Ferroelectric Base Multiple Radiations Source for In-Situ Multifunctional Analytical Instruments

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ABSTRACT

A ferroelectric based multiple source radiation device was developed and tested at JPL. This device was shown feasibility to emit five radiation types enabling a new generation of compact, low power, low mass in-situ analysis instruments. These radiation types include visible light, ultraviolet, X-ray, as well as electron and ion beams. These types of emitted radiation can support multiple instruments that can potentially be used in future NASA missions to detect water, perform mineralogical/chemistry analysis and identify biological signatures. The source consists of a ferroelectric wafer having a continuous ground electrode on one side and a grid-shaped electrode on the other side. This source is placed in a vacuum tube and is used to generate plasma by switching high voltage pulses. A series of experiments were performed to evaluate the characteristics of the generated radiation and the results are described and discussed in this paper.

Keywords: Ferrosource, multiple radiation type, planetary exploration, X-ray

1. INTRODUCTION

One of the most important NASA objectives of the planetary exploration program is the study of life existence and origin in our solar system. This effort involves the use of instruments for the detection of water and the characterization of the minerals and geological content. Generally, analyzers that are planned/considered to be used require separate radiation sources for each of the instruments and therefore require extensive number of components, high mass, volume and power. Further, they need a complex manipulation system to transfer the sample from one instrument to another subjecting it to potential contamination along its path. A single source that can produce multiple radiation can lead to a significant reduction in the number of required components (and their associated mass and power requirements) needed over the use of separate radiation sources. Using a single emitting source (with intermediate support fixtures) allows testing the same sample by different analytical methods and thus enhancing the amount of obtained information and accuracy that can be achieved. The combination of independent data collected from the same sample using such a source can significantly enhances the reliability of the data and the number of independent properties that can be measured. The use of such a source can eliminates the need for a complex sample handling mechanisms of transferring the sample from one instrument to another increasing the hardware reliability and reducing potential contamination. Since the developed source is based on the use of ferroelectric materials it offers the additional benefit of potential operation at extreme environments (high and low temperature and pressure).

Recently, such a prototype of ferroelectric based multiple radiation source was developed and its feasibility was demonstrated [Bar-Cohen et al. 2002]. This device was shown to emit five radiation types enabling a new generation of compact, low power, low mass in-situ analysis instruments. The emitted radiation types include visible light, ultraviolet, X-ray, as well as electron and ion beams. The source consists of a ferroelectric wafer having a continuous ground electrode on one side and a grid-shaped electrode on the other side. This source is placed in a vacuum tube and is used to generate plasma by switching high voltage pulses. Generally, these radiation types on are used or planned to be used in future NASA missions to detect water, perform mineralogical/chemistry analysis and identify biological signatures. For example, an X-ray source can be used to produce a three-dimensional density map of a sample by operating as a CAT-scan tool. Heterogeneities detected by X-ray interrogation can then be subjected to spectroscopic investigation using UV light (which will produce characteristic fluorescence patterns based on distinct types of organic molecules) and visible light which will highlight absorptive characteristics of the sample derived from minerals and from biomolecules. Moreover, X-ray diffraction will allow mineralogical identification while an electron beam can be used to produce X-rays from the sample itself for elemental analysis or, possibly in a more advanced system, be used to produce electron microscopic images.

2. FERROSOURCE AS A MULTIPLE RADIATION TYPES EMITTER

The concept of a single source of multiple radiations is based on the use of the plasma that can be emitted by a ferroelectric disk [Bar-Cohen et al. 2002]. The concept is envisioned to lead to a device as shown schematically in Figure 1. A series of optical and electronic focusing and collimation elements will be used to control the beam directivity in support of future potential instruments.

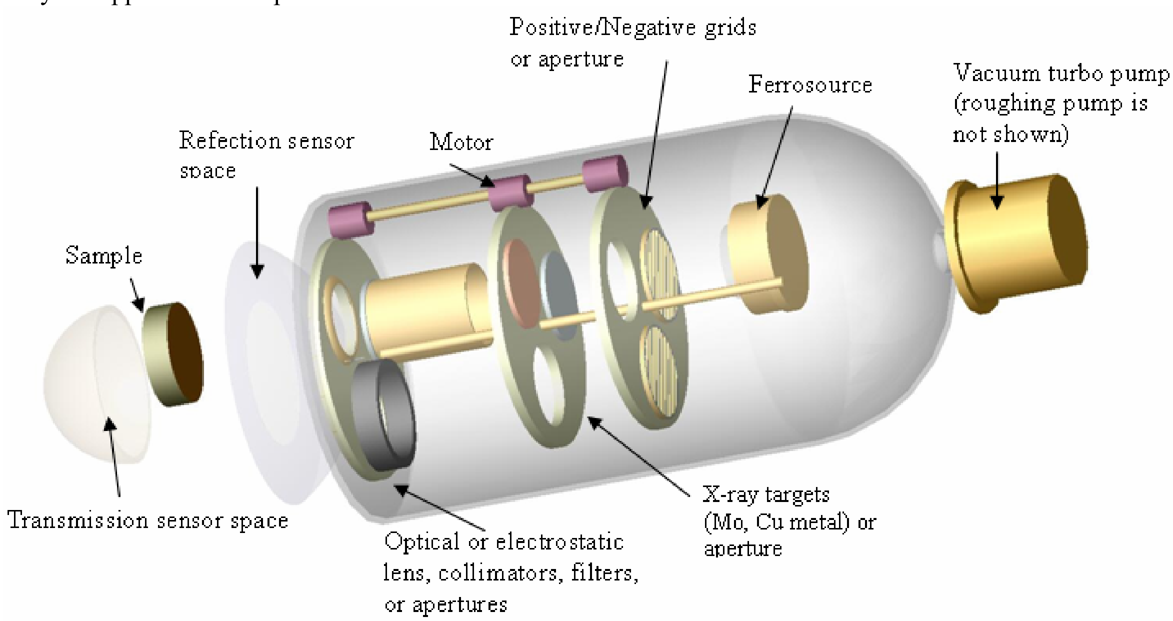

FIGURE 1: A schematic view of the envisioned multi-radiation emitter using a single ferroelectric source.

Such a ferroelectric disk, named ferrosource, consists of a continuous ground electrode on one side and a grid shaped electrode on the other side (see Figure 2). Experiments applying voltage pulses onto the disks with grid electrode have shown the generation of plasma as a result of an incomplete discharge [Rosenman, et al, 2000]. The plasma discharge is initiated at the triple points (metal – vacuum - ferroelectric junctions), where the applied electric field (~10^4 V/cm) of the driving voltage pulse is enhanced up to 10^7 -10^8 V/cm due to the high dielectric constant of the ferroelectric wafer. The produced plasma has a density of up to 10^{12} cm^{-3} and it was the basis of our multi-radiation emitter, where UV and visible light are produced directly by the plasma and separated by optical filters. Further, charged particles are extracted and/or accelerate to emit the other radiation types. The application of accelerating voltage pulse allows the extraction of electron and ion beams with a current density of several tens of A/cm^2.

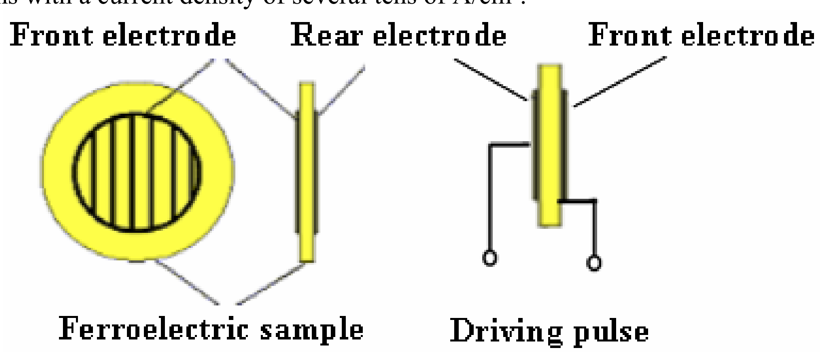

FIGURE 2: A schematic view of the ferroelectric cathode that is the key source of the multiple radiation types.

A drive electronics that generate 25KV voltage pulses was made. Also, a setup was constructed using a vacuum chamber having multiple ports with windows and electrode feed-through and vacuum piping allowing controlled operation and observation. A schematic view of the setup is shown in Figure 3 and a photographic view is shown in Figure 4.

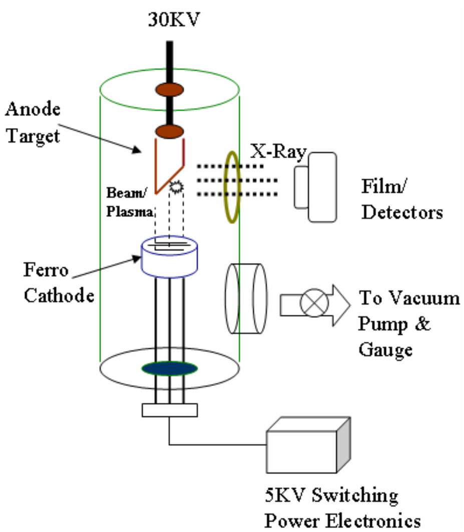

FIGURE 3: Schematic of the recently constructed experimental setup for testing the Ferrosource operation feasibility.

FIGURE 4: A photographic view of the Ferrosource test setup.

Using this setup the feasibility to emit pulsed radiation of visible (see Figure 5) and UV light (using a UV detector) which are the direct result of producing plasma, were demonstrated. Filters was used to separate the emission of these two radiation types.

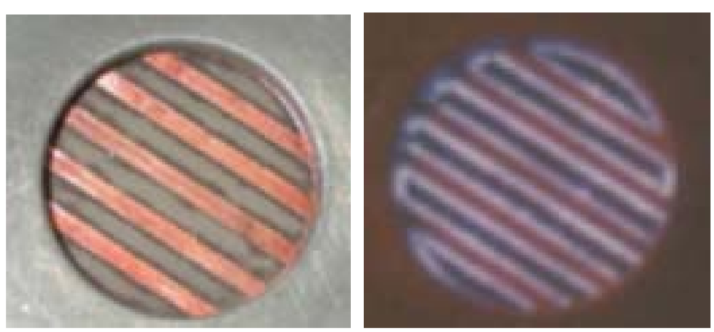

FIGURE 5: Plasma light emission (right) generated from a cathode grid (left). The diameter of the electrode area is 20-mm.

3. METROLOGY AND PRELIMINARY TEST RESULTS

A series of experiments were performed to evaluate the characteristics of the generated source and the emitted radiation as follows:

Visible Light

Direct observation of the emitted visible light from the produced plasma has shown strong emission in room daylight condition. A direct view of the light from the grid area is shown on the right of Figures 5 and the radiate light can be seen in Figure 6 where a side view of the setup with the emitted light are shown

FIGURE 6: The currently observed visible light.

Ultraviolet Beam

To record the emitted UV a Combinova Field detector for EMF was first used. The frequency range for this instrument is much lower than UV at 20Hz to 2.0 kHz. The A test result shows a UV related electromagnetic radiation recorded at 0.6 –1.4 V/m with sampling frequency of 0.02 mSec as shown in Figure 8 and 9. Using an averaging process, the gauge reflected a low energy VU.

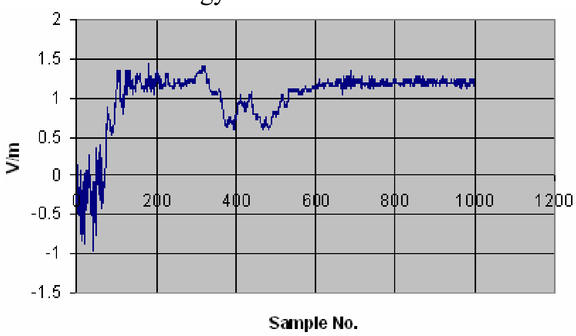

FIGURE 8: Recorded intensity of the UV radiation.

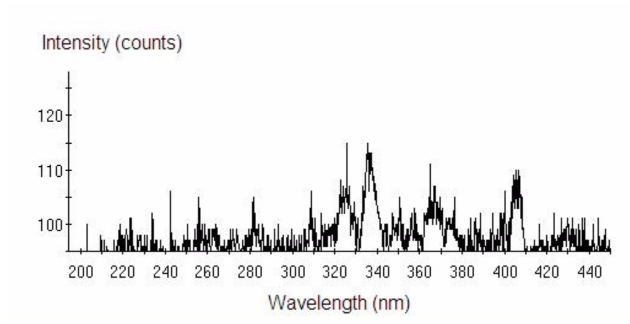

FIGURE 9: The spectrum of the recorded UV radiation.

X-ray Radiation

To record the emission of X-ray a detector Radiation Alert Monitor 4EC (Geiger Muller) was used. This detector was placed 6-in. away from the source and the test was conducted using a 0.375-cm thick Pyrex observation window. The duty cycle of the pulse was $8x10^{-8}$ (0.8-Hz switching frequency between pulse, with 100-ns pulse duration). Using this Geiger Muller Counts, an X-ray level is 0.2 mR/hr was measured. Adjusting for the duty cycle, the short pulse intensity was estimated to reach as high as 2500R/hr.

In order to view the emitted radiation an X-ray radiography film (Polaroid 80/20 ER) was used and it was exposed to approximate total of 108000 pulse or 6.91200E-03 sec to get well exposed pictures as shown Figure 10. In this figure a film in a seal envelope was used and a key was placed on the window to serve as a radiographic shadow.

The intensity of X-ray though an attenuate media can be evaluated using the following equation

$$I = I_0 e^{-\mu t}$$

where I_0 is the source intensity, μ, t is the attenuation coefficient r and thickness of the filtering media, respectively. The parameter μ= ρc, where ρ is the density and c is the attenuation coefficient. In our experiment the filter is Pyrex glass with t = 0.3175 cm, ρ= 2.23 g/cm^3, c = 0.188cm^2/g (for spectrum with peak energy 15-KV). Thus μ = 0.419-cm^{-1} and the attenuation factor is 0.8754. The obtained spectrum is shown in Figure 11.

Since the developed ferrosource is a short pulsed device, the available X-ray meters that are use as counters/(unit time) to gauge the intensity and energy level are not practical tools for this measurement. The readings from Geiger are saturated and cannot quantify the intensity accurately. Due to the fact that we have short pulse duration of our radiation (100 nano sec), an alternative test was performed using an X-ray pulse detector and X-ray gauge system. The recorded pulses were measured after penetrating varies of thickness of aluminum plates. A layer of 1/16 in thick aluminum plate was placed in the observation windows to gauge the penetrating energy where two extremes are shown in Figure 12.

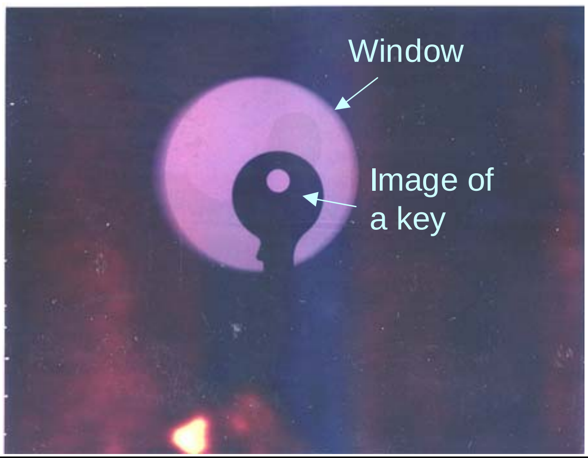

FIGURE 10: An X-ray radiograph of a key recorded though the window of the chamber using the emission from the ferrosource.

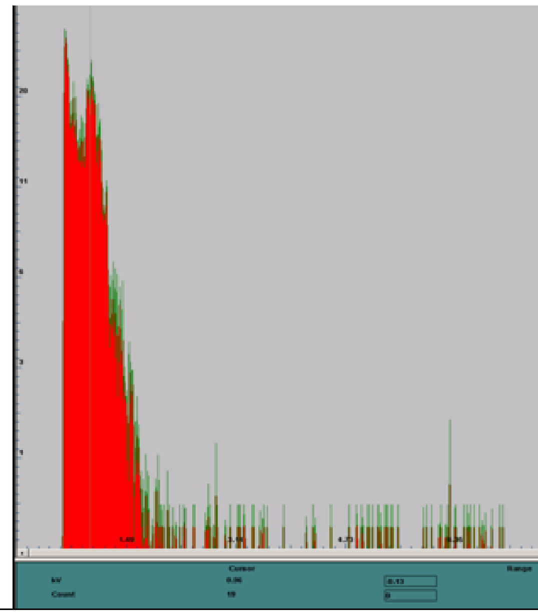

FIGURE 11: The measured spectrum of the emitted X-ray pulse.

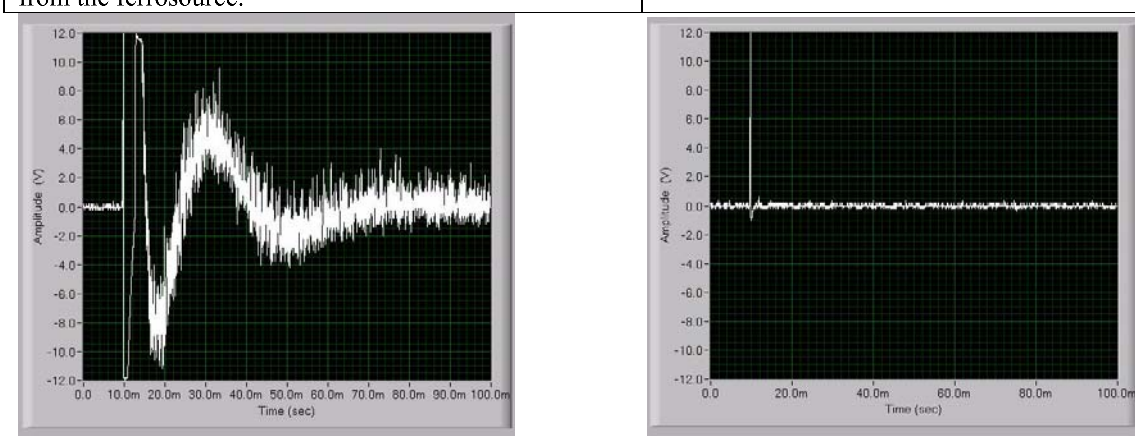

FIGURE 12: Two extreme intensity levels of X-ray recorded by the X-ray pulse detector and X-ray gauge system

4.0 SIGNIFICANCE OF RESULTS

A prototype of a ferroelectric based multiple radiation source was developed and tested. This prototype was used to demonstrate the feasibility to emit five radiation types enabling a new generation of compact, low power, low mass in-situ analysis instruments. These radiation types include visible light, ultraviolet, X-ray, as well as electron and ion beams. These types of emitted radiation can support multiple instruments that would potentially be used in future NASA missions to detect water, perform mineralogical/chemistry analysis and identify biological signatures. The new source was produced using a ferroelectric disk with a continuous ground electrode on one side and a grid-shaped electrode on the other side. The incomplete field generates plasma by a switching high voltage pulse, where various fixtures and sensors were used to produce and measure the emitted radiation types. A series of experiments were performed to evaluate the characteristics of the source and the control parameters.

ACKNOWLEDGMENT

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