Analysis of Geometrical Aspects of a Kelvin Probe

I. Kuehne[1], S. Ciba[1], A. Frey[2]

[1]Heilbronn University, Kuenzelsau, Germany
[2]University of Applied Sciences, Augsburg, Germany

Abstract

In this paper an analysis of geometrical aspects of a Kelvin probe is presented. A Kelvin probe is a non-contact, non-destructive measurement technique to investigate the work function difference of material combinations [1, 2].
It is based on a time varying capacitor where the movable electrode consists of a material A and a fixed electrode of a material B with different work functions [3]. For electrically connected electrodes (e.g. external wire bond) the Fermi levels are equilibrated. Electrons originating from the material with the lower work function flow to the material with the higher work function. Consequently, a contact potential difference establishes and the capacitor is charged.
The vibration of the movable electrode results in a change of the stored electrical energy within the capacitor forcing an electrical current to flow. The work function difference can be determined by measuring this current. Alternatively, a compensated operation can be established by applying an external bias voltage so that the current becomes zero. As a result the bias voltage is equivalent to the work function difference of the electrode materials [4].
On the one hand, the movable electrode can be a plate in order to form a parallel plate capacitor. This guarantees a large capacitance change which results in a current that can be directly measured without a sophisticated electrical compensation scheme. On the other hand, the movable electrode can be formed as a narrow tip what gives the ability to get a lateral resolution by scanning over some area [5]. Here, the capacitance change and so the resulting current are quite low what calls for an electrical compensation circuit.
The presented analysis investigates the capacitance characteristic of the Kelvin probe regarding the geometrical transition from a movable electrode plate to a narrow tip. Moreover, predictions can be done concerning optimum geometry, sensitivity and suitable electrical measurement.

The model is set up with the Electromechanics Interface. For numeric efficiency, a 2D axial symmetry is established in order to model a vibrating capacitor with circular plate/tip geometries (cf. Figure 1). The movable electrode is configured to a prescribed harmonic displacement and a defined electrical potential. The counter-electrode is mechanically fixed and set to electrical ground. The transient behavior is observed and the lateral dimension of the movable electrode is varied by a parametric sweep.

Figure 2 presents the transient behavior of the capacitance over one vibrational period. The nonlinear characteristic of the capacitance and the difference between analytical and

numerical approaches can be seen. Figure 3 shows the nominal capacitance for varying the movable electrode radius. Analytical approaches would underestimate the resulting capacitances especially in the direction to a narrow tip geometry. Figure 4 illustrates that the capacitance change is higher for the numerical.

Using the Electromechanics interface a model was set up to analyse the geometrical aspects of a Kelvin probe. The obtained results provide insight on how the movable electrode can be geometrical optimized with regard to increase the sensitivity and counting for a simple measurement circuitry.

Reference

[1] W. Thomson (Lord Kelvin): Electrostatics and Magnetism, MacMillan & Co., London, 1872.
[2] J. Erskine-Murray: On Contact Electricity of Metals, Proceedings of Royal Society of London Vol. 63, pp. 113-146, (1898)
[3] J. C. Riviere: Contact Potential Difference Measurements by the Kelvin Method, Proceedings of the Physical Society of London - Section B, Vol. 70, pp. 676-686, (1957)
[4] H. Lueth: Solid Surfaces, Interfaces and Thin Films, Springer Verlag, pp. 564-570 (2010)
[5] L. Nony: Principles of Kelvin Probe Force Microscopy and applications, 1st German-French Summer School on noncontact - AFM Porquerolles, p. 80 (2013)
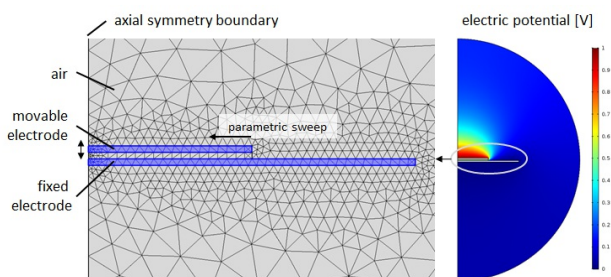
Figures used in the abstract

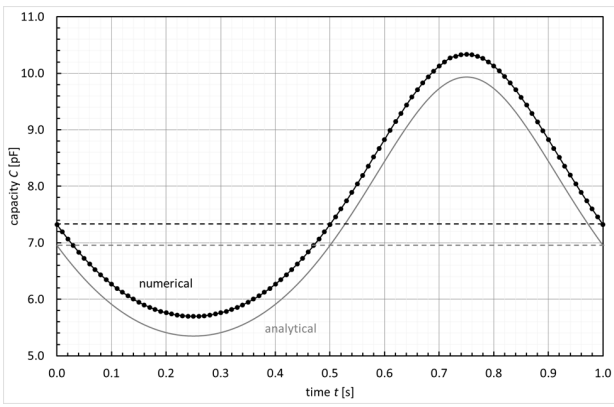**Figure 1**: 2D axial symmetric model setup of the Kelvin probe.

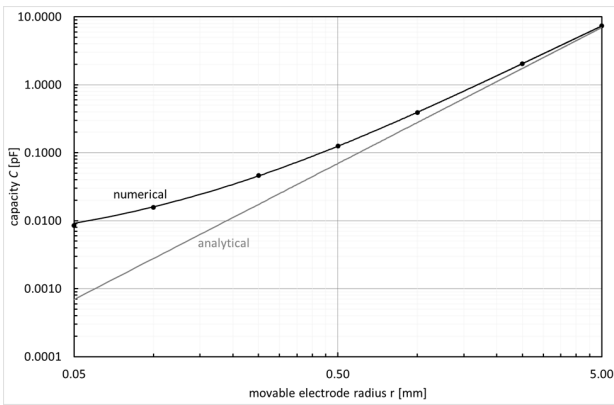**Figure 2**: Transient capacitance behavior of the Kelvin probe.

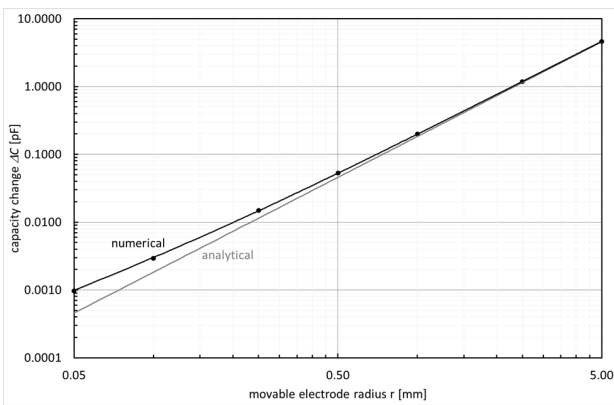**Figure 3**: Transient capacitance behavior of the Kelvin probe.

Figure 4: Capacitance change of the Kelvin probe.