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Proposal of a Technique to Detect Sub-Surface Hot Electrons with a Scanning Probe Microscope

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Ballistic transport of hot electrons has become very important in recent years, and new high-speed devices based on it have been proposed. Hot electron transistors can lead to spectroscopic information about hot electrons in the device. However, a technique able of resolving the spatial distribution of hot electrons is still lacking. To this effect, scanning tunneling microscopy appears as a very promising tool. Ballistic-electron-emission microscopy (BEEM) allows the study of ballistic transport through the base electrode into which the electrons are injected.

Here we prove the possibility of realizing the inverse process to that of BEEM, that is, the detection with a sharp probe of hot electrons generated in a broad sub-surface structure, and propose a technique (Scanning Hot Electron Microscopy, SHEM) and an experimental setup to make it possible (Fig.1). The method involves the injection of hot electrons from inside the sample and its detection with an STM tip. In order to discriminate the hot electron current I_{hot} from the thermal electron current I_{th}, an ac voltage is applied to the sample to modulate I_{hot}; the corresponding harmonic detection is carried out with a lock-in amplifier. However, an ac-component of I_{th} appears due to a residual resistance R_S, and if this component is big enough (as it is the case in usual conditions), I_{hot} will be completely hidden by it and hot electron detection will be impossible.

To overcome the above mentioned problem, we propose a structure in which hot electron energy E_{hot} (typically around 1eV above the Fermi energy) is made higher than the gap barrier V_p by inserting a material with a low work function (cesium, 2.2eV) and by Schottky effect. In this way, hot electrons surmount the barrier rather than tunneling through it. From theoretical results based on the cesium/air/cesium system(Fig.2), we can conclude that, under certain conditions, detection of hot electrons with this technique is possible.

This technique will allow the study of electron wave phenomena in sub-surface semiconductor structures, including both spatial distribution and spectroscopic information of hot electrons in the sample, thus opening a door for new research in the fiels of electron wave devices.

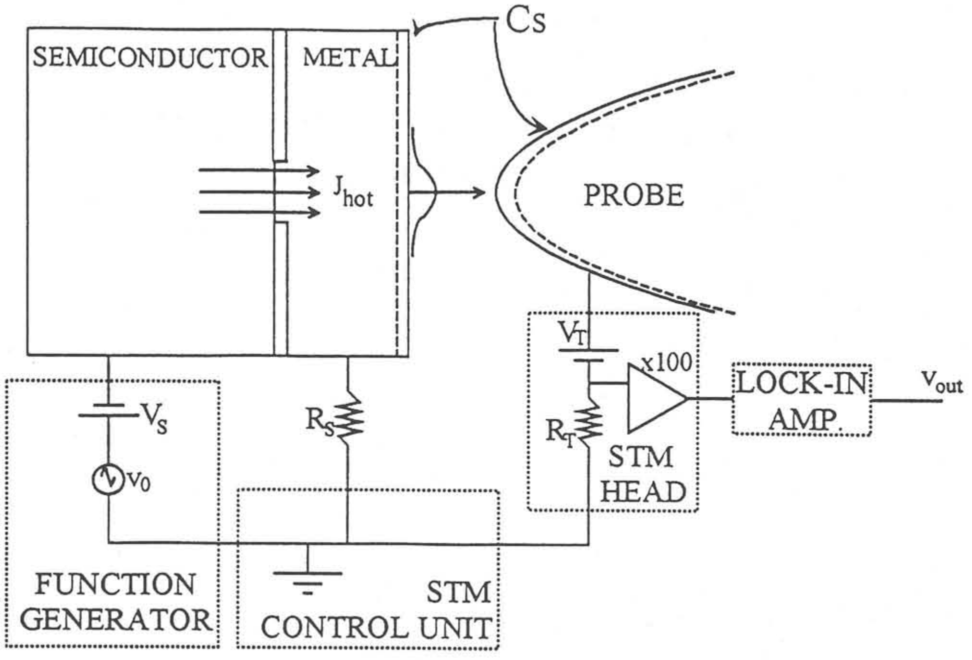

Fig.1: Proposed setup for hot electron detection (SHEM/STM system). The STM is used to provide the piezo voltages to scan the sample surface, and to control the gap distance. A function generator is used to apply a sample bias modulated at a certain frequency, and the fraction of the tunnel current with the same harmonic component is detected with the lock-in amplifier.

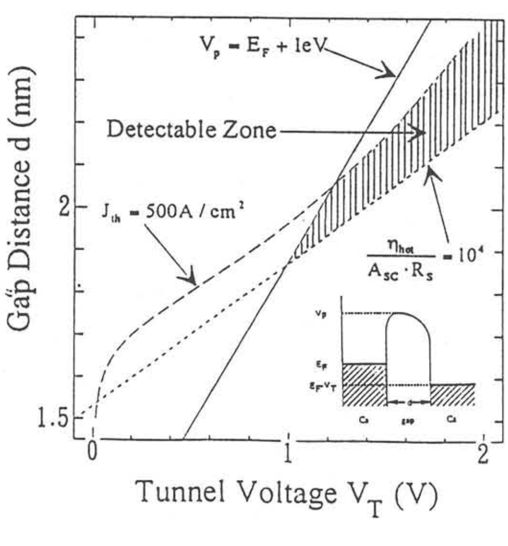

Fig.2: Theoretical conditions for hot electron detection with a scanning probe microscope. Lines in the graph represent the three conditions for hor electron detection: $E_{hot}>V_p$ (continuous line), $J_{th}(dc)>J_{min}$ (discontinuous line) and $dJ_{th}/dV_T<\eta_{hot}/A_{SC}\cdot R_S$ (dotted line), where $\eta_{hot}=10^{-3}$ is the transmission probability of hot electrons from emitter to tip, $A_{SC}=10\mu m^2$ is the area of the diode and $R_S=0.4\Omega$. The hatched area shows the region where detection becomes possible.