A Fully Chip-Scale Integrated X-Ray Source

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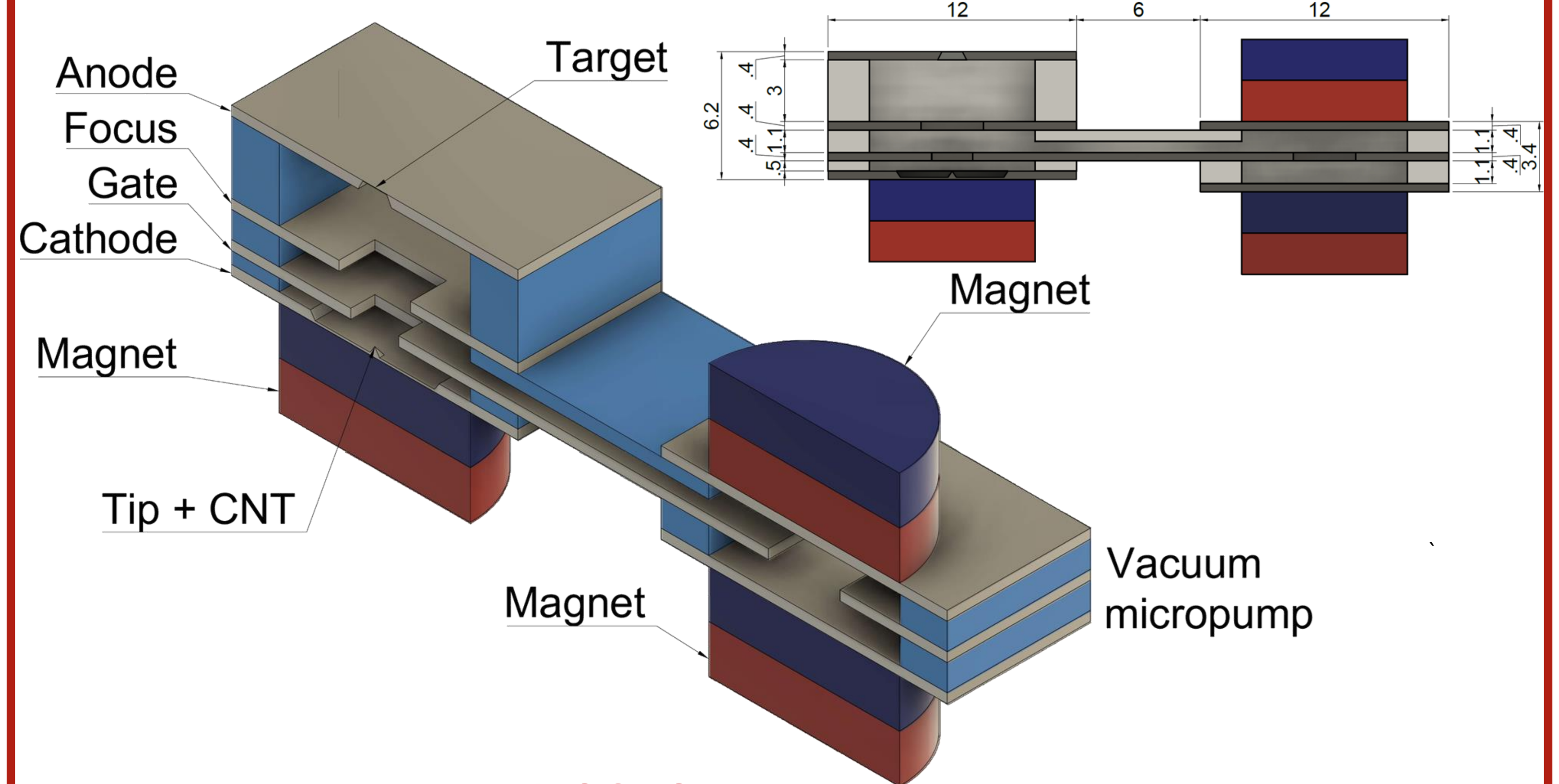
Introduction

In this work we present the first stand–alone X-ray source made in MEMS (micro-electro-mechanical system) technology, which is able to operate outside a vacuum chamber. This source operates in transmission mode and generates radiation up to 30keV. Due to the technological compatibility with other MEMS structures and possibility of adjusting its parameters, this source can be easily applied in different X-ray experiments performed in micro scale. We have overcome the existing problems with hermetic sealing, high vacuum stabilization and risk of electric short-circuits which have so far prevented the realization of such a device.

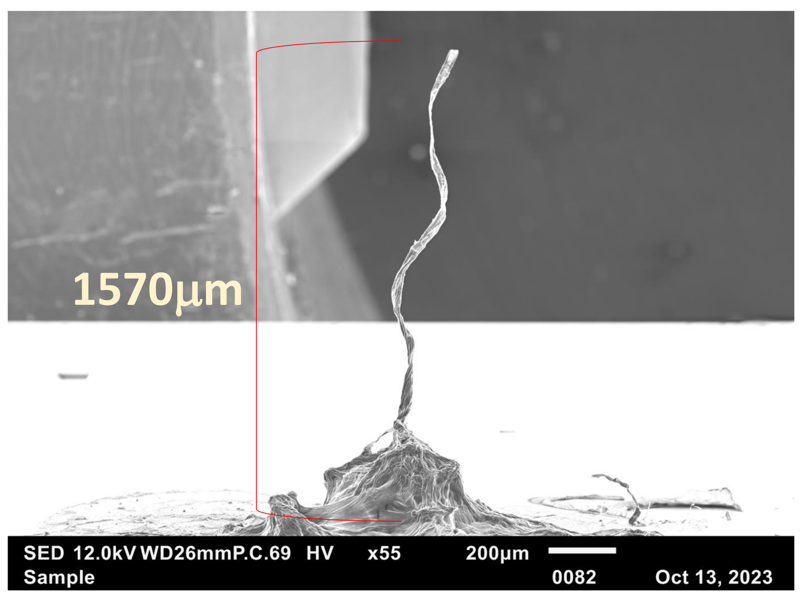
Construction and components of the MEMS X-ray source

- MEMS X-ray source is made out of silicon and glass wafers.
- Silicon chips form the electrodes: a cathode with a field emitter, an extraction gate and a target.
- Borosilicate glass is used for preparation of spacers between the electrodes.
- The X-ray source is integrated with an ion-sorption pump, responsible for providing high vacuum conditions.
- The external dimensions of the complete structure are 30×12×6,2 mm^3.

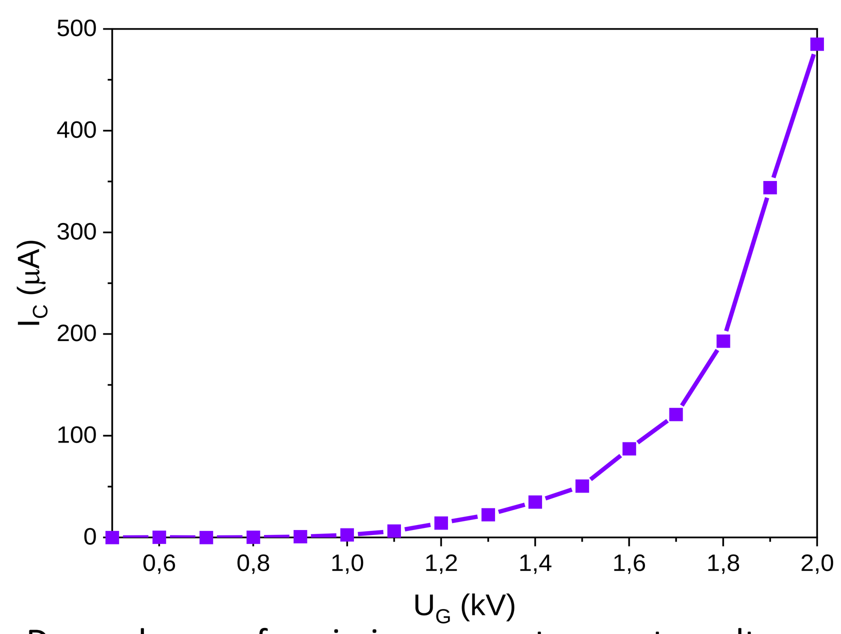


Field electron source

We have developed completely new field electron sources in the form of spatially formed threads made of a composite of carbon nanotubes and cross-linked PVP. Such sources exhibited emission currents on the order of several hundred microamperes and, importantly, were not damaged and their emission properties did not deteriorate after the anodic bonding process, which distinguishes them from other field electron sources made of carbon nanotubes.



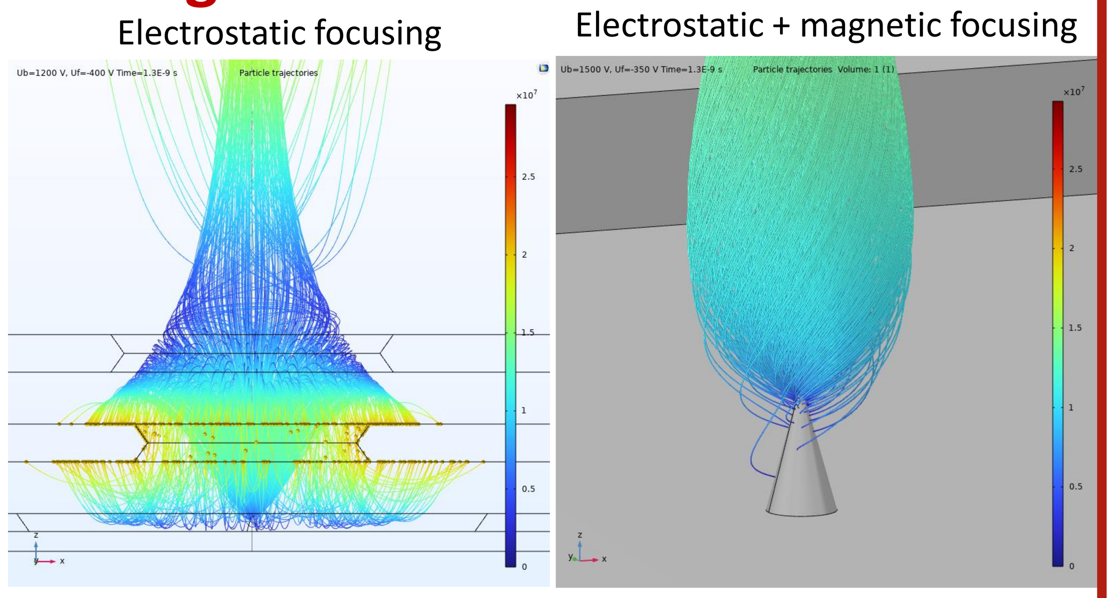
SEM image of the CNT+PVP tip



Dependence of emission current on gate voltage for the CNT+PVP tip.

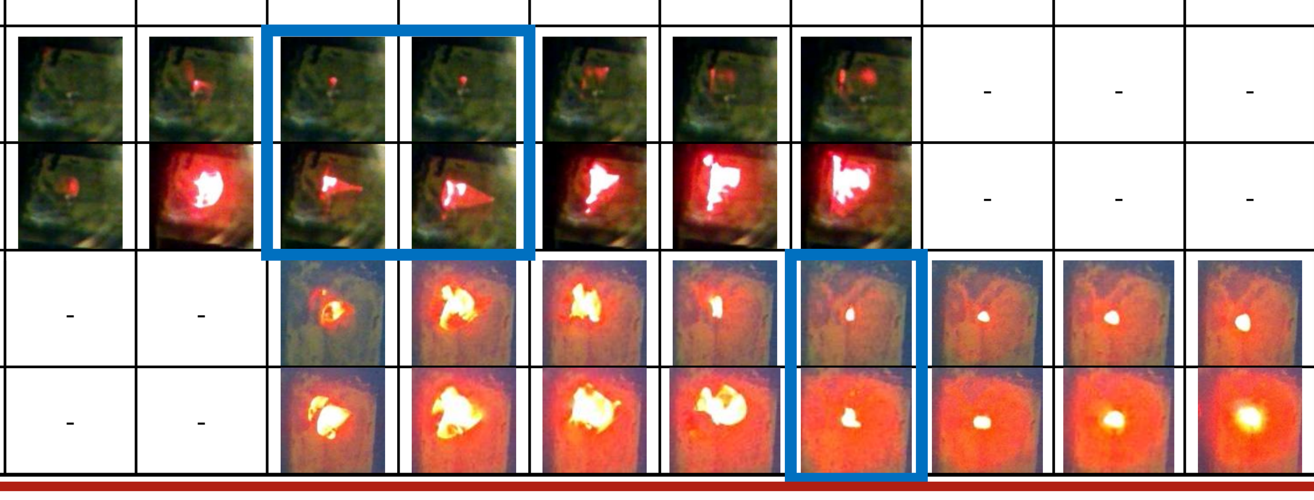
Magnetic focusing of an electron beam

Both focusing methods gives strongly focused electron beam on the screen. However, using magnetic focusing we lose only ~5% of emitted current, thus electron beam spot on the screen is brighter.

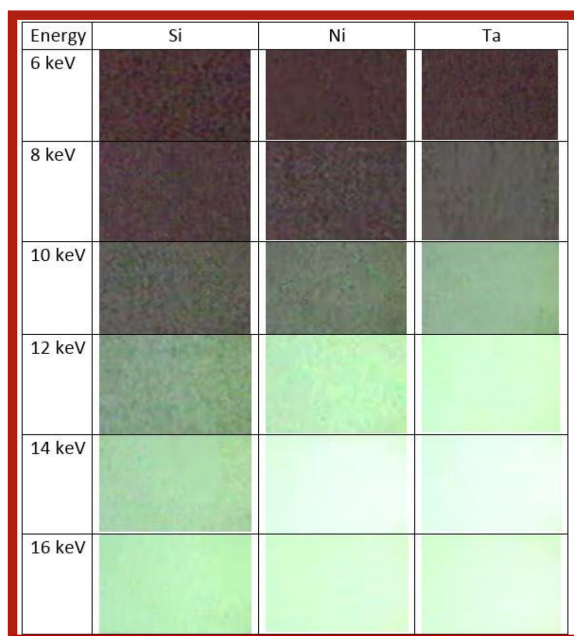


Electron spot images observed on the luminophore (image size: 5.5mm × 5.5mm)

Focus voltage [V]	-600	-400	-200	0	200	400	600	800	1000	1200
without magnet U_{gate}= 1.2kV								-	-	-
without magnet U_{gate}= 1.5kV								-	-	-
with a magnet U_{gate}= 1.2kV	-	-								
with a magnet Ugate= 1.5kV	-	-								

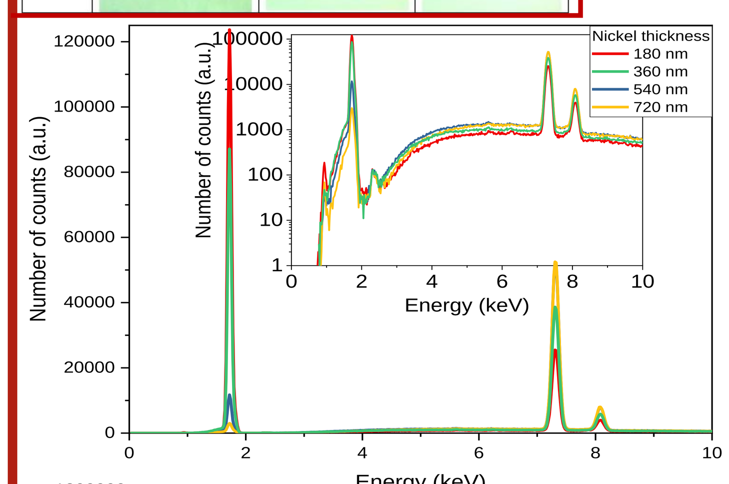


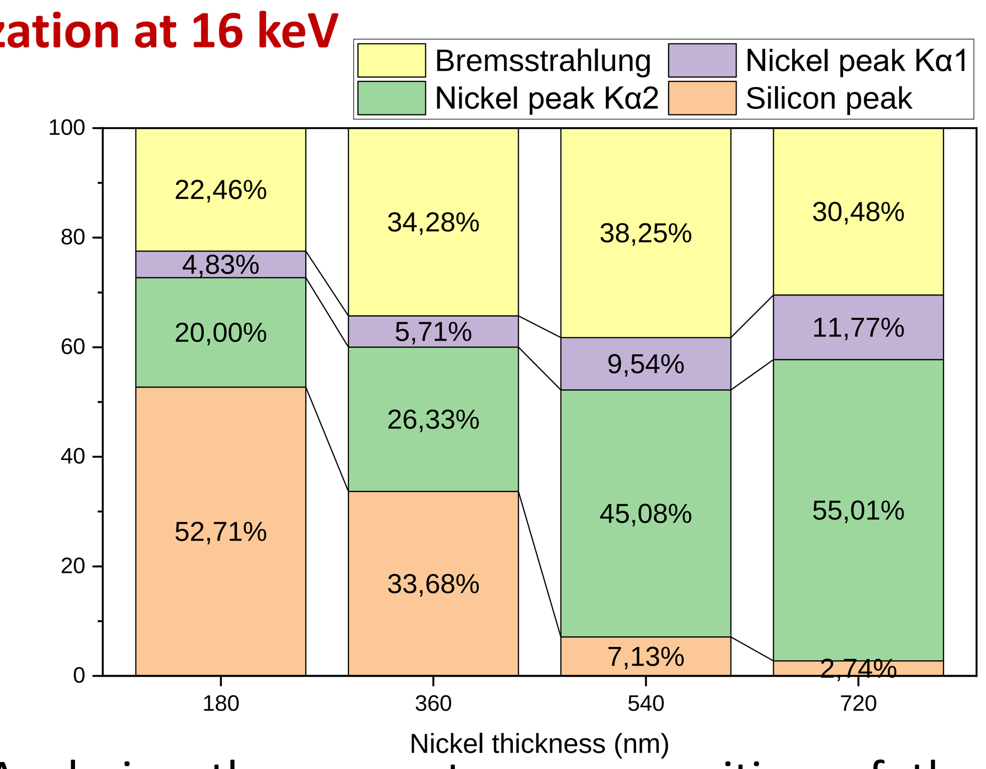
Transmission target

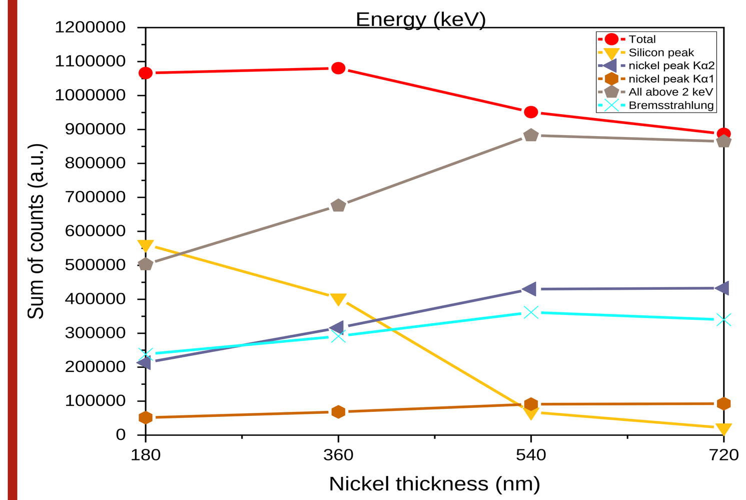


15 µm silicon membrane is used as a substrate for the target. Additional metallization is applied to silicon to improve the intensity of the radiation generated. Nickel and tantalum were tested. The use of metallization on silicon improved the intensity of the emitted radiation.

Emission of monochromatic X-ray for nickel metallization at 16 keV

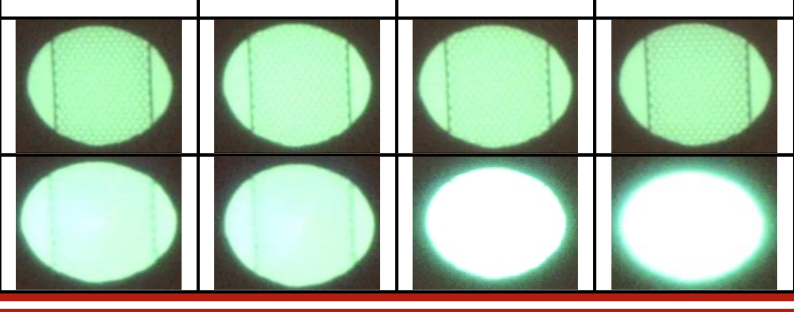




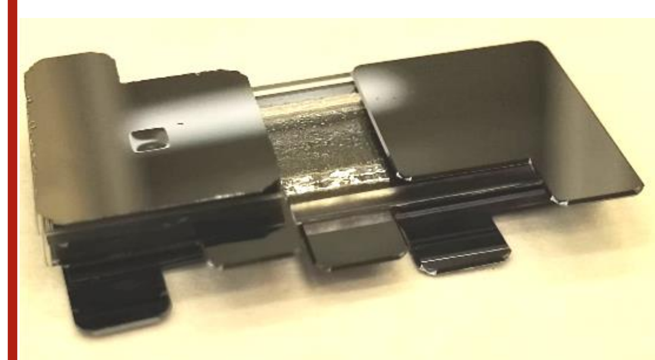


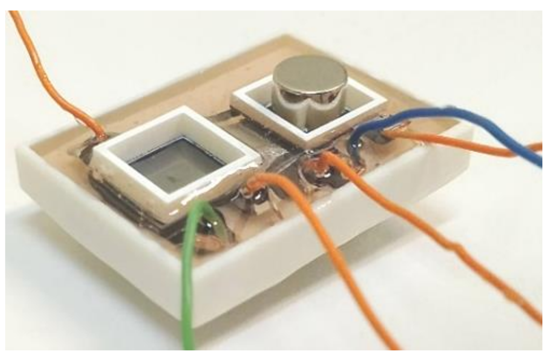
Analyzing the percentage composition of the radiation spectrum, it is apparent that there is a significant increase in the proportion of nickel peaks for the thicker metallizations, where the kα2 peak at 720 nm metallization reaches 55%. By manipulating the metallization thickness, the desired spectral composition including monochromatic radiation can be obtained. It can be seen that metallization significantly improves the intensity of the resulting image.

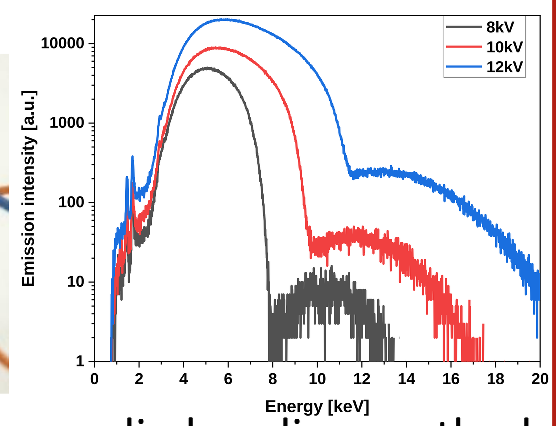
Nickel thickness [nm]	180	360	540	720
12 keV				
16 keV				



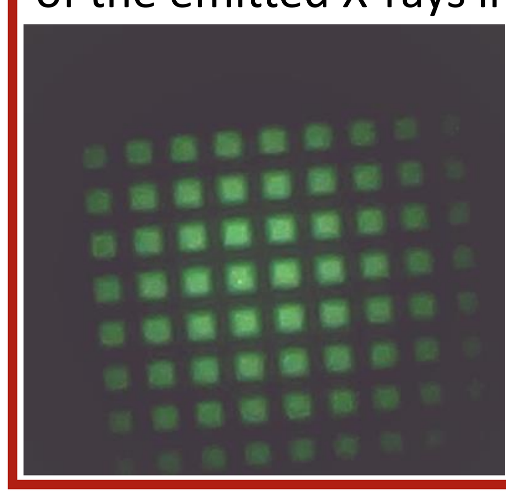
Complete MEMS X-ray source







All silicon and glass elements were connected using the anodic bonding method, with the last bonding performed under vacuum conditions (10^{-5} mbar). The ion-sorption pump is only switched on to ensure that the pressure inside the structure reached 10^{-7} mbar. During source operation the ion-sorption pump was switched off. In order to protect the structure against external breakdowns between the electrodes, the whole chip was covered with an epoxy resin, creating a complete stand-alone MEMS device. Preliminary imaging tests were performed with this X-ray source, examining a silicon mesh, a leaf and a printed circuit board. The spectra of the emitted X-rays in the air atmosphere were recorded.



Conclusions

This work represents a breakthrough achievement in the field of MEMS and vacuum technology - the development of the first fully integrated MEMS-based X-ray source. This X-ray source has been designed to allow precise control of electron emission, electrostatic focusing and electron energy without significantly affecting the other parameters for energies up to 30keV, resulting in efficient X-ray generation. The technology used opens up new possibilities for applications - particularly in MEMS systems used for biological, medical and analytical research at the micro-scale. Additionally, the monochromatic nature of the radiation enables precise medical therapies, the calibration of X-ray detectors, also in space, and the imaging of small objects.

More publications

Acknowledgments

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