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Towards Miniaturized XRF Systems: A MEMS X-ray Source for Space Exploration

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Summary:
The analysis of planetary surfaces composition using X-ray fluorescence (XRF) is essential for understanding geological processes and resource potential. Traditional XRF systems are based on bulky X-ray tubes or radioisotopes, limiting their use in space missions. This work presents a MEMS-based miniature X-ray source integrating a field emission electron source and a transmission target within a miniature silicon-glass structure. The source operates at low power (<0.1 W), while efficiently generating X-rays. By combining it with a small X-ray detector one obtains lightweight, energy-efficient planetary exploration instrument.

Keywords: MEMS, lunar regolith, space, XRF, X-ray source

Introduction

X-ray fluorescence (XRF) spectrometry is one of the most effective, and at the same time nondestructive, methods for analyzing the elemental composition of any materials. In space explorations it perfectly suits for analyzing lunar regolith and other planetary surfaces. Previous space missions have used mainly radioisotope radiation sources and conventional X-ray tubes [1-3]. While effective, these solutions have significant limitations: they are relatively large, heavy, and require significant amounts of energy, which creates a challenge to the miniaturization of scientific instruments for planetary missions. Consequently, there is a need for developing alternative X-ray sources that are compact, energy-efficient, and suitable for autonomous measurement systems.

Microelectromechanical systems (MEMS) technology opens up new possibilities for miniaturization of X-ray sources. By integrating functional components at the micrometer scale, compact and efficient X-ray generation systems can be created [4]. This paper presents a novel MEMS X-ray source that uses a field emitter as an electron source and a transmission target for X-ray generation [Fig. 1]. The silicon-glass structure of the device allows for reduced system weight and dimensions, and the use of a combination of magnetic and electrostatic focusing of the electron beam enables high efficiency. In addition, the source offers the possibility to control emission intensity, energy, and electron beam size. The source enables efficient XRF operation at very low power consumption (<0.1 W).

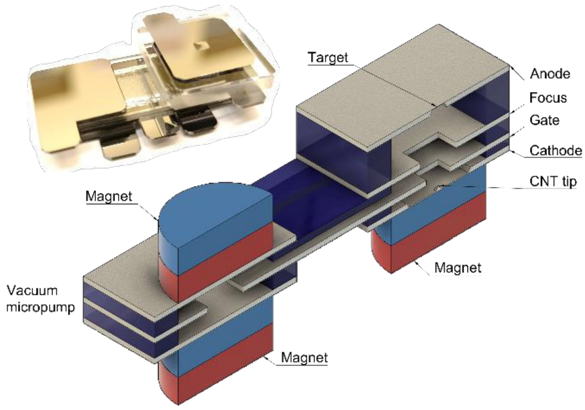

Figure 1. Structure of the MEMS X-ray source

In this article the basic characterization of the X-ray source as well as the analysis of its potential for XRF studies of planetary and lunar surfaces has been carried out.

Device characterization

The X-ray sources for XRF systems must provide sufficient intensity while being compact, energy-efficient, and lightweight.

The developed MEMS X-ray source represents a significant advancement, offering a compact design with high radiation intensity and low power consumption. Unlike X-ray tubes, MEMS source generates intense radiation at low energies [Fig. 2], improving the excitation efficiency for light elements such as oxygen, sodium, or magnesium. The design of electron-optics column allows for precise control over the electron beam, and tailoring radiation characteristics for specific analyses. Operating at lower voltages (from a few to 30 kV), MEMS source requires only 0.1 W, making it energy efficient for planetary missions. With a mass of just 3.7 g for the MEMS structure and 3.4 g for magnets, it is significantly lighter than traditional X-ray tubes.

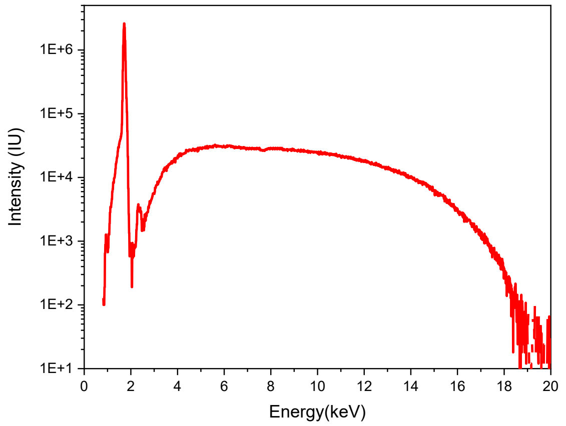

Figure 2. X-ray spectrum emitted by a MEMS source in vacuum

XRF analysis of lunar regoliths

This study investigates the use of a MEMS X-ray source together with compact Ketek X-ray detector to analyze the chemical composition of lunar regolith simulants under vacuum conditions (5E-5 hPa). XRF measurements were performed on four simulants and the results showed a clear and intense signal, particularly for light elements such as sodium (Na), magnesium (Mg), and aluminum (Al). A total of 20 characteristic peaks were identified, highlighting the presence of elements commonly found in lunar basalts and anorthosites, including sodium (Na), magnesium (Mg), aluminum (Al), silicon (Si), phosphorus (P), sulfur (S), chlorine (Cl), potassium (K), calcium (Ca), scandium (Sc), titanium (Ti), neodymium (Nd), iron (Fe), nickel (Ni) and copper (Cu). In addition, a small argon (Ar) peak was detected, indicating the presence of residual amounts of argon in the vacuum [Fig. 3]. The detected elements align with the manufacturer's data for the simulants (except manganese) [5].

Conclusions

This study demonstrates that the developed MEMS X-ray source, with its high intensity in the low-energy range, significantly enhances the efficiency of lunar regolith analysis, particularly for detecting light elements essential for lunar resource exploration and future In situ resource utilization (ISRU) missions.

The presented solution may find application in future planetary missions, offering a lightweight and energy-efficient alternative to traditional sources used for XRF, significantly expanding the possibilities for autonomous analysis of regoliths and other extraterrestrial surfaces.

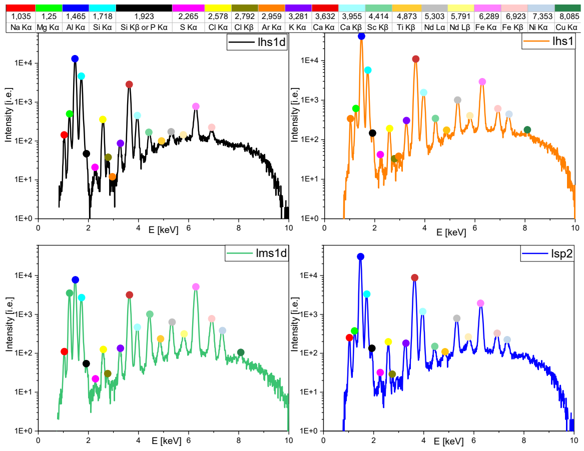

Figure 3. XRF analysis of lunar regolith simulants under vacuum conditions

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