Chapter 1
Introduction

S. Sadewasser and Th. Glatzel

Abstract The Kelvin probe force microscope allows to image surface electronic properties, namely the contact potential difference (CPD) with nanometer scale resolution. With the steadily increasing variety of applications and materials investigated, the increasing trend of research performed applying this techniques is foreseen to continue.

Surface science was revolutionized in 1982 by the invention of the scanning tunneling microscope (STM) by Binnig and Rohrer who received the Nobel prize only 4 years later in 1986 [1]. Shortly after the invention, the first images showing atomic resolution on a Si(111) 7×7 surface were obtained. As this allowed real space imaging of atomic structure, it gave a new turn on nanotechnology research. By means of its working principle, namely the quantum mechanical tunneling current, the STM is inherently limited to the study of conducting surfaces. In 1986, the invention of the atomic force microscope (AFM) solved this limitation by using a tip supported by a cantilever beam [2]. The tip can be scanned across a surface in contact and the deflection of the beam can be measured, for example by employing optical detection on the back side of the cantilever. Using the AFM also insulators were now accessible on nanometer and even atomic scale. Further development led to the non-contact (or dynamical) mode of the AFM [3], where the cantilever is vibrated close to its resonance frequency and changes in the vibration due to tip–sample interaction are employed to maintain a constant distance to the sample

S. Sadewasser (✉)
International Iberian Nanotechnology Laboratory - INL, Avda. Mestre José Veiga s/n, 4715-330 Braga, Portugal
e-mail: sascha.sadewasser@inl.int

Th. Glatzel
Department of Physics, University of Basel, Klingelbergstr. 82, 4056 Basel, Switzerland
e-mail: thilo.glatzel@unibas.ch

S. Sadewasser and T. Glatzel (eds.), *Kelvin Probe Force Microscopy*, Springer Series in Surface Sciences 48, DOI 10.1007/978-3-642-22566-6_1,

surface while scanning across the sample. Forces exerted by the tip on the sample are minimal in non-contact mode; therefore, it is the method of choice for soft samples, as, for example, biological or polymer samples.

A wide field of applications was opened by the combination of the AFM with other measurement methods, which provides access to additional sample properties on a lateral scale in the nanometer range. One representative, the Kelvin probe force microscope (KPFM), was first developed by Nonnenmacher et al. [4] and Weaver et al. [5] and it allows to image surface electronic properties, namely the contact potential difference (CPD). The name "Kelvin probe force microscope" originates from the macroscopic method developed by Lord Kelvin in 1898 using a vibrating parallel plate capacitor arrangement, where a voltage applied to one vibrating plate is controlled such that no current is induced by the vibration [6]. The reduction of this exact principle to the microscopic scale, however, results in poor sensitivity, since the size of the plates is too small to generate a sufficient current. Therefore, in KPFM the electrostatic force is used. The cantilever in AFM is a very sensitive force sensor; thus, the contact potential difference can be measured with high sensitivity. A dc-bias applied to the sample (or the tip) is controlled such that the electrostatic forces between tip and sample are minimized.

Invented in 1991, it took almost 10 years before there was a sizeable number of publications per year involving the KPFM technique (Fig. 1.1). Nevertheless, starting with the new millennium, the KPFM found more and more applications and interest, visible in a considerably increased publication activity. This went hand in hand with the more wide-spread availability of AFM equipment in many laboratories world wide. In the recent years, the publication number is nearly 10 times as high as in the early years after invention. With the steadily increasing variety of applications and materials investigated, the increasing trend of research performed applying KPFM techniques is foreseen to continue. A similar trend can be observed for the number of citations per year (Fig. 1.1).

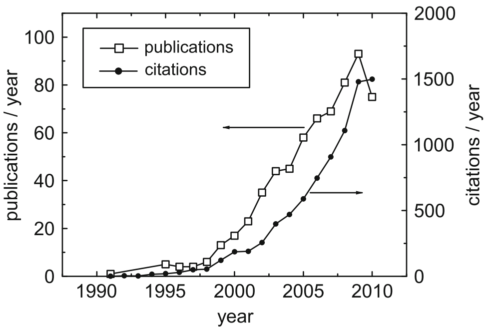

Fig. 1.1 Publications and citations per year since the invention of the KPFM (The search was performed on December 2nd 2010 using the search term "KPFM OR SKPM OR Kelvin force microscopy" in Inspec)

In the recent years, many books and review articles have been published on the topic of scanning probe microscopy, AFM or even nc-AFM [7–9]. Sometimes these books comprise a small description or a chapter on KPFM; however, a major monograph on KPFM has not been published so far. Therefore, interested researchers have to compile their information from a variety of sources. At a time where 20 years have passed since the invention of the KPFM and a steadily increasing number of publications every year, we feel that it is an excellent point in time to provide such a compilation on KPFM. We hope to give an overview about the details of the technique and many examples of their applications in a variety of fields.

The book is divided into two parts. The first part is dedicated to the technique of KPFM itself, providing in Chap. 2 a detailed description of the working principles, the various different techniques that can be employed and advantages as well as drawbacks of the various realizations of KPFM. Chapter 3 will discuss in detail the capacitive cross talk and its effect on KPFM measurements. The effect of the long range electrostatic force on the spatial resolution in KPFM is discussed in Chap. 4, mainly based on analytical and simulation work. Chapter 5 then presents a theoretical discussion about the involved effects in atomic-resolution KPFM, based on a KPFM simulator.

The second part of the book is focused on the application of KPFM to a variety of sample systems and goals. Chapters 6–9 are devoted to semiconductor samples, where in Chap. 6 a general treatment of semiconductor studies is given. Chapter 7 discusses the implications of nanostructures supported on semiconductor substrates, and Chap. 8 is dedicated to the studies of solar cell related semiconductor materials. Chapter 9 deals with the investigation of electrostatic forces for the study of low-dimensional semiconductor structures.

In Chap. 10, the additional insight into catalysts gained by KPFM will be reviewed. Chapter 11 deals with studies of organic molecules on metal substrates and the lessons that can be learned on their electronic properties. Chapter 12 is devoted to the study of biologically relevant materials. Finally, Chap. 13 will review the very recent advances that have been made in the experimental investigations of atomic resolution KPFM.

References

1. G. Binnig, H. Rohrer, Ch. Gerber, E. Weibel, Phys. Rev. Lett. **49**, 57 (1982)
2. G. Binnig, C.F. Quate, Ch. Gerber, Phys. Rev. Lett. **56**, 930 (1986)
3. Y. Martin, C.C. Williams, H.K. Wickramasinghe, J. Appl. Phys. **61**, 4723 (1987)
4. M. Nonnenmacher, M.P. O'Boyle, H.K. Wickramasinghe, Appl. Phys. Lett. **58**, 2921 (1991)
5. J.M.R. Weaver, D.W. Abraham, J. Vac. Sci. Technol. B **9**, 1559 (1991)
6. L. Kelvin, Phil. Mag. **46**, 82 (1898)
7. R. Wiesendanger, *Scanning Probe Microscopy* (Springer, Berlin, 1998)
8. S. Morita, R. Wiesendanger, E. Meyer (eds.), *Noncontact Atomic Force Microscopy* (Springer, Berlin, 2002)
9. E. Meyer, H.J. Hug, R. Bennewitz, *Scanning Probe Microscopy* (Springer, Berlin, 2004)