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-REVIEW ARTICLE-

New-Age Pyroelectric Radiographic X-Ray Generators

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Abstract

Medical imaging history has begun with the discovery of X-rays. X-rays that are widely used since their invention in different areas from projectional radiography to computed tomography. Year by year their technology is improved in many aspects especially for their generation of which tubes are changed to get the most efficient rays. Nowadays different mechanisms are studied to obtain X-rays; one of them is pyroelectricity phenomena. Pyroelectricity is a material's electricity generation from temperature changes. The output spectra of the pyroelectric X-ray generator is quite similar to traditional X-ray tubes, which gives a chance for replacing low-voltage pyroelectric X-ray generators instead of high-voltage conventional X-ray tubes. The results of conducted experiments and continued studies show us that the use of pyroelectricity for X-ray generation has great advantages. More portable X-ray devices may be available in the near future, and these new designs offer safer and easier to operate since they use only 12 Volts instead of kiloVolts. In conclusion, healthcare technologies require high budges in general, this low-cost alternative might make the radiological imaging available for low-income countries. In this paper, the fundamentals of X-ray generation from pyroelectric material is reviewed, a device on the market, COOL-X, is investigated, and both conventional method and pyroelectricity methods are compared.

Keywords:
Pyroelectricity, X-ray generation, Medical radiology.

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Introduction

Medical imaging history has begun with the discovery of X-rays. Wilhelm Conrad Röntgen, the German physicist, conducted experiments on these cathode rays. He coated the tube with black cardboard. Then he noticed that the barium platinocyanide coated paper, at a certain distance, was shining. The crucial point was the different directions of this coated paper and the cathode x-rays. He concluded that other rays must have been emitted from the tube. He called these rays as X-rays where X refers to the unknown. He repeated the experiments by placing different objects in front of the tube. He saw his hand's bones on the screen in one of these experiments. The first published radiographic image is his wife's hand. They put her hand in front of the tube and exposed to X-rays. A photographic film is used to get the image (Carroll, 2011). This invention spreads around the world quickly. An x-ray tube is developed to generate these rays (Figure 1). An x-ray tube basically consists of three elements; the cathode, the anode, and the glass envelope (Figure 2).

X-ray tubes require high energies to accelerate the electrons in the anode. An additional high voltage generator is used in an x-ray machine to meet this energy demand. These voltage generators are capable to generate from 5 to 400 kilovolts (kV) for different applications. Generated x-rays are restricted before directed to the patient by using a collimator. The collimator is an essential part of an x-ray device for both preventing overdosing the patient and enhancing the image quality. These x-rays are applied to the patient.

X-rays are attenuated while passing the patient's body. These attenuated x-rays are collected via passing through grids and strip leads. Grids are lead strips are essential to reduce the amount of scattered radiation among the film's pixels to improve image contrasts (Smith & Goel, 2018). To obtain a radiograph, films can be used. Nonetheless, films are inefficient to detect x-rays. Intensifying screens or flat panels have been mounted to the device instead of films in digital radiography systems recently. There are two types of flat panel detectors: direct or indirect. Indirect detectors include a scintillator layer which produces visible light when it is exposed to the ionizing radiation and this light is detected by photodiodes. Then these converted electric charges are read out by thin-film-transistor (TFT) arrays. On the other hand, direct detectors use amorphous selenium layer to convert the x-rays directly to the visible light in the TFT-array readout process (Kotter & Langer, 2002).

Figure 1. X-ray tube outside view

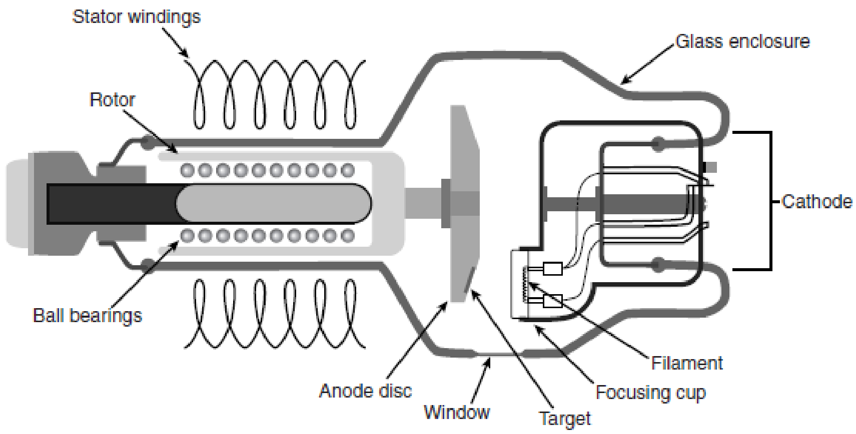

Figure 2. Diagram of an X-ray Tube

X-ray Based Imaging Modalities

Projectional Radiography: This oldest x-ray imaging technique creates two- dimensional (2D) images of the interior part of the body. This basic system given above is used to obtain images. X-ray attenuation of different tissues makes a contrast on the image. In spite of the technological improvements, this technique still keeps its value due to its efficiency. This image is used in diagnosing the disorders on the different parts of the body.

Fluoroscopy: Similar to projectional radiography, it is used to acquire 2D images of the inner body. The fluoroscopy is suitable to acquire real-time images. While x-ray is directed to the patient, a different detection system is used to transfer real-time images to a screen. Depending on the detector differences, high heat capacity x-ray tubes and high power generators become necessary as well (Dance et al., 2014).

Angiography: This type of radiography is a specific application for imaging the arteries, veins, and organs to diagnose disorders with a contrast agent. During the procedure, a thin tube inserted to the blood vessel located in the desired image area and a contrast agent is used to make the vessels visible for x-ray imaging. Also computed tomography (CT), c-arm x-ray systems and magnetic resonance imaging techniques used in angiography too.

Mammography: This type of radiography enhances monitoring only breasts by reducing the radiation dose. It creates a detailed image of breasts and plays an important role to diagnose breast cancer in early stages. Mammography device has a different geometric shape for x-ray tubes to prevent the visualization of other tissues than breasts.

Dental Radiography: This type of radiography is used in only dental applications to visualize teeth and jaw bone. Because of imaging obstacles of the teeth, slightly different techniques must be used for imaging. In one of these techniques, the imaging receptor is placed inside the mouth, intraoral radiography. In another technique, the imaging receptor is placed exterior of mouth and then exposed to x-rays. In addition to this basic classification, dental radiography has other subgroups such as panoramic x-rays, dental computed tomography, cone beam computed tomography.

Computed Tomography: Projectional radiography techniques give only 2D images of the three-dimensional (3D) structures. This type of radiography was developed to see these 3D structures. A computed tomography system has a similar tube and detector that are rotated around the patient to acquire images from different angles. These acquired images are reconstructed to obtain a 3D image. The computed tomography devices divided into five generations by regarding the number of detectors, the types of the beam, and the movements of both the tube and the detector.

X-rays are still one of the most common imaging techniques and they are evolving with new technologies. In this study, the possible use of newly-developed pyroelectric x-ray generators instead of existing x-ray tubes is investigated and discussed.

Pyroelectricity

Pyroelectricity is a phenomenon that describes the voltage generation capability of some materials when their temperature change. These pyroelectric crystals caused a spontaneous polarization when they are heated or cooled. This polarization generates a temporary voltage. This polarization affected by the pyroelectricity coefficient of the material and the speed of the temperature change (Figure 3) (Brownridge & Raboy, 1999).

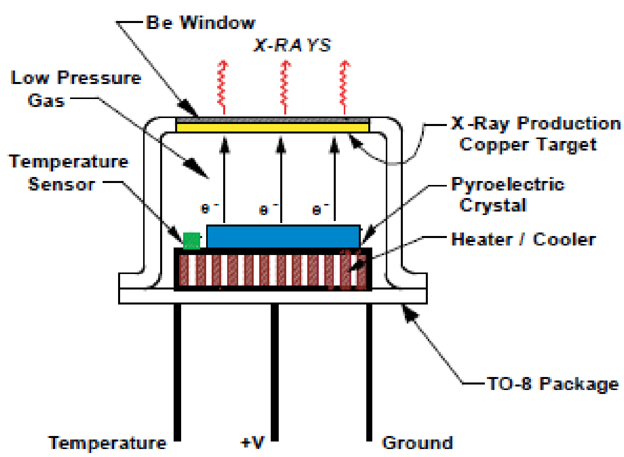

Figure 3. Schematic of Cool-X X-ray generator

Pyroelectric crystals have several applications including fire alarms, radiometers, laser detectors, thermal imaging. The first study was conducted to generate X-ray using a pyroelectric crystal three decades ago (Brownridge, 1992). The x-ray production from thermally cycled pyroelectric crystals of LiNbO3 (Lithium Niobate), LiTaO3 (Lithium Tantalate), and CsNO3 (Cesium Nitrate) was investigated (Brownridge & Raboy, 1999). Based on these studies, a novel marketable pyroelectric X-ray generator (Figure 4) is developed now by Amptek Inc., Bedford, MA, so-called COOL-X (COOL-X X-Ray Generator, 2019). This miniature device gives a new opportunity to put forward the X-ray technology.

Figure 4. Cool-X X-ray generator

The COOL-X has unique specifications. For example, it generates X-rays when it is thermally cycled between 2-5 minutes and uses Cu (Copper) as the target (Kusano et al., 2014). The characteristic and bremsstrahlung x-rays are produced in both heating (Figure 5) and cooling (Figure 6) stages (COOL-X X-Ray Generator, 2019).

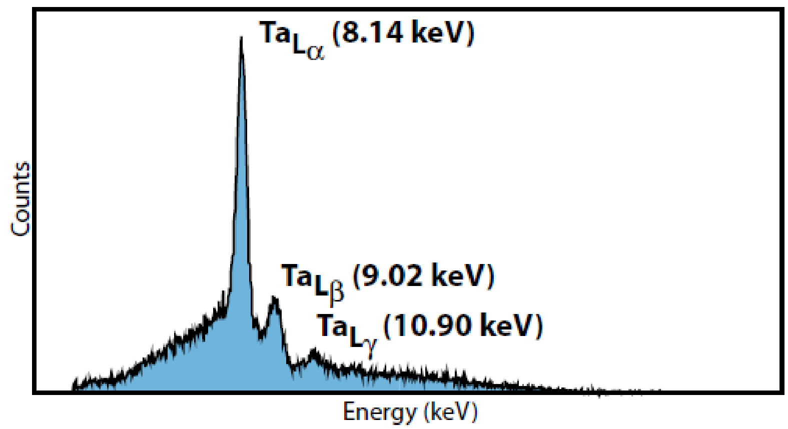

Figure 5. Heating Phase Spectrum of COOL-X

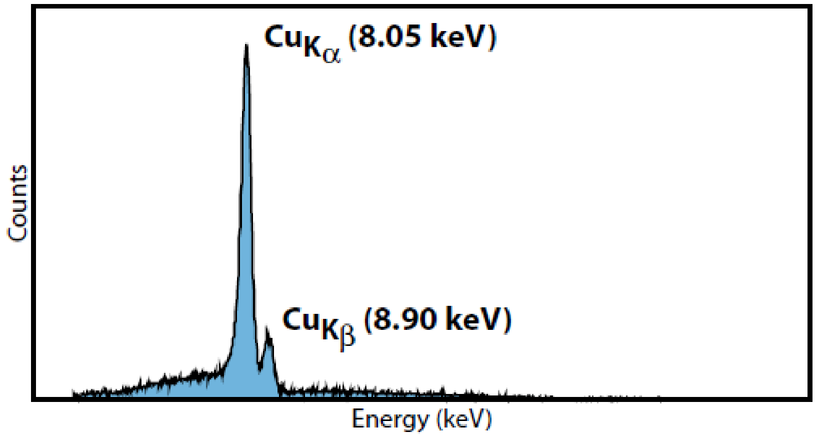

Figure 6. Cooling Phase spectrum of COOL-X.

Using pyroelectric crystals has many advantages over conventional x-ray tubes. First, dimensions of pyroelectric crystal are much smaller than those of conventional x-ray tubes. For example, the dimension of the COOL-X is 15 mm x 10 mm (COOL-X X-Ray Generator, 2019). The smaller dimension makes the x-ray sources portable and easy-to-use. In a recent study, this may also make teaching x-ray physics to the students possible by using the pyroelectric crystals in education (Shafroth & Brownridge, 2002). In addition, establishing airtight canning is relatively expensive in producing a conventional x-ray tube. Since this is not an essential procedure in a pyroelectric-based x-ray device, its price is lower than the conventional one. Furthermore, pyroelectric generators do not require high voltages to work and can work with a battery pack of 12 volts. This allows creating a low-cost radiological imaging system as a whole.

Nonetheless, the obtained energy from a commercially available device has the maximum energy level of 170 keV (Figure 7) (Brownridge & Shafroth, 2002) but the maximum energy level from the COOL-X is 35 keV (Figure 8). There are only a few studies to handle this energy issue. In a recent study, using an extra second crystal in a reverse orientation will increase the x-ray energy. They reported that there is an improvement in the maximum energy level varied from 107 keV to 184 keV (Geuther & Danon, 2005). In another study, the second crystal will not affect the x-ray energy as reported previously, the energy level is only doubled by comparing to that of a single crystal system (Kusano et al., 2013).

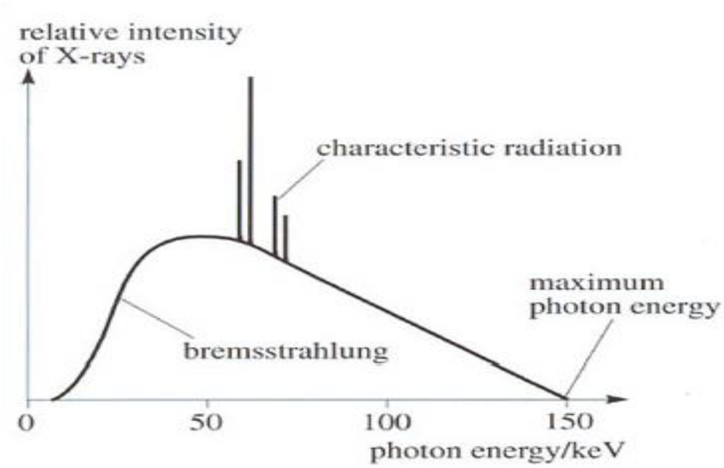

Figure 7. A typical x-ray spectrum with a tungsten target

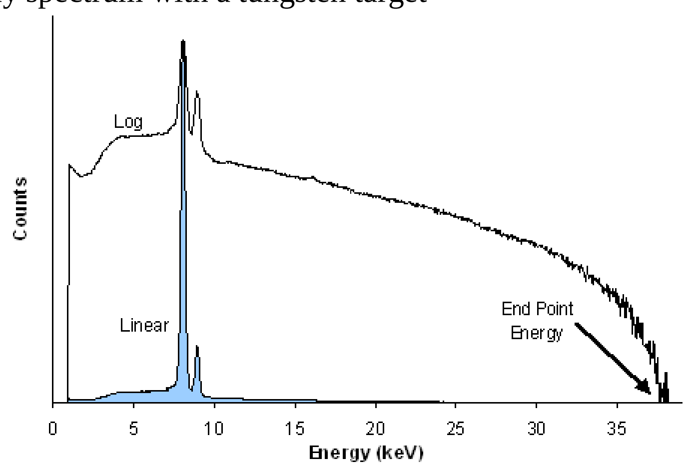

Figure 8. COOL-X x-ray spectrum with a copper target

Discussion

It can be concluded that the spectra of a pyroelectric x-ray generator are quite similar to that of the traditional one by comparing the figures 7 and 8. As a result of this, there is a chance of replacing the low voltage used pyroelectric x-ray generators instead of conventional x-ray tubes that required high voltage. Results show us that the use of pyroelectricity for x-ray generation has great advantages as summarized in Table 1. All in all, the design of compact and portable x-ray devices will be possible due to small sizes of pyroelectric crystals in generators. In addition, the newly designed devices will become safer and easier to operate since high voltages are not required hereinafter.

Every x-ray application area will get benefits from pyroelectric x-ray generators. Especially in medical radiology, the energy range of pyroelectric generators is compatible with the boundaries to acquire images from the body. Pyroelectric x-ray generators can be used in the veterinary radiographic applications due to their energy spectra. In addition, since the healthcare technologies are a high cost in general, new equipment designs by using this low-cost device will give opportunity access to these technologies in low-income countries.

Table 1. Comparison summary of discussed x-ray generation types.

Pyroelectricity X-ray Generation	**Traditional X-ray Generation**
Low voltages applicable.	High voltages required.
Compact device designs.	Greater device designs.
Low cost	High cost
Energy spectra need to be higher for wide range applications.	Both low and high energies are obtainable.
Due to low voltage, safer to use.	High voltages are a danger while operating.

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