# MM-WAVE NEAR-FIELD SCANNING RESISTIVITY MICROSCOPE

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## ABSTRACT

We have used a near field mm-wave scanning probe to image resistivity of different materials. We compare the near-field to the far-field imaging and find an optimal distance range for the near-field imaging.

Microwave and mm wave scanning probe techniques have recently attracted much attention. They were used to map resistivity [1], current distribution in microwave resonators [2], defects in composites [3], semiconductors [4], etc. These techniques use a special antenna which is raster scanned over the surface under study while the reflection/transmission from the surface is measured. Reflectivity measurements yield information on the resistivity and/or topography. The sample is mounted either in the far-field or in the near-field of antenna. The far-field geometry is easier for calculations and modeling, however, its spatial resolution is determined by the wavelength and rarely exceeds 1 mm. The spatial resolution of the near-field imaging is not limited by the wavelength and may be less than a micron [4,5]. However, calculation of the field distribution in the near-field of antenna is rather difficult which renders the near-field imaging less quantitative than the far-field imaging. Therefore, the spatial resolution and the contrast in the near-field imaging strongly depend on the probe-sample separation. We have recently demonstrated a mm-wave near-field probe for resistivity imaging with a 30 μm spatial resolution [1]. Here we analyze its operation at different probe-sample separations in order to find the optimal range for imaging.

We use a resonant slit antenna as a scanning probe [1] and measure the intensity of the reflected wave from different samples. The probe consists of a thin narrow slit (width of 20 μm) cut in the edge of a rectangular waveguide. The edge of the waveguide is made wedge-like. The probe is a part of the millimeter-wave reflection bridge. The design of the probe and the bridge was described elsewhere [1]. The device operates as follows. The probe is fed by the HP-83558A source module operating at ~77 GHz. Reflected wave from the sample is picked up by the same probe and is measured by a square-law detector. We use an E-H tuner for impedance matching in order to minimize reflection in the absence of the sample. The sample is mounted onto computer-controlled X-Y-Z stage. To achieve resistivity maps we move the sample in the X-Y plane at constant Z. In the present work we emphasize measurements in which we move the sample only in Z-direction. The measurements are done in both directions (i.e., when the sample is approaching to the probe and when the sample is going away from the probe). To avoid mechanical contact between the probe and the sample, we introduce an optical technique to measure probe-sample separation. This was done by focusing a laser beam from the He-Ne laser just under the slit and by measuring transmitted light by a photodetector. When the probe does not touch the sample, the light passes through a narrow opening between the probe and the sample. When the sample touches the probe, the optical path is blocked so that no light comes to the photodetector. The diameter of the optical beam in the focus is ~10 μm which allows us to measure the probe-sample separation with a 1 μm accuracy. We used several samples with different conductivities. The sample sizes are~2.5x2.5cm$^2$ and considerably exceed the probe-sample separation.

Figure 1 demonstrates reflectivity of different samples in the far-field of the probe. A pattern of maximums and minimums arises from the standing waves between the probe and the sample. Residual reflected signal of ~10 μV is due to incomplete isolation (-30 dB) provided by the bridge. The maximums of the standing wave for Cu and Cr samples appear at the same distance while for the glass and the silicon wafer these peaks appear at different distances. This is due to the fact the mm-wave penetrates glass and silicon, so that the reflected wave comes both from the upper and lower surfaces of the sample. Reflectivity in peaks is higher for materials with higher conductivity. However, reflectivity at a *given distance* depends on resistivity in a complicated way due to the standing waves in the sample.

Figure 2 demonstrates the near-field reflectivity for the same materials. It is several orders of magnitude higher than the far-field reflectivity. At distances above ~50 μm the dependence of reflectivity on resistivity becomes complicated and at 100 μm the near-field reflectivities for such different materials as Cr, Si and glass almost coincide. However, at distances below 50 μm reflectivity

0-7803-4603-6/97/$5.00 (c) IEEE

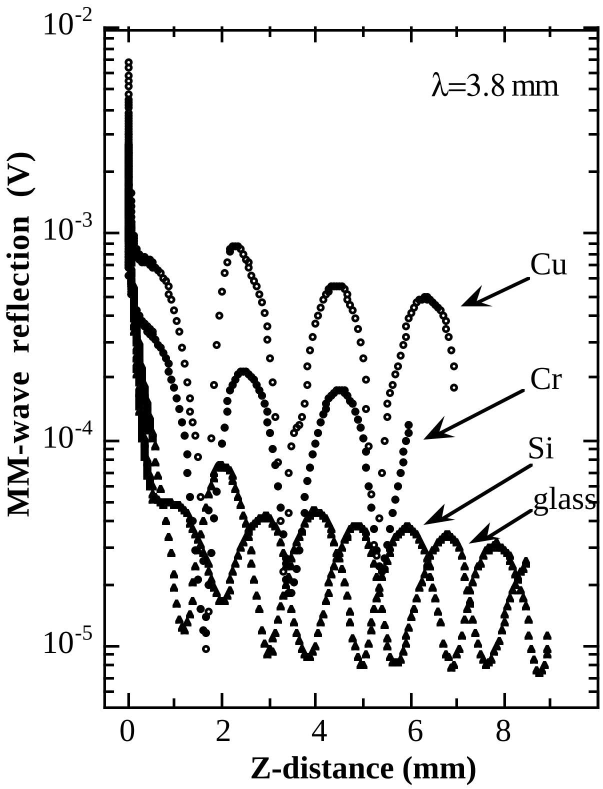


Fig. 1. Far-field reflectivity of several materials at 77GHz in dependence of the probe-sample separation. The probe is a resonant slit antenna with the width of 20 μm. **Cu**-is a polished copper block, **Cr**-is a thin chromium film (sheet resistance~2kΩ) on a 1 mm-thick glass substrate, **Si**-is a standard silicon wafer, **glass**-is a 4-mm thick plate.

varies monotonously with resistivity. This simple monotonous dependence is probably due to strong decay of the near-field of antenna with distance, so that the most part of the reflected wave comes from the upper surface (even for transparent samples). The 50 μm distance is determined not by the wavelength, but rather by the lateral size of a radiating aperture (20 μm) and by the field concentration in the longitudinal direction arising from the curvature of the wedge-like end of the waveguide. By measuring reflectivity in this extremely near-field region, the contrast comes either from the variations of the resistivity and/or dielectric constant of the upper surface or from topography. The contrast at larger probe-sample separation is related to resistivity in a complicated way and may depend on the sample thickness.

We draw the conclusion that the resistivity mapping in the near-field of aperture-type antenna should be better done at the probe-sample separation of the order of the size of the aperture. Otherwise, the relation between the reflectivity and resistivity becomes extremely complicated. The question is open whether the same conclusion is valid for other probe types, such as a coaxial tip [2,4,5].

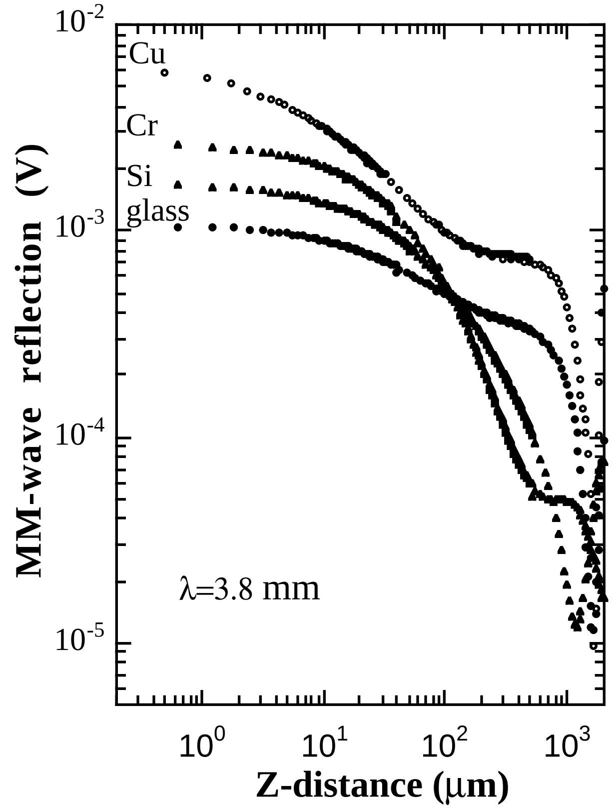


Fig. 2. Near-field reflectivity of several materials (see Fig.1) at 77GHz in dependence of the probe-sample separation.

We acknowledge experimental assistance of A.Galkin and support from the Horowitz and Klatchky foundations.

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