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Contactless current measurements using a needle sensor

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Abstract

We present an improved method for measuring currents in packaged integrated circuits (IC) for the purpose of test and failure analysis. We use a quartz resonator, called needle sensor, to detect the magnetic field of the device under test (DUT). Thus, the measurement principle is similar to conventional magnetic force microscopy. Compared to a cantilever-based scanning force microscope the advantage of a needle sensor is the much easier test access because of its geometry. With this probe we realized current measurements with a sensitivity of 100 μA. The results are verified by using a simple model describing the basic principle of our measurement setup.

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Keywords: Scanning force microscopy; Magnetic force microscopy; Quartz resonator; Failure analysis

1. Introduction

As the packing density and complexity of modern integrated circuits (ICs) increase there is a demand for advanced function and failure analysis methods in contactless and chip-internal measurements to localize e.g. leakage currents or power dissipations. One promising tool with high lateral resolution and sensitivity is the magnetic force microscopy (MFM) [1], based on scanning force microscopy (SFM) [2]. Applications of MFM in current measurements are current contrast imaging on sub-μm conducting lines with a sensitivity of a few μA and below [3,4] or quantitative measurements to study e.g. current crowding on defects [5].

Until now there are only cantilever-based MFM sensors for current measurements. Because of the large geometry of these sensors the test access to ICs already packaged is limited. Thus, a sensor

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with small dimensions in lateral direction, like a needle sensor, is preferable.

The needle sensor consists of a quartz resonator with a probe tip mounted at the front end [6]. The oscillation direction is perpendicular to the device under test (DUTs) surface. Thus, the needle sensor enables a much better test access to packaged ICs. However, present experiments with the needle sensor are mostly restricted to topography measurements [7–10]. First measurements have shown the applicability of such a sensor for contactless electrical measurements [11].

In this paper we present the suitability of the needle sensor for current contrast imaging with high sensitivity. As an example we demonstrate its applicability for contactless current measurements on a packaged IC.

2. Principle of SFM with a needle sensor

2.1. Force detection with a needle sensor

The needle sensor is a microfabricated sensor with a high-quality factor better than 10^4. Its active component consists of an electrically driven quartz resonator. The oscillation direction of this quartz resonator is lengthwise and therefore it is mounted at the nodal point of its mechanical oscillation. The dimensions of the quartz resonator are $0.13 \times 0.08\,\text{mm}^2$ and 2.7 mm, respectively. A standard atomic force microscopy (AFM) tip is fixed at one end of the quartz resonator to achieve a high lateral resolution. Fig. 1a shows a schematic illustration of a needle sensor, whereas Fig. 1b demonstrates the test access to an IC, which can be easily realized.

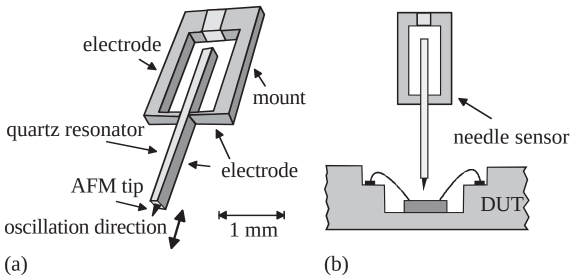

Fig. 1. Needle sensor: (a) schematic illustration of a needle sensor, (b) test access to a bonded IC.

To detect forces acting on the end of the quartz resonator the needle sensor is driven at its resonant frequency ω_r. Any force interaction will cause a decrease of the amplitude $\hat{u}_o$ as well as a phase shift $\Delta\phi$ of the output signal $\hat{u}_o \cos(\omega_r t + \Delta\phi)$ referenced to the input signal $\hat{u}_i \cos(\omega_r t)$. The phase shift $\Delta\phi$ is proportional to the force gradient in oscillation direction grad(F_z) and can be used for a control circuit to obtain topographic images of a DUT. With this test setup, one can achieve vertical and lateral resolutions of 0.1 and 10 nm, respectively, in air under noncontact mode [7].

2.2. Current measurements with a needle sensor

Current measurements are based on the detection of the magnetic field around a current carrying conducting line. Thus, the tip of the needle sensor has to consist of a magnetic material which is magnetized in the sensors oscillation direction, which is the z-direction.

Assuming that the tips magnetic moment is a single dipole with a component m_z only in z-direction the following equation can be derived [12]:

$$F_{z,\text{mag}} = -\frac{\partial W_{\text{mag}}}{\partial z} = -\mu_0 m_z \frac{\partial H_z}{\partial z}. \quad (1)$$

By using a model of a single current carrying wire with its cross-section in x/z-plane Eq. (1) leads to

$$F_{z,\text{mag}} = \mu_0 m_z I \frac{xz}{\pi(x^2 + z^2)^2}. \quad (2)$$

As the needle sensor consists of a piezoresonator one cannot measure the acting force directly but only the force gradient. To understand which directional derivative is predominant Fig. 2 shows a detailed principle for current measurements with a needle sensor. In this case the needle sensor is scanning with a constant height over the DUT's surface. Its oscillation direction with an amplitude of less than 1 nm is along the z-axis and causes a change in the force $F_{z,\text{mag}}$.

Additionally, there will be another force change because of the scanning direction along the x-axis.