Ultramicroscopy 145 (2014) 1–2

Contents lists available at ScienceDirect

Ultramicroscopy

journal homepage: www.elsevier.com/locate/ultramic

Editorial

Foreword to the special issue low-voltage electron microscopy

Today, low voltage electron microscopy is a topic of high relevance all over the world; in Japan [1], America [2], and Germany [3] particular research projects are even dedicated to unravel the atomic and electronic structure of radiation sensitive matter with 60 kV electrons and below. It seems that research comes back to its voltage-routes of the early days of electron microscopy, when in 1933, the German engineer and later Nobel Laureate Ernst Ruska approached the German Research Foundation for support to develop an "Übermikroskop" with a 60 kV electron beam enabling the visualization of the structure of sub-micrometer objects such as viruses which cannot be imaged with the light microscope [4]. What happened since then? The dreams of Otto Scherzer [5] and of Richard Feynman [6] to realize atomic-resolution electron microscopy has become true by the correction of the aberrations of the electron lenses [7,8,9]. Today mankind benefits from a more detailed insight into the atomic and electronic structure of matter than ever before.

Sub-Angstrom resolution is now possible not only at relatively high voltages between 200 kV and 300 kV but down to about 60 kV. Owing to the progress in aberration correction, single atoms and single atomic columns can be imaged distantly from each other even for materials which are destroyed at voltages above the knock-on threshold. This threshold is for most low-Z materials below 60 kV. The improvement of the resolution by means of aberration-correction goes in parallel with contrast enhancement due to the fact that more path-corrected electrons contribute to the image. Moreover, the contrast is strongly increasing by lowering the voltage and the old approach of Wilska with his high-contrast 6 kV electron microscope in 1964 [10] becomes now a renaissance. Alternative low-voltage strategies such as scanning electron microscopy, low-energy electron microscopy (LEEM), and diffractive imaging have been improved or newly developed with the aim to enhance resolution, contrast, and the surface-sensitivity at the same time. Aberration-correction of the unavoidable chromatic and spherical aberrations of round electron lenses has become an important strategy [11,12].

The driving force for all these developments is predominantly radiation damage, or with other words: imaging the pristine structure of an object; a topic of enormous relevance ever since for biological objects and nowadays for those present and future materials, which are bridging the former frontier between materials and life sciences. It is worth to mention that in the very first volume of Ultramicroscopy in 1976 two research groups published their results on how much the beam energy can be reduced while still gaining useful signals from the sample surface with contradicting opinions [13,14].

In this respect also our new issue comes back to its routes with publication addressing *theory*, *instrumentation*, *application* and *general* question on the low-voltage topic and repeating the question from 1976 at the end, on "how low" we should go with the accelerating voltage, as you will see below. It is not always easy to draw borderlines between "high voltage" and "low voltage". Atomic resolution can now be achieved with voltages down to about 20 kV. For a TEM and scanning TEM this is very low, but for a SEM and LEEM this voltage is very high. You will, however, have to follow the discussion in the papers to understand the terminology.

To theory: Three papers on theoretical questions are aimed for understanding low-voltage low-dose data: on image calculations for low-voltage and low-dose (Lee et al.), on image processing for low-dose data (Meyer et al.) and on image reconstruction of low-dose, low-voltage holographic data (Latychevskaia et al.). These papers show that new routes of image analysis, reconstruction, and image calculations need to be applied for correctly understanding low-dose and low-voltage data.

To instrumentation: Three papers are devoted to instrumentation showing very new approaches for imaging electron-beam-sensitive materials including lattice imaging in an SEM (Konno et al.), aberration-corrected, dual-beam low-energy electron microscopy (Mankos et al.), and low-voltage TEM and STEM (Sasaki et al.).

To application: Four further papers are targeting the application of high-resolution low-voltage TEM/STEM/SEM/electron holographic imaging to practical problems in materials science, life science and to those objects which are composed of hard and soft matter (Bell et al., Boothrough et al., Drummy et al., Longchamp et al.)

To general topic on low voltage: The low-voltage issue is finishing with three papers addressing basic questions on the choice of the accelerating voltage (Egerton), on how to convert an electron microscope into a low-voltage microscope (Stöger-Pollach), and how low should we go in the acceleration voltage (Stöger-Pollach) with emphasis on the discussion of the suppression of the excitation of Cerenkov losses and the reduction of the inelastic delocalization in electron energy loss spectrometry.

We do hope that you are as excited as we are about these topics and publications, that they meet your interest and motivate you to join the low-voltage community with thrilling publications in the future. There is plenty of work to be done as you know: "Science never solves a problem without creating ten more." (George Bernard Shaw)

http://dx.doi.org/10.1016/j.ultramic.2014.05.002
0304-3991/

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Received 2 May 2014; accepted 5 May 2014

Available online 17 May 2014