Detection of the angular distribution of the signal electrons in VLESEM

Miroslav Horáček

Institute of Scientific Instruments AS CR, Královopolská 147, CZ-61264 Brno, Czech Republic
http://www.isibrno.cz; e-mail: mih@isibrno.cz

Summary: The aim of this work is to design a detector for the angle and energy-selective detection of signal electrons in very low energy scanning electron microscopy (VLESEM), based on the directly electron-bombarded CCD sensor (EBCCD). The planar CCD sensor is very suitable for conversion of the area information carried by impinging electrons of the signal beam into the electrical signal that can be further processed.

1. Separation and detection of the signal electrons in VLESEM

The essential element of a low energy electron microscope (LEEM) which makes it different from the classical microscope (TEM) is the cathode lens. The advantages of the immersion objective (magnetic lens plus cathode lens) were fully recognized only recently [1]. So far, experiments demonstrating capabilities of very low energy scanning electron microscopy (VLESEM) have been realized at ISI Brno. Secondary and backscattered electrons are reaccelerated in the cathode lens and their trajectories are similar to those of the primary beam electrons. The main (central) part of the signal electron beam is not detected by classical SEM detectors. A solution is to separate the signal and the primary electron beams, and only next to detect the signal beam with its most useful part of electrons. The Wien filter is suitable for the separation of the primary and the signal electron beams. The main benefit of the use of this separator is that the trajectories of the primary beam remain the same as those without the separator.

A schematic arrangement of the optics with an immersion objective, Wien separator and electron bombarded CCD detector is shown in Figure 1. The primary electron beam (up to 10 keV) from the source of electrons passes through the Wien filters which are balanced so that the axial ray with the nominal energy is not affected. Next, the primary beam passes through the deflection system, is focused by the magnetic lens, decelerated to the desired energy by the cathode lens and scanned over the specimen. The beam of signal electrons accelerated by the cathode lens approximately to the primary energy, passes through the immersion objective lens and it is deflected by the Wien filter to the region of the electrostatic transport optics shielded from the primary beam. The transport optics directs the signal beam to a suitable detector [2].

The arrangement employing the Wien filter makes the angle and energy-selective detection of signal electrons possible and gives rise to the corresponding sort of contrast, if the signal is properly collected. The use of CCD is very suitable for this purpose. The planar CCD sensor converts the angular distribution of electrons of the signal beam into the electrical signal that can be further processed, which makes it possible to form the image corresponding to the signal electrons from the selected areas of the CCD sensor.

2. Experiments and results

For the first experiments we used the easily available low resolution sensor suitable for direct detection of electrons - Virtual phase CCD TC211 made by Texas Instruments (192 pixels (H) by 165 pixels (V)-"o by p"), i. e. the front side bombardment mode was used. The average EBS gain G (number of signal electrons in the potential well generated by one incident electron) and detection efficiency ε as a functions of the incident electron energy E were measured and calculated for 3, 4 and

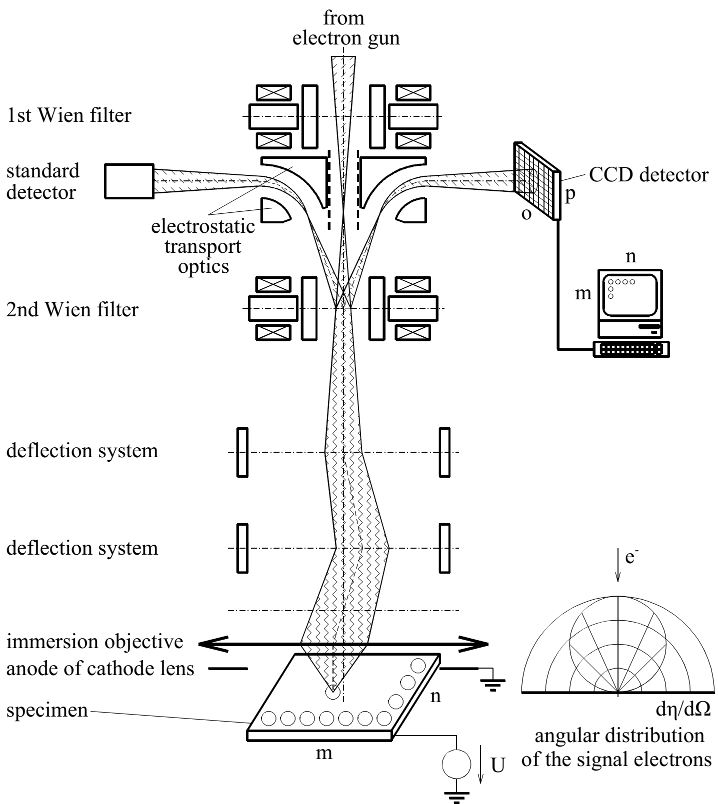

Figure 1: *VLESEM with EBCCD detector.*

5 keV. The values of the gain and detection efficiency corresponding to the electron energy are G = (0.13, 0.23, 0.44), ε = (1.6×10^{-4}, 2.1×10^{-4}, 3.2×10^{-4}). Such a gain is too small to create the image of the specimen (with the resolution "m by n" 512 x 512 points) by detecting the angular distribution of the signal electrons (as shortly described above and more in detail in [2]) in reasonably short time (up to 10 min).

A solution can be to replace the sensor by a low resolution thinned back-side illuminated CCD with an efficiency higher than 0.1 at energies below 5 keV. Such a sensor is now produced and commercially available (80 x 80 1:1 image format; *G (2 keV)* = (150 ÷ 200) ≈ *ε (2 keV)* = (0.27 ÷ 0.36)). Using this sensor, the total time to scan one image of the specimen and to collect the signal electrons and to process the signal from CCD for 512 x 512 points of the scanning matrix was calculated to be 13 min (including collection-integration time for 1 point of the order of 10^0 ms).

We can compare thinned back-side directly bombarded CCD with detectors using electron-photon conversion and only next using CCD to detect photons. In [3] a system with the YAG scintillator and fiber optics was presented and gain *G (100 keV)* = 142, and for P20 screen *G (100 keV)* = 780 were measured and calculated. After translation on 2 keV we can estimate *G (2 keV)* ≈ 3, and for P20 *G (2 keV)* ≈ 16. In [4] a system with the YAG scintillator and lens optics was presented. From the presented parameters we can estimate *G (2 keV)* ≈ 1.2.

The EBS gain of the detector is the key parameter for use in VLESEM. That is because we must process a very high amount of data in a short time (512 x 512 images of "o by p" CCD sensor).

For TC211 the dark current as a scale factor of the radiation damage was measured. The measured values fluctuated during the experiments from 5.0 nA/cm^2 to 19.0 nA/cm^2 in the dependence on the temperature and electron energy. The dose during one measurement was of the order of 10^9 electrons/pixel. The total dose was approximately 2×10^{10} electrons/pixel during 10 hours. On using the back-side bombarded CCD at energies of up to 5 keV a significant damage is not expected and a dynamic range above 50 dB for integration time under 10 ms is expected.

The experiment based on the back-side illuminated CCD as an area-selective detector of electrons in low energy electron microscopy is supported by the grant no. 102/00/P001 provided by the Grant Agency of the Czech Republic, and it is carried out at the laboratories of the Institute of Scientific Instruments, Brno, Czech Republic.

References

[1] M. Lenc, PhD Thesis, Delft University of Technology, The Netherlands (1992).
[2] M. Horáček, Journal of Computer-Assisted Microscopy, **Vol. 10**, No. 1 (1998) 23.
[3] S. Kujawa, D. Krahl, Ultramicroscopy **46** (1992) 395.
[4] R. Sikeler, K. H. Herrmann, ICEM 13-Paris (1994) 217.