Abstract

This doctoral dissertation concerns the development and implementation of a fully integrated, miniature X-ray source using MEMS (Micro-Electro-Mechanical Systems) technology. The aim of the research was to design and implement an autonomous X-ray generation system with low power consumption, small dimensions, and potential applications in mobile, integrated analytical and diagnostic systems.

This thesis analyzed the current state of knowledge regarding the physical foundations, mechanisms of X-ray generation, and technical solutions, with particular emphasis on miniaturization. Based on a literature review and an analysis of the limitations and challenges encountered in existing miniature X-ray sources, the design, technological, and operational requirements for the newly designed source were formulated. Based on these assumptions, the world's first MEMS X-ray source was developed, consisting of a field-effect cathode (made of silicon blades and/or a composite of carbon nanotubes and PVP (polyvinylpyrrolidone)), an electron-optical column enabling electron beam focusing, a transmission target optimized for X-ray generation in the energy range up to 25 keV, and an integrated ion-sorption micropump ensuring high vacuum. The technological process was based on photolithography, silicon and glass etching, deposition of metallic layers, and anodic bonding under controlled conditions.

Experimental studies included characterization of the field emitters (measuring I-V characteristics, emission stability, and electron spot size), verification of target properties (the effect of material and geometry on the spectrum and radiation intensity), tests of the beam focusing system, and assessment of the vacuum conditions within the structure. The integrated device was tested for X-ray generation outside the vacuum chamber. Studies were conducted on the intensity, energy, spatial distribution, stability, and repeatability of radiation generation.

The obtained results confirmed the possibility of generating X-rays with controlled parameters in a microscale, hermetic MEMS structure. The developed solution opened up potential applications in compact X-ray fluorescence (XRF) analyzers, integration with microfluidic "lab-on-chip" systems for biological and chemical research, and in satellite instruments requiring miniature calibration sources.

This work contributes to the development of microsystems technology by: developing stable electron microemitters, developing new methods for electron beam control, optimizing transmission targets, developing methods for encapsulating and maintaining a vacuum in MEMS structures, and integrating a complete X-ray generation system in a single structure. These results provide a foundation for further research on microtomography, in situ X-ray spectroscopy, and next-generation hybrid radiation sensors.

Keywords: miniaturization, MEMS, X-ray source, field emission, ion–sorption micropump, XRF.