Micro-X-ray Sources from Flowing Gases and PZT Crystals

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Abstract—**We report for the first time the observation of low intensity (~ 10^5 photons/cm^2.s) soft X-rays (1 – 30 KeV) from flowing gases (N_2, Ne, He, and Ar) in capillaries and piezoelectric lead zirconate titanate (PZT) crystals at room temperature. The no-slip boundary condition of gas flow at the capillary boundary may lead to friction between the gas molecules and surface dangling bonds of SiO_2 causing chemical bond formation and breakage that generates soft x-rays. The X-ray spectrum of the gas was Gaussian with no characteristic emission lines. The spectrum shape was dependent on the velocity of the flowing gas with the x-ray mean energy and full-width-at-half-maximum being inversely related to each other. The PZT x-ray also did not have any characteristic emission lines, and its mean energy depended on the amplitude and the type of excitation voltage (square, sinusoidal and pulse) waveforms applied to the PZT.**

Keywords—x-ray production; x-ray spectra; triboluminescence; piezoelectric crystals; gases; PZT

I. INTRODUCTION

Miniature x-ray sources can be used along with a digital camera of a cell phone (with appropriate scintillator) to obtain x-ray images of broken fingers and other body parts and can be very beneficial in preliminary medical examinations in the field. They may also find interesting applications in sensing certain molecules and pathogens through x-ray fluorescent spectroscopy (XFS). There is also interest in understanding how x-rays can be produced by relatively low energy interactions encountered in triboluminescence, sonoluminescence, and from peeling off of scotch tapes [1,2]. The x-rays produced in most of these cases are believed to be due to bremsstrahlung from the charges produced and then discharged by the frequent separation (breaking of the chemical bonds) and attachment (formation of chemical bonds) actions. In addition, x-ray generation has also been reported when pyroelectric crystals are heated and cooled periodically in vacuum in the presence of a metal target [3]. Triboluminescence has been known for centuries but poorly understood even today. Gas flow through capillaries can be carefully controlled and different gases can be flown through different capillary structures (nano-textured, soft versus hard walls, porous, metallic, semiconducting, and insulating, etc.) and can be used to study and illuminate the fundamentals of triboluminescence. Here, we report a new type of triboluminescence in which some mechanical perturbations (flowing gases, vibrating PZT crystals) produce x-rays.

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II. X-RAY FROM FLOWING GASES

Fig. 1 shows the setup from which x-ray was detected. It consists of a jet of gas issuing from a glass pipette. The jet is directed at the window of a Cadmium Telluride (CdTe) x-ray detector (Amptek X-123). The detector was was calibrated using two gamma ray emission lines of Americium 241 and with the x-ray fluorescence lines of copper and silver. The x-ray spectrum for a jet of nitrogen gas flowing from a glass capillary nozzle is shown in Fig. 2 for different gas flow rates. The flow rate was measured by placing a hot wire anemometer 25 cm from the gas nozzle mouth. The nozzle has a mouth diameter of 0.8 mm. The x-ray detector was placed 20 mm from the nozzle mouth. Further, the flow of the gas was monitored and controlled with a valve and an anemometer (Omega FLT-41G and FLT-39G) to study the dependence of the x-ray emission on gas flow rates. The spectra for different volumetric flow rates are given in given in Fig. 3.

In addition to nitrogen gas, we obtained the radiation from other flowing gases as well. The spectra of these gases had the same flow rate dependence as that of nitrogen. In Fig 4, the spectra for flowing helium, argon, neon, and nitrogen at the same volumetric flow rate were presented together for comparison. The experimental conditions for these measurements were the same as that in the nitrogen setup.

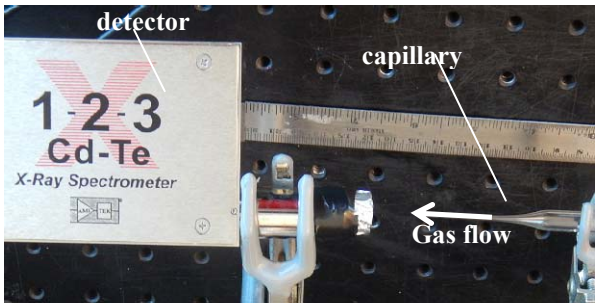


Fig.1: Setup for detecting x-ray emission from a flowing gas.

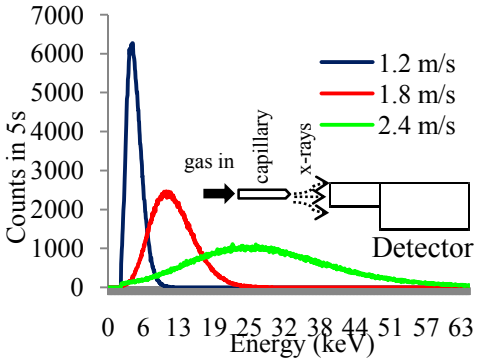


Fig. 2: X-ray spectra of flowing gas, with schematic, for different gas flow velocities.

Recombination radiation is known to occur when charged particles produced through the rubbing action between two surfaces recombine. Therefore, if such charge generation and recombination in flowing gases are responsible for x-ray generation, then an applied electric field will perturb the generation and recombination process, and consequentially the x-ray spectrum. Therefore, to investigate the existence/non-existence of charge particles effects in x-ray emission, an electric field was imposed on the path of the flowing gas.. Fig. 5 shows the x-ray spectra parameters for different applied voltages on a 10 mm path of flowing nitrogen gas. The spectra show no definite relationship with the applied voltage. Therefore, recombination radiation was ruled out as the cause of the x-ray generation.

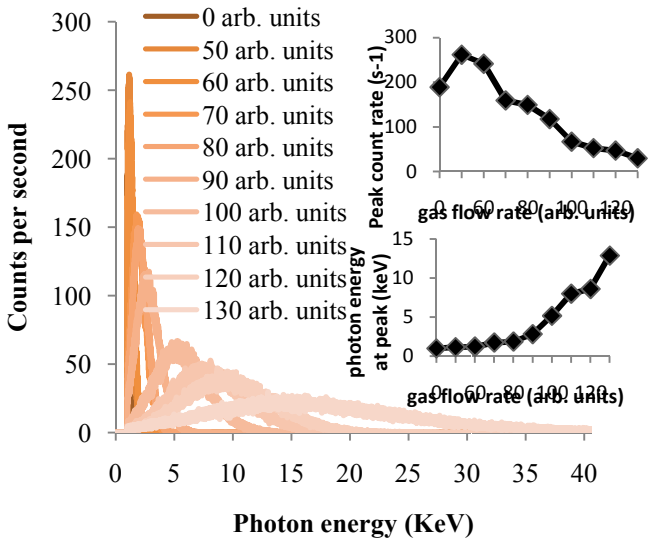
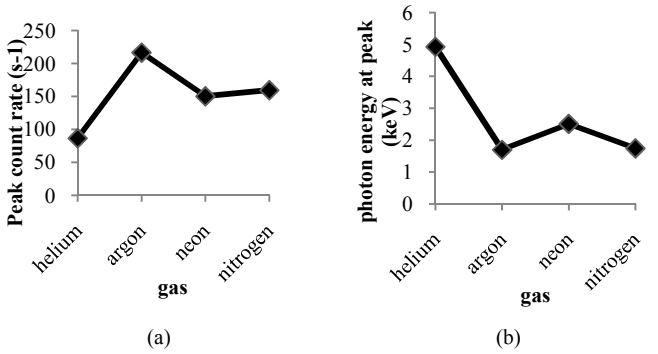


Fig. 3: X-ray spectrum of flowing nitrogen gas for different gas flow rates Higher flow rates spreads out x-ray energy. The top inset shows the photon maximum flux, and the bottom inset shows the mean energy of the spectra, respectively, as a function of flow rate. The higher the flow rate, the lower the maximum photon count rate (flux), the higher the mean energy an x-ray spectrum. Peak count rate is inversely proportional to mean energy.



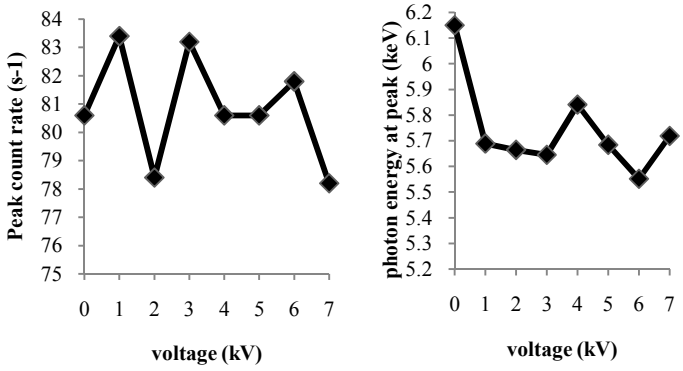
(a) (b)

Fig. 4. X-ray spectra paramters of different gases at same volumetric flow rate (a) shows the maximum peak rate for the different gases. (b) shows the x-ray photon energy where the peak rate occurs.

Finally on the x-ray emission form flowing gas, Fig. 6 shows the variation in the x-ray spectra for different separation distance between the detector and the gas nozzle mouth. From these spectra, it can be seen that the detected energy of the x-ray is reduced with increasing distance. This is likely to be because the gas flow velocity reduces at father distances from the nozzle due to diffusion.

III. X-RAY FROM PZT CRYSTALS

In addition, we observed x-ray emission from a piezoelectric transducer when we excited it at around its resonance frequency. The setup to measure the radiation is shown in Fig. 7. The setup consisted of a 32 kHz PZT crystals at room temperature placed 27 mm away from the x-ray detector. The x-ray spectra for the transducer when driven by different amplitudes of a 31.72 kHz square waveform are given in Fig. 8. It was observed that the square waveform excitation gave higher x-ray mean energy than sinusoidal and triangular waveform excitations.



(a) (b)

Fig. 5: X-ray spectra parameters for different imposed electric field on flowing gases. (a) shows the maximum peak rate for the different gases. (b) shows the x-ray photon energy where the peak rate occurs.. The spectrum does not vary in a definite manner with the imposed electric potential.

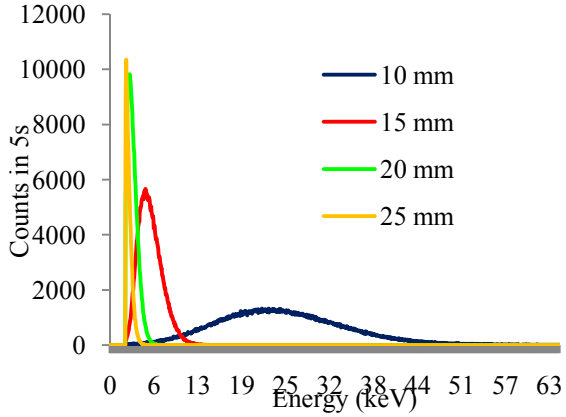


Fig. 6: X-ray spectra of flowing gas for different separation distances between gas nozzle and detector.

IV. CONCLUSIONS

In conclusion, we have reported the detection of x-rays from flowing gases and excited PZT crysals. The x-rays were detected with a commercial CdTe detector. The mean energy of the detected x-rays decrease with increasing distance of the x-ray detector from our x-ray sources. This property of our x-ray places a big limitation on the use of this x-ray emission for practical applications. We are pursuing means by which our x-rays can be concentrated so that it can be used for typical x-ray applications (imaging, fluorescence, etc.). For example, we are exploring enhancing x-ray emission by modifying the texture of the capillary walls from which the gases are issuing.

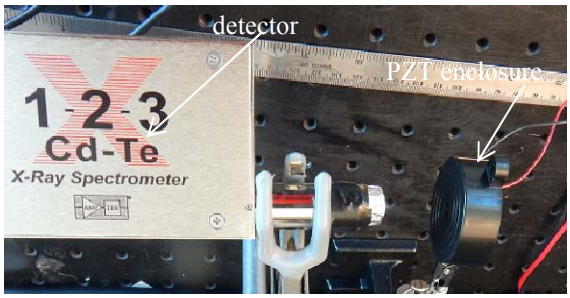


Fig. 7: Setup for detecting x-ray emission from a piezoelectric PZT crystal. The crystal is enclosed in the black plastic enclosure.

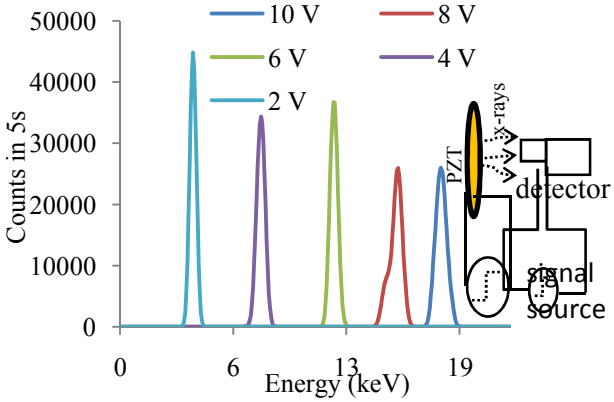


Fig. 8: X-ray spectra from piezoelectric PZT crystal, with schematic, for different peak-to-peak voltages of square wave excitation.

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