Scanning Electrochemical Microscopy for Electrochemical Energy Conversion and Storage

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Scanning electrochemical microscopy (SECM) is a type of scanning probe microscopy (SPM) where an electrochemical reaction at a microelectrode is used to generate information about an electrochemically (in)active surface in its immediate vicinity. Careful preparation and knowledge of the microelectrode response as well as the application of a suitable method enable the study of spatially resolved electrochemical kinetics or the electrocatalytic activity of any structure or material. In addition to a wide range of other applications, the method has become particularly well established in the research field of electrochemical energy storage and conversion.

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Scanning probe microscopy (SPM) techniques can be used to obtain lateral-resolved information by measuring the interaction between a probe and a surface. The size of the probe determines the achievable resolution, which can range from hundreds of micrometers to several picometers. The probe is moved laterally along the surface using motor or piezo actuators and its response is recorded in dependence of its position. This data can be processed to form an image. SPM has many uses, such as studying materials, understanding effects, and visualizing. However, the individual methods have diverging advantages and disadvantages, instrumental realization, and information provided.

In this field, the invention of scanning tunneling microscopy (STM) by Binnig and Rohrer in 1982 marked the very beginning of the development of various SPM techniques [1]. STM involves a sharp metallic needle with a tip of several atoms being lowered down to a conductive surface until a tunnel current is observed. The working distance is typically less than 1 nm and the height of the probe can be controlled by the tunnel current. This technique can achieve single atom resolution, but it is essential that the surface is conductive. This main disadvantage was overcome by the development of scanning force microscopy by Binnig, Quate, and Gerber in 1986, better known as atomic force microscopy (AFM) [2]. In this technique, the attractive and repulsive interactions between the probe and a conductive or non-conductive surface are used for characterization. The tip, here a cantilever, works as a force sensor and can provide nanometer resolution. Besides these two very common techniques (STM and AFM) that use physical interaction between probe and sample, Bard presented a scanning electrochemical microscope (SECM) in 1989, which uses electrochemical reactions for surface probing and imaging [3]. In contrast to the previously mentioned techniques, SECM initially used relatively large probes that are referred to as (ultra)microelectrodes in this context. The preparation of these microelectrodes was highly reproducible, and their use also simplified the instrumentation and requirements for damping. Furthermore, knowledge from electrochemistry at large electrodes could be transferred, which enabled the modeling of the observed electrochemical processes. It was quickly demonstrated that SECM could be applied to a broad variety of research fields (surface interaction, interfaces, and biological systems). This variety is also evident when looking at the number of electrochemical methods that were transferred from macroscopic to micrometer-sized electrodes. SECM can be considered as “true” chemical microscopy, where an electrochemical reaction at a micro- and later also nanoelectrode is used to obtain laterally resolved information from the surface in close proximity.

Besides many other applications, SECM has become a prominent method in the research field of electrochemical energy storage and conversion. To meet the growing global demand for electricity in the coming decades, powerful devices for storage and conversion must be developed. Furthermore, suitable materials must be found to act as electrodes or electrocatalysts in the converter systems, such as fuel cell, electrolyzers, and batteries. These materials must be characterized in terms of activity, stability, and selectivity. By applying SECM as an electrochemical in situ technique, it can provide a deeper understanding of the processes and structures of materials in order to finally create tailored materials for energy storage and conversion application.

References

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