(Si) x-ray detector, inserted into a port in the side of the outer chamber, views the crystal and target through a 0.25 mm thick beryllium window in the inner chamber wall. Monitoring of the crystal temperature is accomplished by means of a thermocouple attached to the copper block.

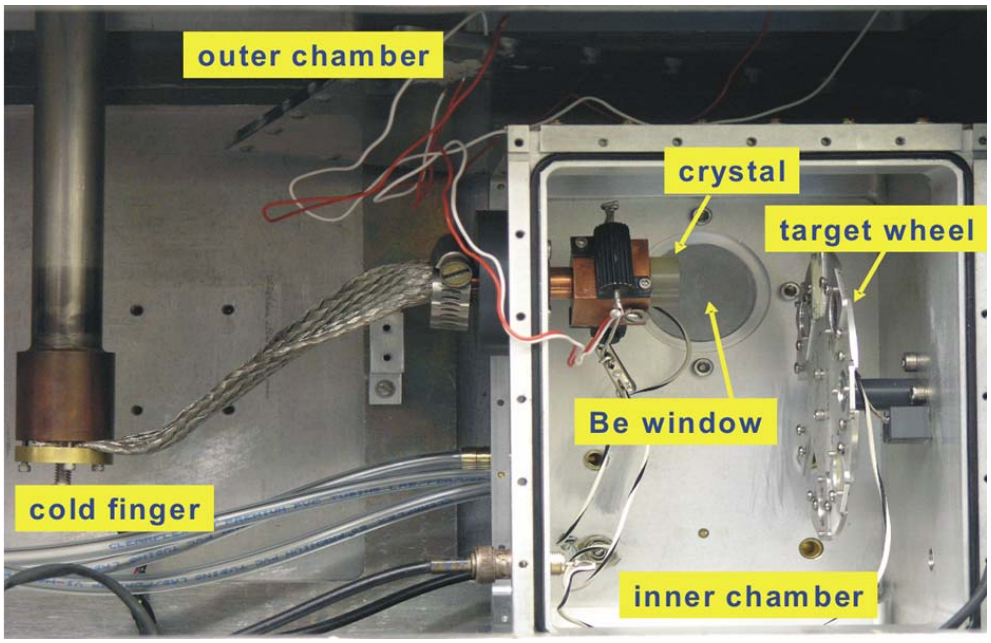

Figure 1. A photograph of the pyroelectric crystal accelerator system.

The crystal was mounted with its z − surface (which is positive during heating and negative during cooling) facing the target. The distance between the target and the crystal face was 4.0 cm. During the heating cycle, electrons from gas molecules in the inner chamber are field ionized by the strong electric field and accelerated toward the surface of the crystal. As a result, bremsstrahlung and x rays are emitted as the electrons impact the crystal surface. During the cooling cycle, the electrons are accelerated toward the target, causing bremsstrahung and x rays to be emitted from the target surface. Spectra of the radiation observed in the Si(Li) detector during a typical heating and cooling cycle are shown in Fig. 2.

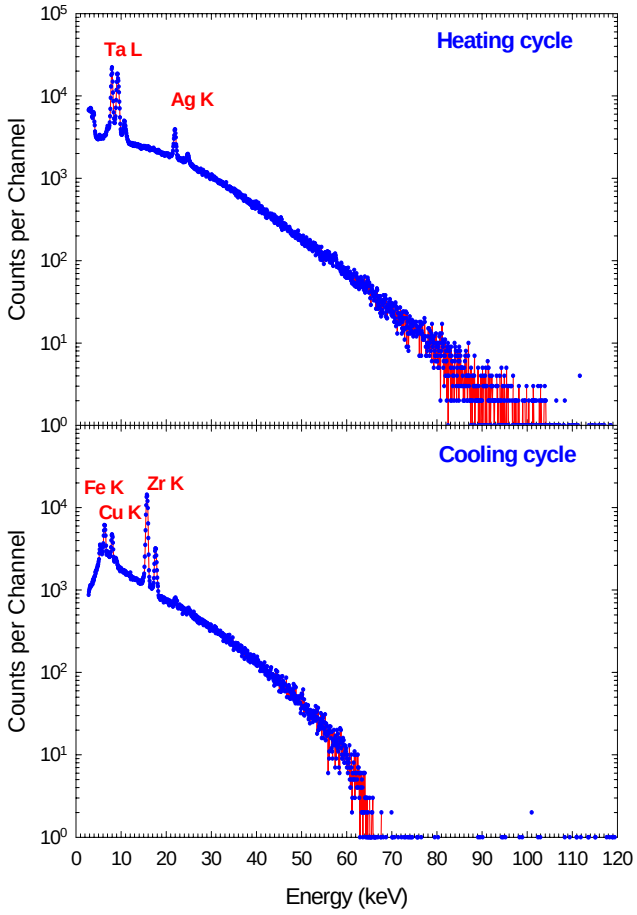

Figure 2. Spectra of radiation observed in the Si(Li) detector during a heating and cooling cycle.

The Ta L x-ray lines appearing in the heating cycle spectrum originate from tantalum atoms in the crystal, while the Ag K x rays are from a thin coating of silver on the crystal surface. The target used during this run was a zirconium foil, and hence Zr K x rays were observed during the cooling cycle. The Fe and Cu K x rays in the cooling cycle spectrum originate from the screws that held the target to the target wheel. The most prominent feature in each spectrum is the large bremsstrahlung continuum. The endpoint of a bremsstrahlung spectrum provides a measure of the electron acceleration potential created between the point of origin and the crystal surface. The above spectra indicate that the acceleration

potential during the heating cycle is approximately 100 kV, while during the cooling cycle, it is about 65 kV. The lower potential achieved in the cooling cycle may be due to the fact that the cooling rate was much slower than the heating rate.

The counting rate in the Si(Li) detector and the temperature of the Cu block are shown as a function of time in Fig. 3 for one of the runs. Typically, the count rate in the Si(Li) detector rises rapidly as the crystal is heated and soon reaches a maximum. Thereafter, it slowly decreases until the power to the resistive heaters is turned off. After the crystal begins to cool, the count rate again rises, but at a much slower rate of ascent, reaches a maximum, and then decreases very slowly. The maximum count rate obtained in any of the runs was 2.2×10^4 s^{-1} during the heating cycle. Taking into account the detector solid angle fraction and efficiency curve, the total photon emission rate (above 3.5 keV) was approximately 3.6×10^9 s^{-1}. Finally, in a run in which 5 mTorr of nitrogen was injected into the inner chamber, a current integrator connected to the target registered a positive particle current of 1 na.

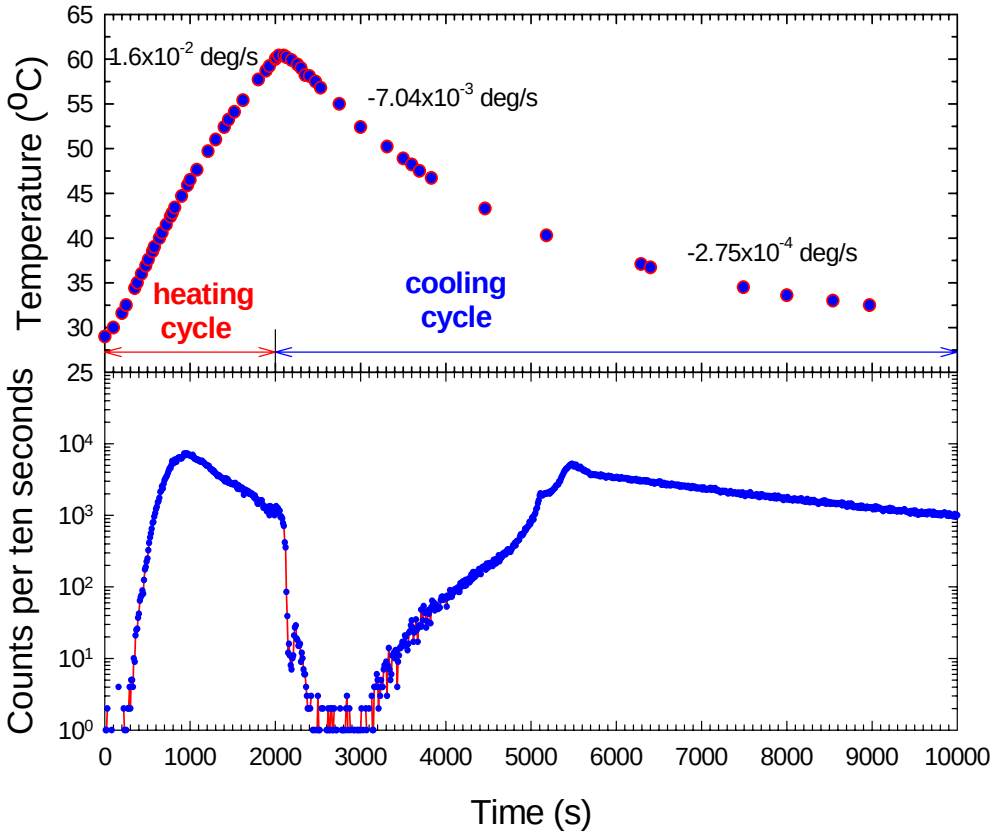

Figure 3. Counting rate in the Si(Li) detector and temperature of the Cu block as a function of time for one of the runs.

[1] B. Naranjo, J. K. Gimzewski, and S. Putterman, Nature **434**, 1115 (2005).

[2] J Geuther, Y. Danon, and F. Saglime, Phys. Rev. Lett. **96**, 054803 (2006).