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Micro-Spectroscopy in the Low-Energy Regime: Secondary Electron Detection and Energy Analysis in the Scanning Field-Emission Microscope

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In a Scanning Field-Emission Microscope (SFEM) [1-3] originating from the topografiner technology [4], the tip-surface distance is few nanometers to few tens of nanometers and the electrons impinging on the target are field emitted from the tip. Accordingly, SFEM is not only capable to map the surface micro-topography - as done in conventional Scanning Tunnelling Microscopy - but electrons can escape the tip-surface junction and their intensity detected as a function of the surface position (imaging mode). The SFEM operates at very low primary energies ($\leq 100\text{eV}$) [5], so that the fundamental mechanisms relevant for the generation and emission of Low-Energy Secondary Electrons are poorly understood. Energy analysis of these electrons would provide useful information, essential e.g. for understanding the origin of contrast in imaging. However, such an energy analysis is made technically difficult by the presence of extremely strong ambient electric fields at the site of origin of the electrons. To overcome this limitation, we have designed and implemented a prototype miniature energy analyser, employing a Bessel Box (BB) [6] technology. The compact design of such a BB, mountable in direct proximity of the tip-surface region, could provide a decisive help toward refining the energy analysis of these Low-Energy Secondary Electrons and toward shedding light on the tangled phenomenon of secondary electron emission. Energy enhanced electron detection in SFEM could lead not only to a novel miniaturized spectro-microscopy device but also provide information about fundamental mechanisms of low energy electron scattering and secondary electron production.

1. Introduction & Motivation

The release of electrons from a target induced by electron excitation leads to the formation of an electron spectrum whose characteristic energy (and momentum) distribution can be investigated by means of energy resolved spectroscopies. Characteristic spectral features can be directly linked to the electronic structure of the target (both below and above the vacuum level), to inter-band transitions and to further excitation channels, such as those involving collective modes of the electron gas, commonly known as *plasmons*. In addition, the angular distribution of elastically scattered electrons can deliver information on the long-range order of the investigated target (diffraction).

Alternatively to electron excitation, electrons can be injected into the surface of a material, e.g. using the direct quantum mechanical tunnelling in a Scanning Tunnelling Microscopy (STM) experiment. This quantum tunnelling effect is routinely exploited for imaging purposes, with the aim of obtaining information about the surface morphology and composition. In particular, STM probes the local density of states of the sample surface, by monitoring

the tip current while scanning across the surface. STM can be operated, however, in a field emission mode, when the tip is retracted to few nanometers or few tens of nanometers. In this mode, a new electronic system is created at the junction, consisting of those electrons which actually manage to escape the tip-surface junction. It has been shown - and we also are going to discuss this in the present paper - that (mainly through the work function, Φ , of the surface), intensity variations (contrast) in SFEM images enable to retrieve chemical information about the probed area.

The largest component making up every electron signal detected either via spectroscopy or in microscopy is provided by the Low-Energy Secondary Electrons (LE-SEs with kinetic energies $\leq 50\text{eV}$) [5]. For this reason, a detailed understanding of the generation-ejection mechanisms of these ubiquitous SEs from solid surfaces is of paramount importance to properly interpret the detected signal and important features such as the contrast in imaging.

One unique possibility to combine knowledge and information retrieved from both worlds of microscopy and spectroscopy - is feasible in the SFEM (known also under the acronyms of NFESSEM, SFM [1,2] and

FE-STM [3]), a technique directly descendent from the topografiner technology [4], which enables to measure both the surface topography (through the field emitted current) as well as detecting those electrons which manage to escape the tip-surface tunnel junction.

The presence of strong electrostatic fields in the junction region where the electrons are excited renders the detection of the emitted electrons inherently difficult in the SFEM mode, both by limiting the escape of the electrons, by complicating their detection and by hindering the interpretation of the detected signal (like the contrast formation).

With the aim of improving detection and analysis, we are currently performing tests on a miniature electron detection unit employing a Bessel Box energy analyser [6]. The reduced dimensions of such a compact energy analyser has the potential of enabling its employment very close to the sample surface, thus minimising the aforementioned electric fields effects.

Preliminary experimental results demonstrate the capability of this analyser to collect electron spectra. They are discussed along with the design and implementation of this miniature energy analyser into our SFEM system. The gathered notions are further used in an attempt at interpreting both the contrast formation and its reversal in SFEM-images.

2. Experimental & Design

The STM-based instrument is operated in a mode where the tip is retracted from the sample surface at a typical distance of some tens of nanometres (5-30 nm range) and with negative voltages of the order of few 10 of V. A well-defined electron-beam emitted from the tip is accelerated towards the surface, inducing the generation of low energy electrons. The intensity of these ejected electrons (both inelastically back-scattered and low energy secondaries) is used to produce topographic images with high spatial resolution. The sample current is monitored as well as the intensity of those electrons which manage to escape the tip-sample junction. Those travelling almost parallel to the surface are collected using a channeltron by means of which the total electron yield is recorded. (see fig. 1(a)). The SFEM instrument described in this work is currently endowed with a conventional hemispherical energy analyser (shown in figure 1(a.)). This allows performing the energy analysis of those electrons that escape the junction (average energy resolution: about 1.5eV, when operated at pass energies ranging from 20 – 100 eV).

Particular care is dedicated to the optimisation of the electron optics at the entrance of this analyser, with the aim of reliably acquiring complete electron spectra at low primary energies, e.g. of ≤ 60 eV. The entrance cone of the analyser is positioned at ca. 3cm distance from the junction. This complicates the collection of the electrons in presence of the strong electrostatic field at the surface. To overcome these limitations, a very compact electron energy analyser optimized for low-energy operation has been designed to be placed in

close proximity to the sample, with the objective of rendering energy analysis more efficient. Such miniature energy analyser (shown in fig. 1(b.)) combines a Bessel-Box (BB) analyser [6] with an electron channel multiplier (channeltron). Experimental results demonstrating the capability of this analyser to collect electron spectra are discussed.

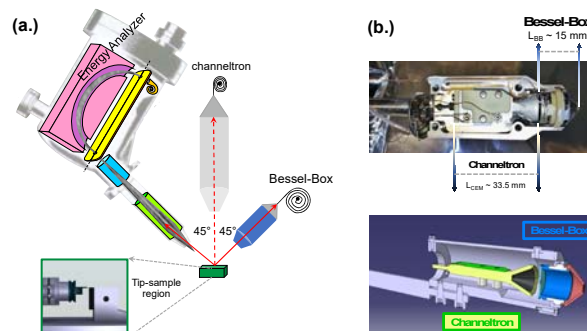


Fig. 1 (a.) Upgraded version of our SFEM experimental chamber with implementation of the Bessel-Box analyser enclosing a 45° angle with the single channeltron. (b.) *Upper panel*: photograph of the BB equipped with a channeltron, as actually mounted in the test chamber. *Lower panel*: Technical drawing of the miniature analyser shown in cross-section.

3. Summary & Conclusions

The SFE-Microscope, as presented here, is a powerful tool enabling the investigation of the tangled processes involved in secondary electron emission from different perspectives, mingling observations obtained via Microscopy to those gained through Spectroscopy.

The characteristic features and experimental capabilities of the SFEM instrumentation are discussed along with fundamental aspects inherent to the production of secondary electrons in the low energy regime. Further, the implementation of a novel miniature energy analyser and its characterisation are presented.

4. References

- [1] D. A. Zanin *et al.*, *Advances in Imaging and Electron Physics*, Vol. **170**, 227 (2012), DOI:<https://doi.org/10.1016/B978-0-12-394396-5.00005-1>
- [2] T. L. Kirk, *Advances in Imaging and Electron Physics*, Vol. **204**, 39 (2017), DOI: <https://doi.org/10.1016/bs.aiep.2017.09.002>
- [3] L. De Pietro, PhD Thesis, ETHZ, (2016), DOI: <https://doi.org/10.3929/ethz-a-010792873>
- [4] J. S. Villarrubia *et al.*, *Natl. Inst. Stand. Technol., Spec. Publ.* **958**, 214 (2001).
- [5] A. Bellissimo, PhD Thesis, Università degli Studi Roma Tre, (2019), URL:https://www.researchgate.net/publication/332684398_Multiparameter_Analysis_of_Genesis_and_Evolution_of_Secondary_Electrons_produced_in_the_Low_Energy_regime
- [6] A. Suri *et al.*, *IOP Conf. Series: Journal of Physics: Conf. Series* **902** (2017) 12017, DOI: <https://doi.org/10.1088/1742-6596/902/1/012017>