LA-UR- 98-610

CONF-980740--

Title:

ULTRAFAST SCANNING TUNNELING MICROSCOPY (STM) USING A PHOTOEXCITED LOW-TEMPERATURE-GROWN GALLIUM ARSENIDE TIP

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Submitted to:

Ultrafast Phenomena '98
Muenchen, Germany
July 12-17, 1998

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Ultrafast scanning tunneling microscopy (STM) using a photoexcited low-temperature-grown GaAs tip

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Picosecond transients on a metal stripline are detected with a low-temperature-grown GaAs tip photoexcited by 100-fs, 800-nm pulses. The transient is investigated by varying the tip-sample separation.

Ultrafast scanning tunneling microscopy (STM) using a photoexcited low-temperature-grown GaAs tip

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In the quest for atomic spatial and picosecond temporal resolutions, several groups[1-4] have integrated an STM tip with an ultrafast optoelectronic switch that gates the tunneling current from the tip. We report a novel ultrafast STM tip consisting of a cleaved GaAs substrate with a 1-μm thick epilayer of low-temperature-grown GaAs (LT-GaAs) deposited on the face. Since LT-GaAs has a carrier lifetime of 1 ps, the photo-excitation of the tip with an ultrafast above-bandgap pulse provides carriers for the tunneling current and photoconductively gates the current from the tip with picoseconds time resolution. We use this tip to detect picosecond voltage transients on a coplanar stripline. A mode-locked Ti:sapphire laser provides 100-fs, 800-nm optical pulses at a repetition rate of 82 MHz. The output of the laser is split into a pump beam and a time delayed probe beam. The probe beam is focused on the LT-GaAs tip tunneling above a stripline. The pump beam generates the voltage transients by optically-switching the LT-GaAs epilayer between the striplines. The transient signal is revealed via lock-in detection for each value of delay τ.

The stripline consists of 50 μm wide, 7 mm long platinum lines deposited 10 μm apart on a 1 μm LT-GaAs epilayer and are held at a voltage difference of 15 V. The tip consists of a LT-GaAs square of 0.04 mm^2 100 μm-thick bonded to a tungsten wire using a gold contact pad and conducting epoxy. The dark resistance of the tip is typically 3-10 GΩ. We emphasize that this simple tip design locates the photo-gate at the point from which the current is tunneling from the sample.

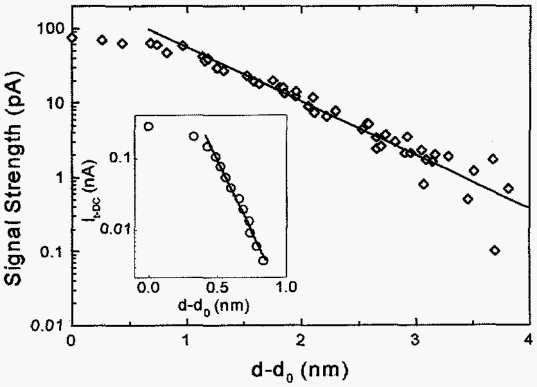

Figure 1. Tunneling signal strength versus relative tip-sample separation. The inset shows the I$_{DC}$ versus Z dependence for the tip without light at an STM bias of 3.5 V. Lines are best exponential decay fit. The decay constants are 0.60 nm and 0.11 nm with and without illumination, respectively.

Figure 1 reveals the dependence of the transient tunneling signal strength [$I_{t\text{-}AC}$(max.)-$I_{t\text{-}AC}$(t<-7ps)] as a function of the relative tip-sample separation (d-d$_0$) for the optically-switched tip with 38 mW laser pulses. The STM bias voltage is held to zero and the photo-current is directed from the tip to the sample.[5] The inset shows the DC tunneling current versus relative tip-sample separation without tip illumination. The large decay constant of the transient signal strength indicates that contamination of the tunnel barrier is enhanced when the laser beam is focused on the tip.[6,7] Figure 2a shows the cross-correlation of the voltage pulse propagating along the stripline. The first pulse is the correlation signal at zero delay, and deconvolving this 4.0 ps waveform yields a voltage pulse width of 2.8 ps. The second pulse at 27 ps is a reflection off the end of the stripline. Figure 2b reveals the transient signals from the LT-GaAs tip sampling the voltage pulse in contact (solid line) and in tunneling (dotted line) with the stripline. The two waveforms are almost identical and are free of spurious signals. The width of the first peak is 3.3 ps, indicating a temporal resolution of 1.6 ps after deconvolution.

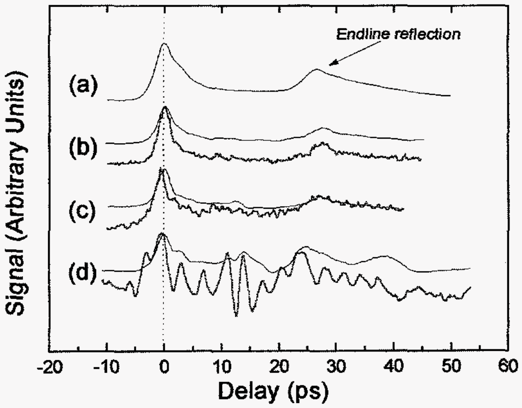

Figure 2. (a) Cross-correlation of the voltage pulse on the stripline. Transient detected with (b) LT-GaAs STM tip, (c) LT-GaAs with gold deposited on the apex, and (d) sharp tungsten tip attached to a photo-switch. In Figures 3b-3d solid lines are the signals for tip in contact, and dotted lines are the signals in tunneling mode.

For comparison we present the waveforms using two different tip designs. Figure 2c is the signal using the LT-GaAs tip with gold deposited on the apex.[2] This signal is relatively clean, however, when the tip is in tunneling, the time resolved signal precedes the signal in contact indicating the presence of a capacitive coupling between the tip and the stripline. The second peak, delayed about 12 ps from the main pulse, is an artifact since it is not observed in the cross correlation signal (2a). The same distortion is enhanced using a sharp tungsten tip attached to a gating photo-switch[1,3] as shown in Figure 2d. The dotted line, which is the tunneling signal, exhibits even more oscillations since it depends on the derivative of the contact signal.

In conclusion we have shown that the use of a photoexcited LT-GaAs tip in ultrafast scanning tunneling microscopy results in a tunneling signal waveform free of temporal distortion with a temporal resolution of 1.6 ps.

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