Possibility of Carrier Profiling Semiconductors by Terahertz Spectroscopy with Terahertz Radiation Generated in a Scanning Tunneling Microscope

Dmitrij G. Coombs and Mark J. Hagmann, Member, IEEE

Background: Others have introduced two methods for carrier profiling by terahertz spectroscopy.

In the first method [1] of transmission-mode time-resolved terahertz spectroscopy a mode-locked femtosecond laser generates pulsed terahertz radiation that passes through a silicon specimen. Amplitude and phase changes are measured in the time domain and the Drude model is used to calculate the average carrier density as a function of time.

In the second method [2] radiation from a CW terahertz laser is focused on a conical metal tip in an atomic force microscope for near-field enhancement of the radiation at the surface of a silicon sample. The back-scattered terahertz radiation is measured with interferometric techniques and the Drude model is used to determine the time-averaged carrier density with a spatial resolution of approximately 40 nm.

Terahertz radiation from a STM: A mode-locked ultrafast laser focused on the tunneling junction of a scanning tunneling microscope (STM) superimposes harmonics of the laser pulse repetition frequency on the DC tunneling current. The power measured at each of the first 200 harmonics (up to 15 GHz) varies inversely as the square of the frequency due to stray capacitance shunting the tunneling junction [3].

Fourier analysis suggests that in the tunneling junction the harmonics have no significant decay up to a frequency of $1/2\tau \approx 33$ THz where $\tau = 15$ fs is the laser pulse width. Two different analyses will be presented to model the generation of the frequency comb within the tunneling junction. The first is based on the observed current-voltage characteristics for the nanoscale tunneling junction. The second is a solution of the time-dependent Schrödinger equation for a modulated barrier. Both analyses indicate that optical rectification of the pulsed laser radiation in the tunneling junction causes harmonics of the pulse repetition frequency of the laser and that these harmonics may extend to terahertz frequencies. This is consistent with measurements and analysis of optical rectification in ZnTe [4], showing that the spectrum of this terahertz source consists of 4×10^9 harmonics of the laser pulse repetition frequency.

Conclusions: It appears that the tunneling junction may be used as a sub-nm sized source of terahertz radiation. Transmission and back scattering could not be used but loading of this source by the finite conductivity of the semiconductor would cause a loss varying inversely with the carrier density. Carrier dynamics could be measured by time-domain measurements as in [1], and time-averaged carrier profiling as in [2], but presumably with finer resolution due to the sub-nm size of the terahertz source.

References:

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Dmitrij G. Coombs and Mark J. Hagmann are with NewPath Research L.L.C., Salt Lake City, UT, 84115, USA (e-mail:dmitrij@comcast.net and mhagmann@newpathresearch.com, respectively).

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