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Spatiotemporal measurements with an ultrafast scanning tunneling microscope

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We use an ultrafast scanning tunneling microscope (USTM) to resolve voltage transients propagating on a coplanar waveguide (CPW). The photoconductive (PC) switch connected to the CPW; at each position the delay time is varied. The illumination principle is illustrated on the CPW. The main signal (at delay time, T = 11 ps) is confined to the center electrode where the voltage is initially increased at the photoconductive switch. The laser pump beam generates a voltage pulse on the CPW; the probe beam gates the current picked up by the tunneling tip. Sample and probe substrates are low temperature grown GaAs. The use of a fiber enables flexible positioning of the tip over a range of 50 μm (only limited by the scanning range of the piezo tube). The instrument can be used to map out the field lines for the common mode spread between the center and bottom lines of the CPW. In this case, the voltage on the center line has been blocked by the gap. The field lines for the common mode spread continues beyond the gap. Here the signal on the center line has been blocked by the gap.

Figure 2 shows a gray-scale contour plot of a pulse generated by illuminating an in-line gap of a CPW. The main signal (at delay time, T = 11 ps) is confined to the center electrode where the voltage is initially increased at the photoconductive switch. With measurements in which the tip is in contact we test the laser position and ensure that the voltage is only increased on the center line. Figure 1 shows that there is an additional contribution that is preceding the main pulse and extending over the whole scanning range. We explain this result with the pulse generation principle; by illuminating an in-line gap we generate a differential mode together with a common mode. The field lines for the common mode spread out in space to the closest ground electrode.

We test this explanation by exciting a pulse between the center and bottom lines of the waveguide. In this case, the voltage on the center bias line is decreased and increased on the ground line, and a pure differential mode is generated (Fig. 3). The initial pulse (T = 8 ps) is confined to the two electrodes and does not show any trailing, unconfined components. Because of a reflection from the in-line gap (see inset, Fig. 3), the transient signal map shows more detail. Only the pulse on the center line is reflected from the in-line gap (T ≈ 13 ps). This reflection contains a common mode contribution. Measurements on the other side of the gap show that the pulse on the bottom line continues beyond the gap. Here the signal on the center line has been blocked by the gap.

In summary, we demonstrate the use of a USTM for mapping voltage transients on transmission lines and show that the instrument works as a transient voltage probe coupled through the geometrical capacitance of the tip-electrode gap.

Figure 1 Schematic setup of the USTM. The probe consists of a 5-μm PtIr wire glued to the 10-μm transmission line. The other end of the wire forms the tunneling tip. The sliding contact photoconductive switch is illuminated through a fiber that is glued in place.

Figure 2 Spatiotemporal measurement of a voltage transient generated with an in-line gap on a coplanar waveguide displayed by a gray-scale contour plot. White represents the maximum amplitude and black the minimum amplitude. The illumination principle is illustrated on top.

Figure 3 Gray-scale contour plot of a voltage transient generated by excitation between the lines. The illumination principle is illustrated on top.