Increased versatility for carrier profiling of semiconductors by Scanning Frequency Comb Microscopy (SFCM)

Timothy Birch and Mark J. Hagmann, Member, IEEE, NewPath Research L.L.C.

Background

We are developing a new method for the carrier profiling of semiconductors that shows promise for nm-resolution which is required at the new sub-10 nm lithography nodes. A mode-locked ultrafast laser focused on the tunneling junction of a scanning tunneling microscope (STM) generates a regular sequence of pulses of minority carriers in the semiconductor. Each pulse of carriers has a width equal to the laser pulse width (e.g. 15 fs). In the frequency domain, this is a microwave frequency comb (MFC) with hundreds of measurable harmonics at integer multiples of the laser pulse repetition frequency (e.g. 74 MHz).

After the minority carriers diverge rapidly into the semiconductor as a Coulomb explosion, the pulses become broader and decay, so that the MFC has less power with a spectrum limited to the first few harmonics [1]. The frequency-dependent attenuation of the MFC is determined by the resistivity of the semiconductor at the tunneling junction so SFCM is closely related to Scanning Spreading Resistance Microscopy (SSRM). Harmonics of the MFC are measured with high speed, and high accuracy because the signal-to-noise ratio is approximately 25 dB due to their extremely narrow (sub-Hz) linewidth.

New capabilities of the apparatus

Now we superimpose a low-frequency signal (e.g. 10 Hz) on either the applied bias or the voltage that is applied to the piezoelectric actuators of the STM to cause sidebands at each harmonic of the MFC which are less affected by the artifacts.

(1) Previously it was necessary to use only passively-modulated mode-locked lasers because the electrical signal that is required to actively-modulate a mode-locked laser causes electrical interference at the exact frequencies of the MFC. However, superimposing a 10 Hz signal causes sidebands of the nth harmonic at n x 74 MHz + 10 Hz and n x 74 MHz – 10 Hz which only reflect the phenomena at the tunneling junction.

(2) Previously it was necessary to use lasers having a photon energy less than the bandgap energy of the semiconductor to avoid forming electron-hole pairs which cause surge currents at the exact frequencies of the MFC. These artifacts exceed the power of the MFC because they occur over the full surface of the semiconductor. However, only the part of the semiconductor at the tunneling junction contributes to the sidebands. This technique shows promise for increasing the versatility and practicality of our new method for carrier profiling.

References:

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