1. Abstract
Role of defects, whether present in bulk or at the interface, becomes increasingly important in nanoscale devices. Electrically-active defects in semiconductors often act as unintended generation-recombination centers, affecting the electrical and optical properties. Conventional methods to study deep levels, such as deep level transient spectroscopy and photo-induced current transient spectroscopy often becomes impractical for nanoscale devices. 

In this poster we show the implementation of a powerful technique based on cross spectrum to study low-frequency noises(LFN) in nanoscale devices. The accurate measurements of the noise signal in nanoscale devices such as field effect transistors (FETs) are extremely challenging because the device noise, which is proportional to the dc current, becomes comparable with the instrumental noise of the measurement setup. To overcome this issue, we implemented a LFN measurement method based on dual-channel cross-spectrum analysis technique. As a test bed we studied LFN in silicon nanowire (SiNW) field-effect transistors (FETs), correlated technique enabled sensitive noise measurement resulting in three orders of magnitude difference in power spectral density (PSD) as compared with conventional single-channel uncorrelated noise measurements. 

Results indicated presence of electrically active deep levels at 0.44 eV and 0.42eV for n-dope NiNWs grown using Au and Ni catalyst respectively. For the p-doped wires, the deep levels were identified at 0.38 eV and 0.22 eV in NiNWs grown using Au and Ni catalyst. Other parameters like capture-cross section and level deep defect concentration were also estimated.

2. Theory
Low frequency noise or "spontaneous fluctuations" in current through semiconductors exists due to the stochastic nature of the conduction process.

Measuring noise power spectral density (PSD) of the dc current flowing through a semiconductor, one can estimate energy level, time-constants, and density of the generation-recombination (G-R) centers present in the sample. Typically for device exhibiting G-R noise, the PSD can be described by Lorentzian behavior, i.e., \(\frac{a}{(\omega_0^2 - \omega^2)^2 + \gamma_0^2 \omega^2}\), where \(\omega_0\) is the low-frequency amplitude and \(\gamma_0\) is the characteristic frequency. G-R process is prominent at moderate temperatures with time-constant \(\tau = 1/kT\) which can be related to the trap energy-level and capture-cross section by the relationships: 

\[ln(\gamma_0) = (\Delta E/kT) - (\Delta H/kT) - \frac{m}{2}
\]

\[\tau = \frac{1}{kT} \exp(\frac{\Delta E}{kT})
\]

Where \(N_G\) is the trap-energy, \(\gamma_0\) and \(\eta_0\) are the electron and hole capture-cross sections, respectively, \(\theta_0\) is the degeneracy factor, \(T\) is the temperature and \(m_e\) and \(m_h\) are the electron and hole masses, respectively. From the slope of the plot of \(ln(\gamma_0)\) vs. \(1/kT\), we can extract the energy position of the trap-level, and the intercept will give us the capture cross-section. It should be noted that often degeneracy values are not accurately known and hence may affect the capture cross-sections and trap density calculations.

3. Noise measurement setup

Figure 1. Setup for the Cross-spectrum noise spectroscopy

4. Working principle of cross-spectrum technique

In time-domain, the cross-correlation of two signals is defined as: 

\[\text{Cross-spectrum} = \int f(t)g(t)dt
\]

In frequency-domain the equivalent cross power spectrum of the two-signals is expressed as: 

\[S_{xy}(f) = \text{abs} \left[ \int f(t)g(t)e^{-j2\pi ft}dt \right]
\]

5. Fabrication of devices for LFN measurements

The new method was applied to probe deep levels in Si nanowires (SiNWs) grown by the vapor-liquid-solid (VLS) mechanism using Au and Ni catalyst. Metal catalysts employed in the VLS growth are known to be the sources of unintentional deep level impurities. 

Figure 2. Bird’s-eye view SEM images of (a) Au- and (b) Ni-catalyzed Si nanowires, insets show tips of the nanowires.

6. Electrical characterization prior to LFN measurements

Graph (a) shows the temperature dependent noise measurement done on a single FET device. Evolution of Lorentzian behavior from low to high temperature is clearly obvious. Graph (b) shows the peaks, extracted from the data of graph (a). It clearly depicts how the peak shifts in frequency with changing temperature.

7. LFN measurement results

Graph (a) vs. 1/kT plot for four FET devices (equations 1 and 2). Table shows all the computed values from this plot.

8. Conclusion

This study demonstrated the fact that properly optimized noise measurement setup can be very powerful technique to study carrier fluctuations in semiconductor materials and to understand the quality of nanoscale devices.

9. Contact information

Deepak Sharma, email: dsharma@umich.edu

This work is partially supported by the National Science Foundation under grant numbers ECCS-1128282