Pyroelectric Crystal-Generated Neutron Production: Preliminary Results Using a Portable Vacuum System

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INTRODUCTION

Pyroelectric crystals have been used to achieve D-D fusion.[1,2,3,4] One goal of research conducted at RPI is to develop a portable neutron generator using pyroelectric crystals as an ionization and acceleration source for deuterium ions. The research reported here includes the use of two pyroelectric crystals to generate neutrons in a portable prototype vacuum system. Experiments were conducted to determine an optimal deuterium gas operating pressure for neutron production experiments.

A lithium tantalate crystal ($LiTaO_3$) with a tip was used to ionize D_2 gas and accelerate deuterium ions into a deuterated polyethylene target mounted on a second crystal. The crystals were mounted in a small vacuum chamber with two isolation valves that allow the system to be closed after it has been pumped down and filled with D_2 gas.

THEORY

Brownridge and Shafroth reported that an optimum ambient gas pressure can more than double the maximum acceleration energy achieved using pyroelectric crystals to generate an electric field.[5] They also concluded that this optimum pressure is dependent on the vacuum chamber volume. As such, experiments were conducted to determine the optimum vacuum pressure for the portable prototype neutron generator system at RPI.

An electric potential is generated on the face of a pyroelectric crystal during heating or cooling. This potential gives rise to an electric field which is used to ionize D_2 gas and accelerate deuterium ions into a deuterated target. At higher ambient operating pressures within the vacuum chamber, more gas molecules are available to ionize and accelerate into the deuterated target. Therefore, higher neutron yields are anticipated at higher pressures. As the operating pressure increases above the optimum pressure, the charge on the crystal face is more readily dissipated which reduces the ability to build an electric potential. Additionally, because the D-D fusion cross section is energy dependent, higher acceleration energy increases neutron production.

DESCRIPTION OF THE ACTUAL WORK

Two 20 mm diameter, 10 mm thick $LiTaO_3$ crystals were mounted on thermoelectric heaters. One crystal had a 70 nm radius tip mounted on a 17 mm diameter, 1 mm thick copper disk and generated positive charge upon cooling. A standard DIP socket was used to facilitate changing the tip without altering the rest of the system. The other crystal had a deuterated polyethylene (CD_2) coating and was negatively charged during cooling. The crystals were placed in the portable prototype vacuum chamber that was evacuated to less than 1 μtorr and then filled to between 0.004 and 0.033 torr of D_2 gas. Both crystals were mounted to aluminum vacuum flanges and the flanges were cooled by two fans mounted outside the vacuum chamber.

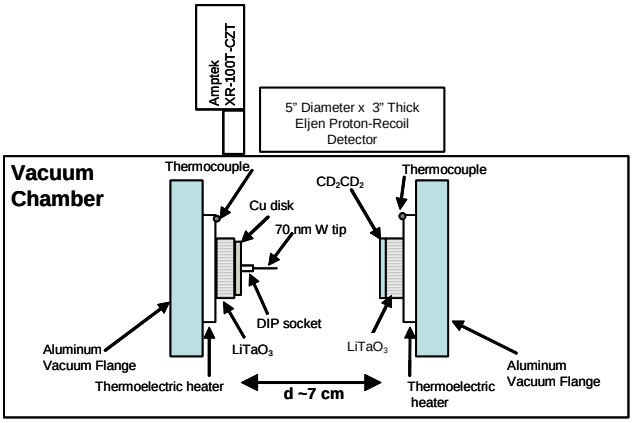

Fig. 1. Experimental Setup.

Two programmable thermoelectric module controllers (Oven Industries, Inc., Model 5R7-388) were used to independently control the two thermoelectric heaters. The crystal with the tip was heated from 20 ºC to approximately 130 ºC over 5 minutes, held at that temperature for 5 minutes and then cooled to 20 ºC over a 5 minute period. The target crystal was heated to 145 ºC over 5 minutes, held at that temperature for 5 minutes and then allowed to cool naturally through radiative heat transfer.

An Amptek XR-100CT, cadmium zinc telluride (CZT) semiconductor diode detector was used to monitor x-ray emission. Neutrons were detected using a 5 inch diameter, 3 inch thick proton-recoil detector (Eljen 510-50x30x-9/301) coupled to a Photonics photomultiplier tube. Fall-time pulse shape discrimination was used to distinguish between neutron and gamma radiation. A BF_3 detector consisting of four Reuter-Stokes Model RSN-108-S neutron counter tubes encased in polyethylene to moderate the neutrons was also used.

X-ray energy provides information about the acceleration potential of the electric field generated by the pyroelectric crystals. It is assumed that deuterium ions

are accelerated to the same energy as the measured endpoint energy of the x-rays. X-ray yield indicates the magnitude of the ion current. Higher x-ray yield, in counts per second, can indicate a higher current of ions from the tip to the target. Successful neutron production experiments generally require accelerating potential energies of above 100 kV and x-ray yields of greater than 10^3 x-rays per second.

RESULTS

Figure 2 depicts the x-ray energy and normalized x-ray and neutron yields versus operating pressure. An optimum operating pressure of about 26 mtorr was found for the two crystal system in the ~450 cm^3 vacuum chamber. This operating pressure is about an order of magnitude higher than deuterium gas pressures previously used for pyroelectric crystal fusion experiments (see references 1 through 4). The total neutron production at the optimal operating pressure was about $1x10^4$ neutrons for a cooling cycle of about 5 minutes.

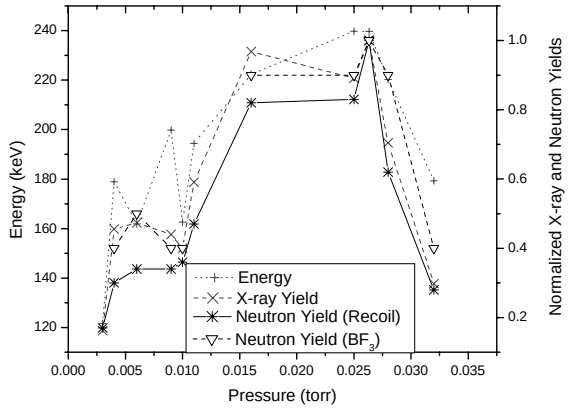

Fig.2. X-ray energy and yield versus pressure.

Perhaps a more important result from these experiments was that the reproducibility of experimental results was greatly enhanced with the use of the programmable thermoelectric module controllers and with higher D_2 ambient gas pressure. Between $1x10^3$ and $1x10^4$ neutrons were produced during each thermal cycle in 34 different experiments conducted over several days.

Additionally, because the BF_3 detector is insensitive to gamma radiation, it was used in conjunction with the proton recoil detector to confirm the production of neutrons. The results in Figure 2 show a strong correlation in detection response for the two different neutron detectors.

CONCLUSIONS

As predicted by theory, an optimum operating pressure of approximately 26 mtorr was determined for the RPI portable prototype vacuum system. With the use of a new thermal management system, experimental results are now more reproducible.

ACKNOWLEDGMENTS

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