Tip Length Optimization for a Pyroelectric Crystal Neutron Source

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INTRODUCTION

Pyroelectric crystals have been used to achieve DD fusion.[1,2,3] The focus of current research is to increase the fusion neutron yield. The research reported here involves varying the length of an electric field-enhancing tip to determine an optimum tip length for pyroelectric crystal fusion experiments.

A lithium tantalite crystal ($LiTaO_3$) with a tungsten tip was used to ionize D_2 gas and accelerate deuterium ions into a deuterated polyethylene target mounted on a second crystal. The length of the copper post on which the tip was mounted was varied. X-ray energy and yield and neutron yield were measured for each length. The optimum tip length for the system was determined by finding the length which generated the highest x-ray energy and intensity and produced the greatest number of neutrons.

THEORY

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. A tip can be used to enhance the electric field and thereby locally increase field ionization.

Equation 1 below is used to calculate the field-enhancement factor near a tip given a "hemisphere on a post" model.[4,5]

$$\gamma = \left(2 + \frac{L}{\rho}\right)\left(1 - \frac{L}{d}\right) \qquad (1)$$

where γ is the field-enhancement factor, L is the tip length, ρ is the radius of the tip (70 nm), and d is distance between the anode and cathode. In the experiments reported here, the crystal with the tip was the anode and the crystal with the target was the cathode during cooling.

Figure 1 depicts a plot of the field-enhancement factor versus tip length and shows an obvious optimum length for field enhancement with a tip length of approximately 1 cm. From this calculation, it was assumed that an optimum tip length could be found given the two crystal system.

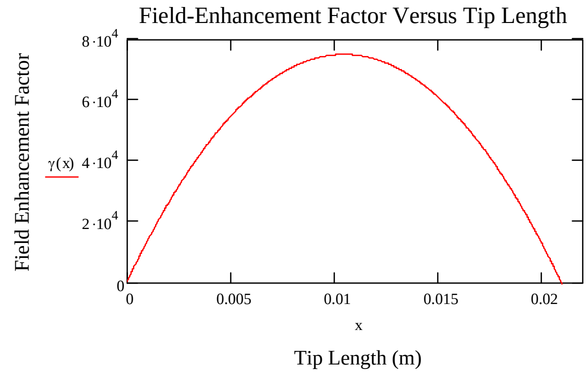

Fig. 1 Calculated tip length optimum

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 coating and was negatively charged during cooling. The crystals were placed in a vacuum chamber evacuated to approximately 1 μtorr and then filled to between 1 and 8 mtorr of D_2 gas.

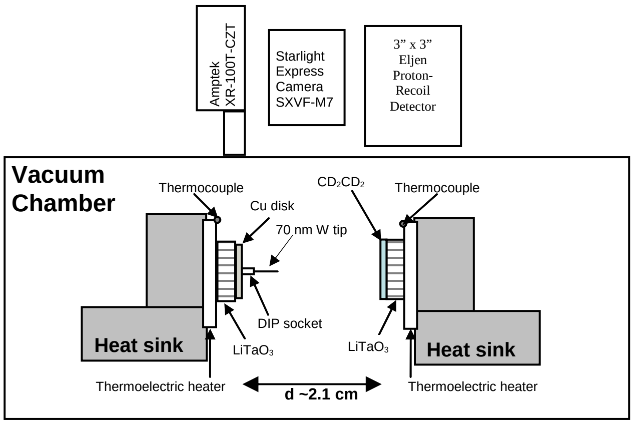

Fig. 2. Experimental Setup.

The crystals were heated to approximately 130 ºC and allowed to cool to ambient temperature through radiative heat transfer. An Amptek XR-100CT, cadmium zinc telluride (CZT) semiconductor diode detector was used to monitor x-ray emission and a Starlight Express, SXVF-M7, 16 bit mono-camera was used to take pictures system during the experiments. Neutrons were detected using a 3 inch diameter, 3 inch thick Eljen 510-30x30x-3/301 proton-recoil detector coupled to a Photonics photomultiplier tube. Fall-time pulse shape discrimination was used to distinguish between neutron and gamma radiation.

X-ray energy provides information about the acceleration potential of the electric field. It is assumed that deuterium ions are accelerated to the same energy as the endpoint energy of the detected 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.

RESULTS

Figure 3 depicts the x-ray energy and normalized x-ray and neutron yields versus tip length. An optimum tip length of around 7 mm was found for the two crystal system. The enhanced neutron yield using the 7 mm tip was likely the result of a stronger ion current over a relatively longer period of time. Evidence of the ion current is shown in the x-ray yield for the 7 mm tip experiments. While higher energy was achieved for 6 mm tip length, the additional ~10 keV energy did not significantly increase the neutron yield.

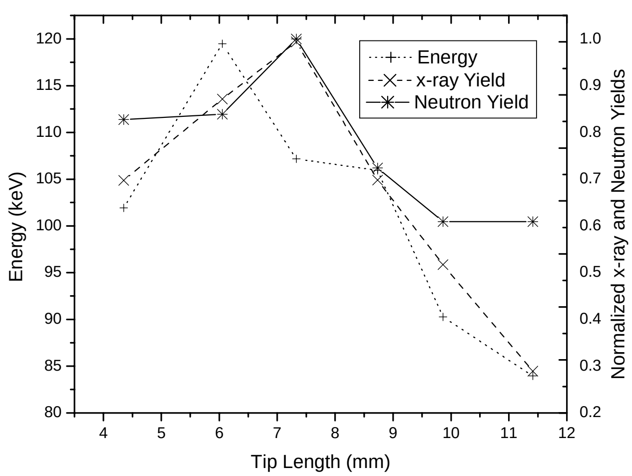

Fig.3. X-ray energy and yield versus tip length.

The Starlight Express camera photos showed a glow believed to be plasma forming at the tip. For longer tips this "plasma" was present during nearly the entire cooling cycle, but due to low acceleration potential an increase in neutron yield was not observed. Figure 4 shows a picture of the glow near the tip.

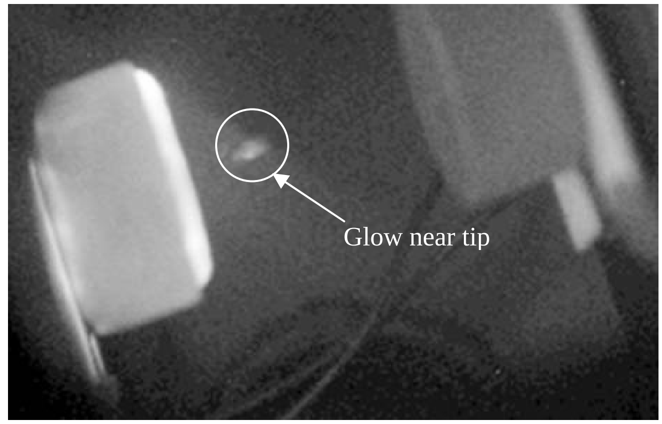

Fig. 4. A glow at the tip

CONCLUSIONS

As predicted by theory, an optimum tip length was found for pyroelectric crystal fusion experiments using a two crystal system. While accelerating energies were not high enough for significant neutron yields, approximately 10^3 neutrons per cooling cycle were detected for some of the experiments. Additionally, a bright glow was observed at the tip possibly indicating plasma formation.

ACKNOWLEDGMENTS

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REFERENCES

1. Naranjo, B., Gimzewski, J., and Putterman, S., "Observation of nuclear fusion driven by a pyroelectric crystal," Nature, 434, pp. 1115-1117 (2005).
2. Geuther, J., Danon, Y., and Saglime, F., "Nuclear reactions induced by a pyroelectric accelerator," Phys. Rev. Lett. 96, 054803 (2006).
3. Geuther, J., and Danon, Y., "Enhanced neutron production from pyroelectric fusion," Appl Phys. Lett. 90, 174103 (2007).
4. Singh, J.P., Karabacak, T., Lu, T.-M., Wang, G.-C., and Koratkar, N., "Field Ionization of Argon using β-Phase W Nanorods," Applied Physics Letters, Vol 85, No. 15, 11 October 2004, pp. 3226-3228.
5. Edgcombe, C.J. and Valdrè, U., "Microscopy and Computational Modeling to Elucidate the Enhancement Factor for Field electron Emitters," J. Microsc. 203, 188 (2001).