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Detection of Electron Beam in Atmospheric Pressure Using CMOS Image Sensor

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Summary:
In the article, a new detection system that enables observation of the electron beam signal passing through a gas layer at atmospheric pressure is presented. An experimental setup consisting of an electron gun (electron emitter, extraction, and focus electrodes), silicon nitride membrane, and a CMOS image sensor is described, as well as first image of the electron beam spot after passing through 400 µm of air at atmospheric pressure is presented.

Keywords: electron detection, field emission, CMOS sensor, MEMS

Introduction

The theory of electron motion in gases dates to the beginning of the twentieth century, mainly due to the work of Townsend [1]. In the middle of the century, more accurate experiments on electron mobility and determination of electron drift velocity were carried out [2, 3]. Recently, new devices capable of mapping the complete spatial-temporal evolution of electron swarms have been reported [4, 5]. They allowed to determine several important parameters, i.e., drift velocity, longitudinal diffusion coefficient, and effective ionization coefficient.

The apparatus' mentioned in [2–5] that are capable of measuring electron swarms are large and complicated, similar to spectrometers. With the evolution of microelectronics and microsystem technologies, vacuum microelectronics systems are being miniaturized, for example, the miniature MEMS scanning electron microscope was developed at Wroclaw University of Science and Technology [6], where the atmospheric pressure electron detection method was developed. The described method shows that the electron signal that passes through silicon nitride membrane is not absorbed by air but can be collected at the anode, as the theory of electron motion in gas predicts. The measured electron signal depends on the gas type, pressure, and distance from the membrane to the detector. To find out how those parameters influence the electron beam in gas a new detection method using a CMOS image sensor needs to be developed to observe the electron swarm development in real time.

Recently, at Ostbayerische Technische Hochschule in Regensburg, Germany, an electron beam detection device was developed that uses the Raspberry Pi High Quality Camera [7]. Their research enables the emission current value to be linked to the signal intensity measured on the camera, so that the electron emission parameters can be measured in real time. The results are obtained in high vacuum.

This article presents the first results of using the CMOS image sensor electron detector developed at the OTH for investigation of electron beam measurements in atmospheric pressure.

Experimental Setup and Measurements

The experiment involves observing a beam of electrons that come out of a vacuum chamber through a silicon nitride membrane (1) mounted on top of a small vacuum chamber, propagating in a gas using a CMOS camera (2) (Fig. 1). Inside the vacuum chamber, a small electron gun, consisting of a silicon electron emitter covered with carbon nanotubes and extraction and focus electrodes, was mounted. The silicon membrane was vacuum sealed to the vacuum flange with a 3 mm hole drilled through. The CMOS image sensor prepared at the OTH Regenburg was placed in front of the membrane.

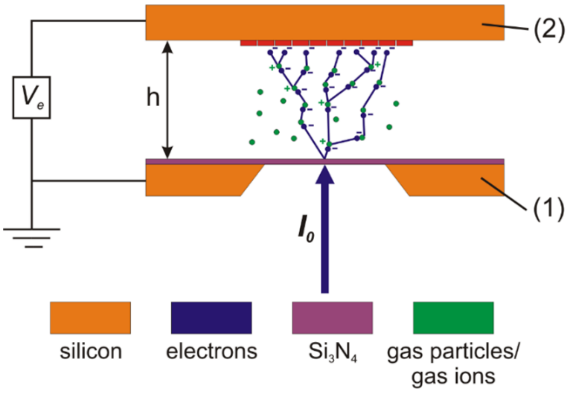

Fig. 1. Basic schematic of the MEMS/CMOS electron detection measurement system.

The experiment was carried out with 10^{-5} mbar vacuum inside the chamber. The emitter was supplied with –2 kV and the extraction voltage was set to –500 V to limit the emission current to limit the initial electron beam current to 1 µA. The voltage at the focus electrode (–2 kV) allowed focusing of the beam to be focused on the membrane. The effect of the electron beam passing through ~400 µm of gas was observed on the CMOS sensor (Fig. 2).

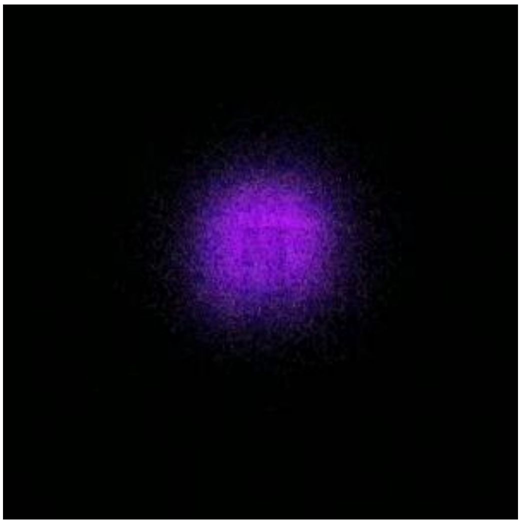

Fig. 2. Image of the electron beam spot taken with Raspberry Pi High Quality Camera.

Conclusions

The results show that it is possible to use the CMOS image sensor for electron beam observation under atmospheric pressure. The CMOS sensor was developed for electron beam current measurements in high vacuum. The sensor is suitable for registering the electron beam spot shape, from which one can observe if the electron emitter is symmetric, but also by calculating the image intensity, the emission current can be calculated.

Similarly, observing the electron beam spot after passing through a gas (Fig. 2) one can observe the diffusion of electrons in a gas, but for now it is not clear if it is possible to calculate the electron beam current from the image intensity. This will be done in the next step of the investigation. We will check what signal is actually detected by the CMOS sensor and how the parameters of the gas (i.e. gas type, gas pressure), and the detection setup (i.e. the distance from the membrane to the sensor) will influence the results.

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