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14. ABSTRACT
The funding of DURIP instrumentation proposal has enabled expansion of the electrical measurement capability in nanowires. Low frequency noise measurement has been set-up using the cross correlation technique. Successful demonstration of noise measurements on the single nanowire of different GaAsSb configurations, namely core-shell, Te-doped and PIN have been demonstrated. The temperature dependence measurement from 4K to 300K has also been demonstrated. The preliminary data obtained indicate the relaxation time for the generation-

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Report Title

Final Report: Characterization of Nanowire Photodetectors

ABSTRACT

The funding of DURIP instrumentation proposal has enabled expansion of the electrical measurement capability in nanowires. Low frequency noise measurement has been set-up using the cross correlation technique. Successful demonstration of noise measurements on the single nanowire of different GaAsSb configurations, namely core-shell, Te-doped and PIN have been demonstrated. The temperature dependence measurement from 4K to 300K has also been demonstrated. The preliminary data obtained indicate the relaxation time for the generation-recombination mechanism to be within the range, 0.2 ms - 0.5 ms. It should be noted that these are preliminary data and require considerable improvement in both the suppression of the noise and mounting of the samples. This can be a powerful tool to provide more insight into the trap location and density in the GaAsSb NWs. The other equipment purchased from this funding, such as the addition of ultrafast I-V modules to the existing Keithley 4200 semiconductor characterization system and picosecond pulsed laser source will be used to provide deeper insight into the fast charge carrier dynamics in the GaAsSb and GaAsSbN nanowires, for potential applications in a wide range of optoelectronic devices at nanoscale.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Durjoy Dev, Manish Sharma, Md Rezaul Karim and Shanthi Iyer, " I-V Characterization and Low Frequency Noise Measurements of Hydrazine Passivated GaAs/GaAsSb Core-Shell and GaAsSb Axial Single Nanowire"MRS/ASM/AVS NC Section Meeting-2016, Raleigh, NC, Poster Presentation, Nov 4, 2016.

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

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Patents Submitted

Patents Awarded

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Names of Post Doctorates

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Names of Faculty Supported

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Names of Under Graduate students supported

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FTE Equivalent:	
Total Number:	

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Inventions (DD882)

Scientific Progress

Technology Transfer

FINAL REPORT
to
ARMY RESEARCH OFFICE

Characterization of Nanowire Photodetectors

DURIP Grant No: W911NF-15-1-0379

Proposal No. 66916-EL-RIP

Period: 08/15/2015- 08/14/2016

Program Manager: William Clark

Shanthi Iyer, Principal Investigator
Department of Electrical and Computer Engineering/
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Table of Contents

Characterization of Nanowire Photodetectors

Introduction

The DURIP funding enabled us to purchase electronic components to set- up the noise measurements and expand the electrical characterization capability to ultra-fast measurements. The objective was to carry out noise measurements and lifetime measurements on GaAsSb single nanowire (SNW). The molecular beam epitaxy (MBE) growth and study of these NWs have been funded by Army Research Office Grants[1,2].

The equipment that were purchased in this grant were dynamic signal analyzer (KT-35670A from Keysight Technologies, current preamplifier SR 570 from Stanford Research System, ultra-fast I-V module (4225-PMU) with remote amplifier/switch- an upgrade to the existing Keithley SPA model 4200 semiconductor characterization system (SCS) and picosecond pulsed laser source PLP-10 from Hamamatsu.

Contributions of Abhishek Motayed and Ratan Debnath from N5 Sensors are acknowledged who provided valuable guidance in the selection of the equipment and operation of the low frequency noise setup.

Work on the low frequency noise spectra of GaAsSb nanowires resulted in a student poster presentation at MRS/ASM/AVS North Carolina Section Meeting 2016 at Raleigh, North Carolina.

Following is a brief description of the use of these equipment in our ongoing research on the GaAsSb NW for the ARO Grant[2].

I. Low Frequency Noise Setup

Low frequency noise (LFN) measurement setup is based on cross-correlation technique[3] that enables the subtraction of the instrument noise from the signal. For this set up as shown in the schematic (Figure 1), two independent low noise current preamplifiers (SR570 from Stanford Research Systems have been used. The source–drain bias is provided by the internal batteries of these two amplifiers, while its outputs are connected to two different channels of Keysight 35670A dynamic signal analyzer. The analyzer is activated in cross-spectrum mode and frequency resolution is set to 1 Hz. The measurements are carried out between 1 Hz to 1600 Hz and the data is averaged over 100 set of readings.

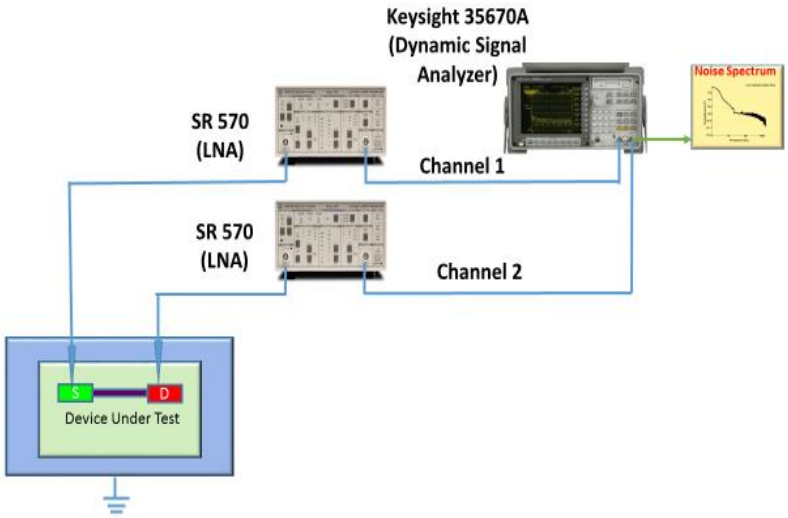

Figure 1: The schematic of the LFN setup.

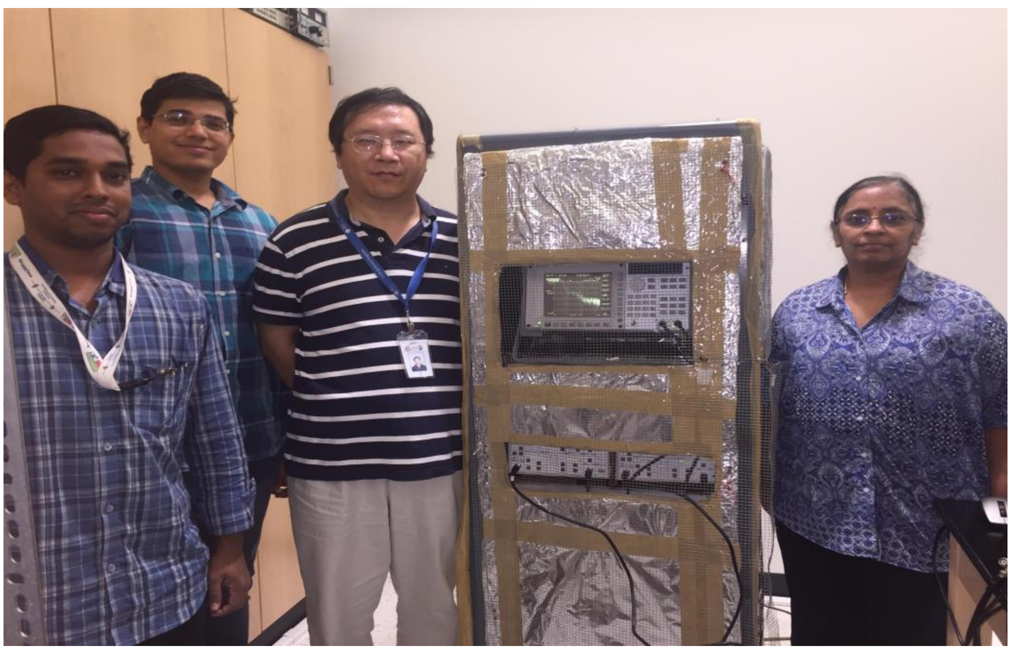

Figure 2: The photograph of the set up inside the faraday cage.
(From Left to right who are involved in this project: Durjoy Dev, Manish Sharma, Dr. Jia Li, Dr. Shanthi Iyer)

The relevant noise parameter being measured is power spectral density (PSD), which is defined as the distribution of the power of the noise signal in the frequency domain. The normalized drain–current noise PSD is defined as

$$S_I(f)^2/I_{DS}^2 = \langle i_{ds}(f)^2 \rangle / \Delta f\, I_{DS}^2 \qquad (1)$$

where $\langle i_{ds}(f)^2 \rangle$ is the mean-square value of the current fluctuations for a particular frequency, f is the effective measurement bandwidth at the discrete frequency point, and I_{DS} is the dc value of the drain current.

Comparison of Low-Frequency Noise Spectra of GaAs/GaAsSb and Hydrazine Passivated Core-Shell SNW

Room temperature noise study was carried out on as-deposited and chemically treated (hydrazine) single NW of GaAs/GaAsSb core -shell (CS) configuration to determine the effect of surface passivation. The NWs were grown by MBE in our laboratory. The details of the growth are provided in Refs. 4-6. The single NWs were obtained by sonicating the sample and drop-cast on Si/SiO_2 surface. Source and drain contacts were then made at the ends of the NW using conventional photolithography followed by the deposition of metal contacts of Ti (30nm)/Au (200nm) using electron beam evaporation as shown in Fig. 3.

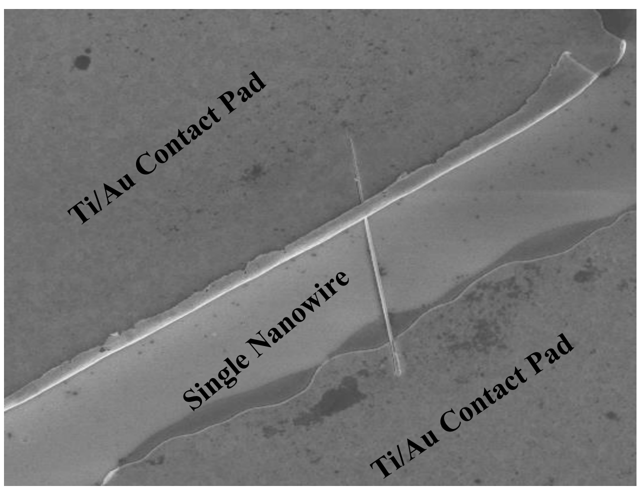

Figure 3: SEM image of single GaAsSb single nanowire across the two metal contacts

Two probe measurement was performed. Figure 4 displays the normalized PSD spectra for as-grown and hydrazine treated GaAs/GaAsSb CS nanowires. The best fit of the spectra with the simulation carried out using Matlab revealed flicker noise at lower frequency having 1/f trend line as given in Eq.2 where α_H is the Hooge's constant and N is the total number of carriers. At higher frequency generation-recombination (G-R) noise is found to be dominant, which was fitted by Lorentzian dependence using Eq.3, where τ is the relaxation time of the G-R process and ω is related to the measurement frequency ($\omega = 2\pi f$). The noise PSD due to a pure single time-constant G-R process is constant till the cutoff frequency f_0 ($\tau = 1/f_0$), above which it rolls off as $1/f^2$ due to discrete states within the bandgap inside the NW.

$$S_I / I_{\mathrm{DS}}^2 = \alpha_H / N f^{\beta} \tag{2}$$

$$S_1 \propto \tau / (1 + \omega^2 \tau^2) \tag{3}$$

Assuming β to be 1, the value of K (= α_H/N) decreases from 0.69 for bare GaAs/GaAsSb core-shell NWs to 0.41 for hydrazine passivated core-shell NWs. This seems to suggest an increase in charge carrier concentration by 1.7 times in the passivated layers. From the shift in the corner frequency of the G-R curve, value of τ was extracted. It decreased from 0.4 ms to 0.3 ms for passivated layer and is consistent with our earlier conjecture of increase in carrier concentration resulting in increased carrier scattering. Further support came from other characterizations, namely, the comparison of the photoluminescence (PL) spectra and I-V curves of as-deposited and passivated samples as illustrated in Fig.5. Low temperature PL spectra of the passivated NWs revealed three fold increase in the intensity, while the I-V curve exhibited an increase in current by ten fold.

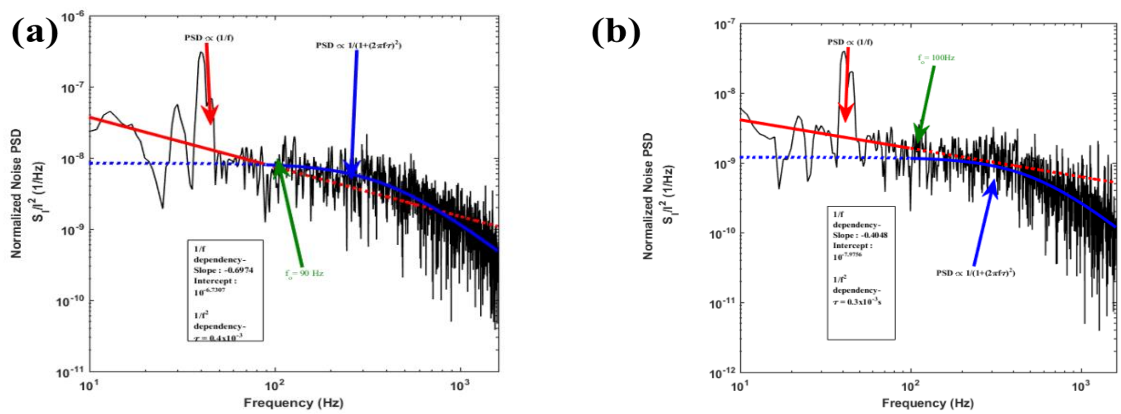

Figure 4: Room temperature low-frequency noise: (a) as-grown GaAs/GaAsSb core-shell and (b) hydrazine passivated core-shell nanowire.

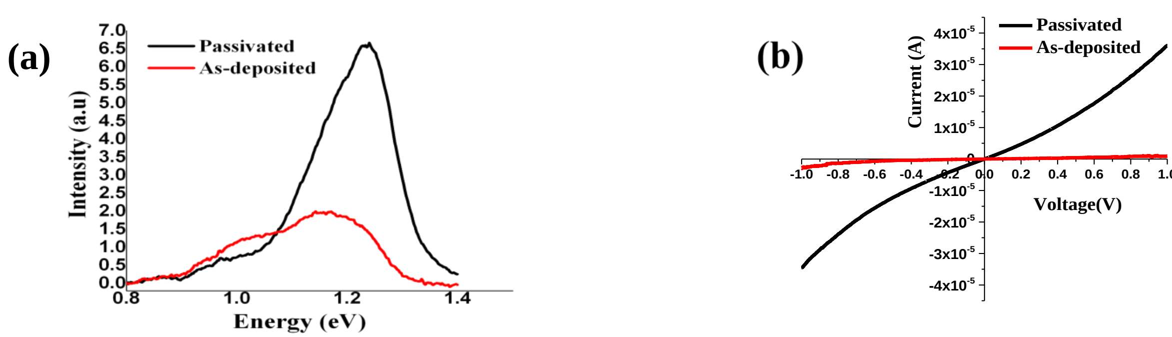

Figure 5: (a) 4K µ-PL spectra and (b) room temperature I-V curve for as-grown and passivated GaAs/GaAsSb core-shell NW.

Temperature Dependence Study of Low-Frequency Noise Spectra of Te-doped GaAsSb Axial SNW

The temperature dependence low frequency noise measurement from 4K to 200K was carried out by placing the device under test (DUT) in a close-cycle Montana Cryostation sample chamber with the same configuration of LFN set-up as described above. However, a special jig was made for mounting the sample in order to carry out low-temperature noise measurements inside the chamber. Thermally conducting and electrically insulating alumina ceramic substrate having a global contact for electrical feed-through were used on which the single nanowire device having source and drain contacts were placed. Gold bonding was performed to transfer contact from source and drain of the device to global contacts. The temperature dependent measurement was performed from 4 K to 200 K. The normalized PSD spectra of Te –doped GaAsSb axial SNW as shown in Fig. 6 reveal clearly the presence of two components of the noise, flicker and G-R, as in the core-shell SNW discussed earlier. The τ values in the range of 0.2- 0.5 ms were extracted from the best fit of the simulated spectra using Matlab to the experimental spectra at different temperatures.

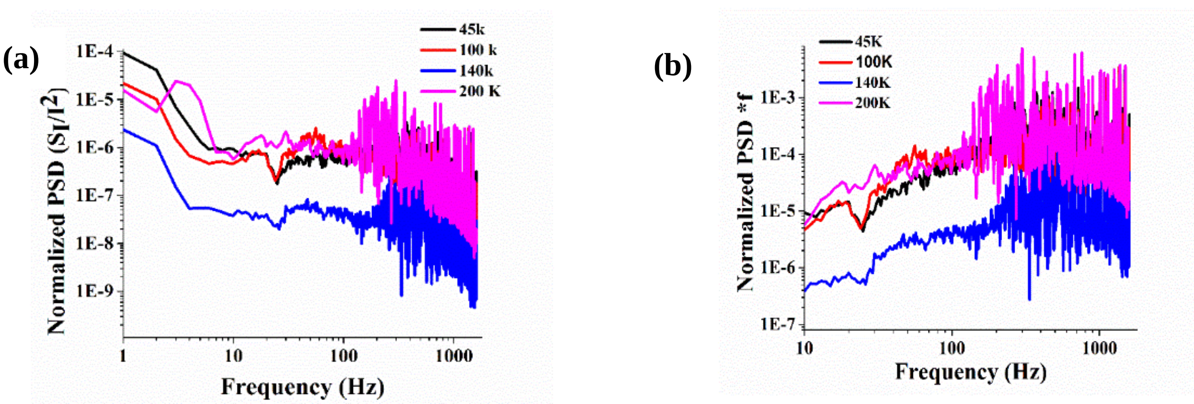

Figure 6: (a) and (b) Normalized PSD vs frequency for single NW GaAsSb axial device at different temperatures.

Temperature Dependence Study of Low-Frequency Noise Spectroscopy of GaAsSb (PIN) SNW

Temperature dependence of SNW of GaAsSb PIN configurations was also examined and shown in Fig.7. τ values varied from 0.2- 0.4 ms, which were again extracted from the best fit of the simulated data to the experimental G-R component of the noise.

Thus we have been successful in making single nanowire contact and carrying out the low-temperature noise measurements. These are the preliminary results and further signal processing need to be performed to improve the signal to noise ratio.

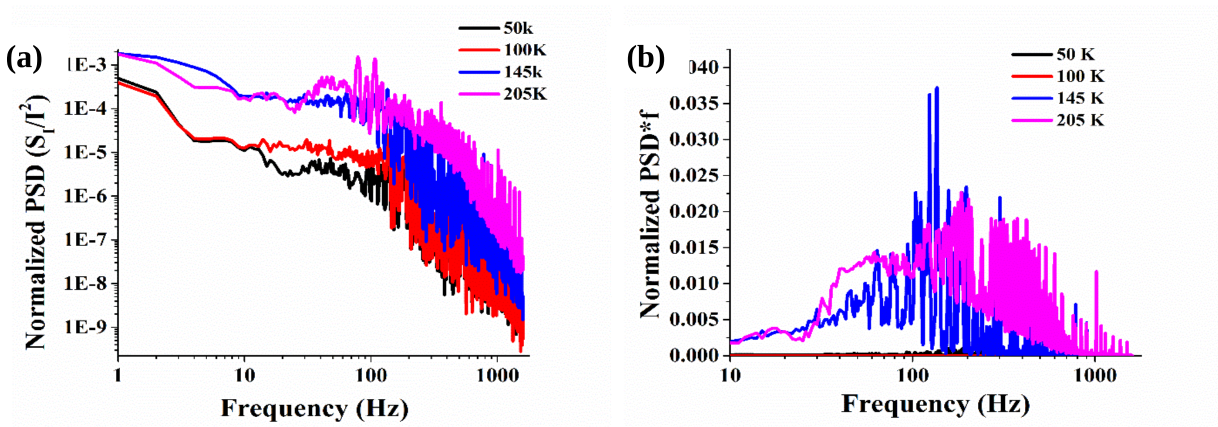

Figure 7: (a) Normalized PSD vs frequency and (b) temperature dependence of normalized PSD*f vs frequency of SNW GaAsSb (PIN) device.

II. Keithley Semiconductor Characterization System Upgrade

Keithley Model 4200-SCS was upgraded by integrating model 4225-PMU along with remote amplifier/ switch, that enable ultra-fast voltage waveform generation and signal observation for expanding the electrical measurement capabilities to ultra-fast measurement applications. The main intent was to use them towards the lifetime measurements of the carriers in the nanowires.

The system was initially tested with a InGaP/InGaAs/Ge triple junction solar cell. A stroboscopic light source was used for illumination of the solar cell and temporal dependence of open circuit voltage was recorded. Illumination was left ON till the steady state was reached. On switching off the light source, an exponential decay of V_{oc} was observed as displayed in Fig.8.

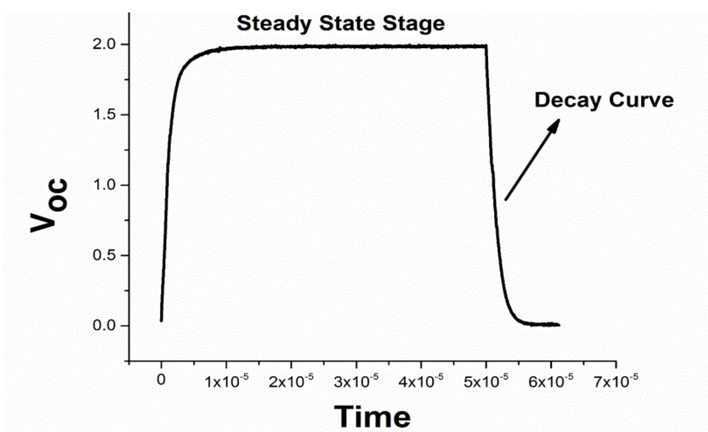

Figure 8: Decay curve of triple junction solar cell using Keithley 4200 SRS System with the 4225-PMU upgrade

We were unable to determine the decay curve in the bare GaAsSb NWs which had no passivating outer shell layer. This indicates the carrier lifetime to be below microsecond range.

This is an expected result due to the presence of large surface defects caused by large surface to volume ratio of the 1-D architecture of the NWs.

III. Picosecond Pulsed Laser Source

In the original proposed project a micro-positioner for $10K was proposed to be integrated with the closed-cycle Montana system to enable movement of the NW inside the chamber to the focused laser spot during the low temperature PL. However, we found a simple solution in-house where the laser source can be moved externally in the micro-range. Hence, the $10K amount was used towards the purchase of picosecond pulsed laser for setting up time resolved photoluminescence spectroscopy.

Hamamatsu picosecond light pulser PLP-10 is an ultrashot pulsed light source that utilizes a laser diode. The picosecond laser system consists of Laser diode head M10306-19, controller C10196 and a focusing lens A10089. The wavelength of the laser is 980 nm with maximum power density 153 mW and pulse duration 52 ps.

Figure 9: Hamamatsu picosecond pulsed laser system

The addition of this laser to our PL system will enable measurement of time-resolved PL spectroscopy and in determining fast charge carrier dynamics in nanosecond or picosecond regime in the GaAsSb NWs.

IV. Summary

DURIP instrumentation proposal funding has enabled expansion of our electrical measurement capability in order to do all the measurement in-house in the nanowires. Low frequency noise measurement has been made successfully on the GaAsSb nanowires and temperature dependence measurement has also been demonstrated. Though there is considerable noise at frequencies beyond 10 Hz due to the measurement being carried out in the close-cycle system these can be tackled by signal processing the data. Mounting of the nanowires also need considerable improvement in order to extract more accurate data on the lifetime of the carrier and will form a powerful tool to get more insight into the location and the density of the traps in the NWs. Operation of the upgrade to existing Keithley 4200 SCS has been demonstrated. This characterization system as well picosecond pulsed laser would enable measurements on the carrier lifetime in future in the ongoing ARO grant[2] and ONR grant[7], though were unable to carry out within the one year grant period of the DURIP .

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