INTEGRATION OF THE BIONANOMATERIAL BACTERIORHODOPSIN AND SINGLE ELECTRON TRANSISTORS

KARL A. WALCZAK[1*], MANORANJAN ARCARY[2], DONALD R. LUEKING[3],
PAUL L. BERGSTROM[2], CRAIG FRIEDRICH[1]
[1]Department of Mechanical Engineering-Engineering Mechanics
[2]Department of Electrical and Computer Engineering,
[3]Department of Biological Sciences
[1,2,3]Multi-Scale Technologies Institute
Michigan Technological University, Houghton, MI 49931 USA

ABSTRACT

Innovation in sensing technology is necessary in order to decrease negative outcomes in the event of a chemical or biological exposure. The sensors currently used to detect chemical and biological agents are too bulky, complex, and costly. The thrusts of this research are to develop sensor technologies. The technologies developed would help create sensor arrays which are: lightweight, disposable, wireless, deployable by hand, and reconfigurable. This paper will present initial results on the development of technology for a sensing platform which incorporates a single electron transistor (SET) with bacteriorhopdin (bR).

1. INTRODUCTION

Bacteriorhodopsin is a photosensitive protein found in the purple membrane (PM) of the bacterium Halobacterium salinarum. When illuminated with light, bR generates a small current and electrical potential by shifting a proton from the intracellular to the extracellular side of the cytoplasmic membrane. This extensively studied (Stoeckenius 1994) protein is extraordinarily robust and can function in extreme environmental conditions (Vsevolodov 1998), in both aqueous and dried states.

The majority of the research on bR has utilized it in an aqueous state immobilized on a conductive substrate. However, there are a significant number of potential devices that could utilize the photoelectric response of bR in the dried state. In the dried state, bR could be integrated with semiconductor-based devices such as metal oxide semiconductor field effect transistors (MOSFETs) (Shin et al. 2007) or single electron transistors.

SETs are composed of four components: gate, source, drain, and quantum islands. These components can be metallic or semiconductors. A SET is a nanotransistor that exploits the quantum mechanical properties of electrons to control the current flowing from the source to the drain (Kastner 2000). The function of room temperature SETs is based on the tunneling of electrons, quantized units of energy, across quantum islands (W dots <10 nm in diameter (Karre et al. 2007)) between the source and drain. Changing the gate potential can change the rate of tunneling electrons between the source and drain.

The minimum current flow or *off* position for the SETs is located in the Coulomb blockade region (horizontal region) of the current verses voltage (IV) curve. The Coulomb blockade is a phenomenon which occurs when there is no tunneling of the electrons between the source, islands, and drain to create a current. Coulomb blockade can be removed by change source bias voltage and/or by adding a gate voltage to align energy levels on the quantum islands with that of the source and drain (Berman 1998). This allows electrons to tunnel between the source and drain. Modulating the gate potential could change the rate of electrons tunneling from the source to the drain.

This paper is going to describe a method of depositing bR on the gate of a SET and then measure characteristic after the integration with both light-on and light-off.

2. MATERIALS AND METHODS

The integration of the photosensitive bionanomaterial bacteriorhodopsin with single electron transistors is a hybrid device, composed of both biological and non-biological components. This paper presents the first report of a bionanomaterial, bR, integrated with a SET. Each of the SETs contains three electrodes Drain\Source\Gate (Fig.1) which are separated by focused ion beam (FIB) etching as shown in Fig. 2. The SETs were fabricated by a process described by (Karre 2007) with a couple of

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
DEC 2008	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Integration Of The Bionanomaterial Bacteriorhodopsin And Single Electron Transistors	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Mechanical Engineering-Engineering Mechanics Multi-Scale Technologies Institute Michigan Technological University, Houghton, MI 49931 USA**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002187. Proceedings of the Army Science Conference (26th) Held in Orlando, Florida on 1-4 December 2008, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**4**	

modifications. First, photolithography was used to decrease the time to FIB devices by patterning the general architecture of the devices as shown in Fig. 1. Second, a liftoff process was used to remove the passivation layer of Al_2O_3 from the device pads. Third, the gate pad size was increased from 100 µm x 100 µm up to 4 mm x 2 mm.

Enlarging the gate pad increases the amount of bR incorporated with the SET as shown in Fig.1. Since the voltage generated by bR from the proton pumping/shifting is vectorial. The more oriented bR deposited on the gate the greater the voltage potential generated. Generating a larger voltage potential on gate will increase the possibility of modulating the SET with bR.

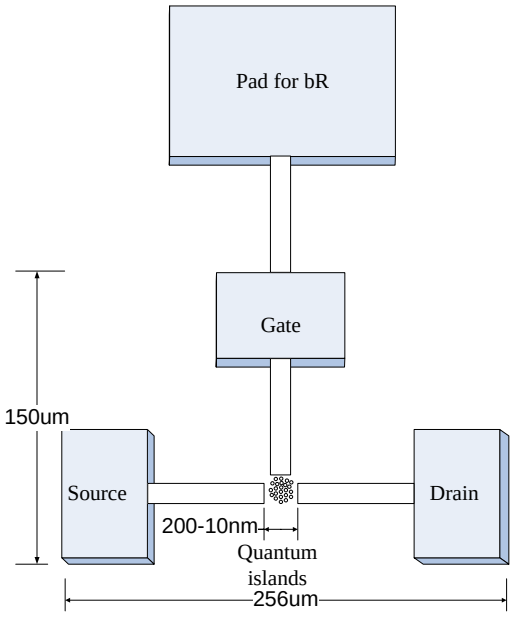

Fig. 1. General architecture for bR SET.

Commercially available high intensity amber light emitting diodes (LEDs) were selected as the excitation source because the peak emission was near the peak absorbance of the bR as shown in Fig. 3. The light source was composed of three high intensity amber LEDs and powered by a constant current source which could be varied. As shown in Fig. 3, the LEDs have a major peak at 595 nm and the bR has a major absorbance peak at 570 nm.

Prior to bR integration with SETs baseline characteristic were established by measuring the IV curves with and without light illuminating the gate pad, where the bR would be immobilized. Baseline characterization indicated that the SETs were not influenced by light.

Bacteriorhodopsin was then electrophoretically immobilized on the gate pads of the SETs. The bR coupled SETs were then characterized again without light to make sure they still functioned after the immobilization process of bR on to the gate pad. The secondary baseline characterization of the SET coupled with bR indicted that the immobilization process did not alter the functionality of the device as shown in Fig. 4. This secondary baseline data was compared to initial baseline experiments measurements which indicted no significant change in the IV characteristics of the device.

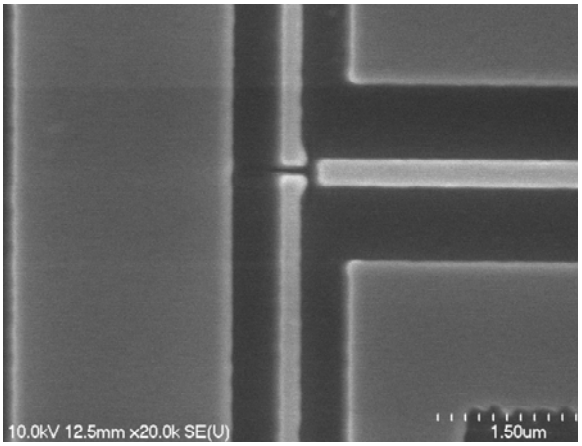

Fig. 2. Electron Micrograph of gap of SET.

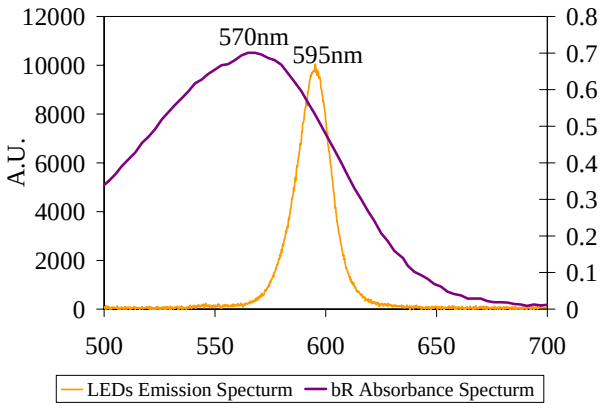

Fig. 3. Emission and absorbance spectrums of amber LEDs and bR, respectively.

3. RESULTS

The SET coupled with bR was shown to be functional, see Fig. 4, without light. Now the influences of excited, with-light, bR immobilized on the gate pad of the SET were measured. The voltage and current generated by exciting bR on the gate of the SET caused a change in the current flowing between the source and drain of the device as shown in Fig. 4. Too ensure that the change in current

across the source and drain was due to the bR and not some artifact of the LED circuit, multiple tests were conducted; blocking the light source and altering the optical power of the light source.

First, the light was blocked without moving the LEDs. Blocking the LEDs eliminated the current change across the source and drain as the LEDs were flashed. Then, the optical power of the LEDs were varied since the voltage potential of bR is dependent on the optical power of the excitation source, the larger the light intensity the larger the voltage potential generated by bR. As shown in Fig. 5, changing the optical power of the LEDs caused a change in the amount of current flowing between the source and drain. These graphs indicate increasing the optical power output of the LEDs increases the change in current flowing between the source and drain.

Next to establish an understanding of the controllability of the SET the bias voltage on the source terminal was varied to attempt to control the current flowing between the source and drain. The bias voltages on the source terminal determined from the characteristic IV curve shown in Fig. 4 which varied from -25 V to 25 V. If the SET is working properly changing the bias voltage on the source terminal will change the current flowing across the source drain gap.

Within the coulomb blockade, -5 V to 5 V, the current flowing from the source to the drain should be minimized. As shown in Fig. 6, there was not a measurable change in the current flowing from the source to the drain.

Outside the coulomb blockade region the current from the source to the drain will flow and be amplified depending on the source bias voltage. The maximum amplification within the measured IV curved ranged from -25 V to 25 V, as shown in Fig. 4, was determined to be at -25 V since the slope is maximum. As shown in Fig. 5, with a source bias voltage of -20 V the change in current from the source to the drain is about 2 picoAmps. From Fig. 7, the change in current is maximized over the measured range at -20 V and minimized at 0 V. Figure 6 also shows that the current flow across the device can be controlled by altering the source bias voltage or the excitation of the bR.

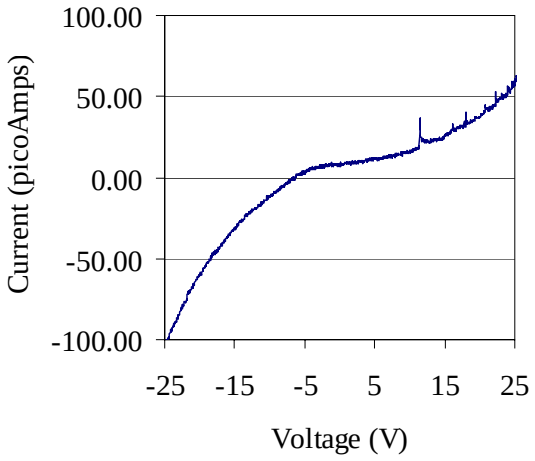

Fig. 4. IV curve of SET coupled with bR.

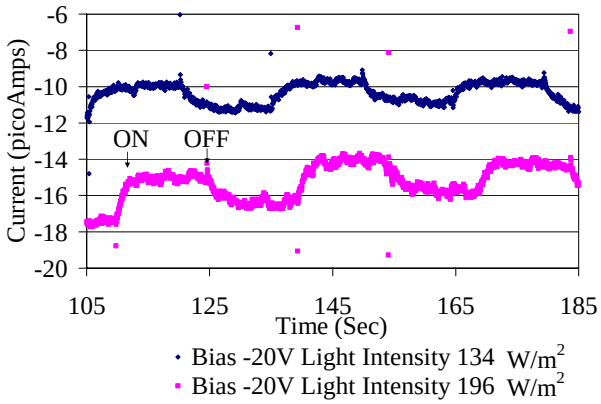

Fig. 5. IT curves of SET coupled with bR, bias with a source voltage of -20 V, and with a flashing light source at 134 W/m^2 (blue) and 196 W/m^2 (pink).

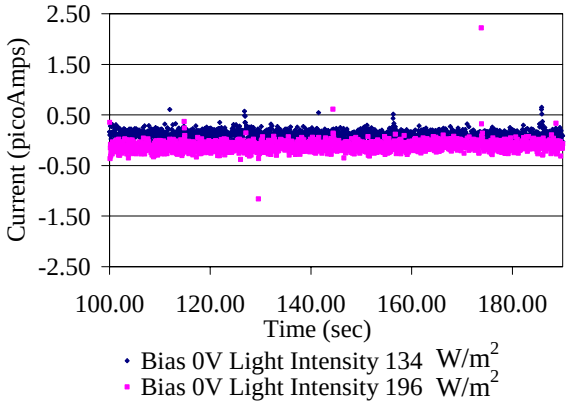

Fig. 6. IT curves of SET coupled with bR, bias with a source voltage of 0 V, and with a flashing light source at 134 W/m^2 (blue) and 196 W/m^2 (pink).

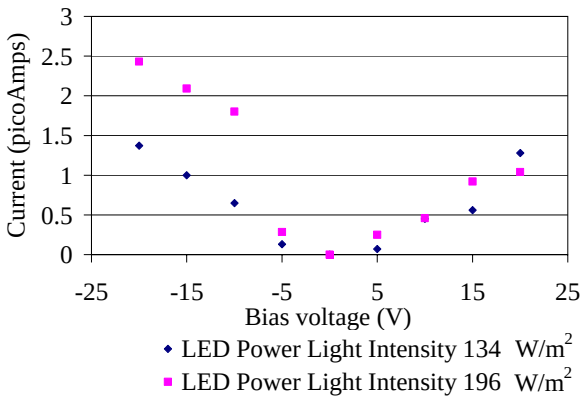

Fig. 7. Change in current verses source bias voltage with a flashing light source at 134 W/m^2 (blue) and 196 W/m^2 (pink).

CONCLUSIONS

In conclusion this work has shown it is possible: 1) to incorporate a bionanomaterial and SET, 2) to modulate the output of the SET with bR, and 3) control the sensitivity of the SET by change the bias voltage. With this initial research into the integration of the bR with SETs it is hoped that this technology developed will eventually lead to creation of an inexpensive, ultra-fast detection, super sensitive chemical and biological toxin sensor. The sensor developed could then be used to save the lives of soldiers and civilians. Further research is being conducted to optimize processing and sensitivity of the bR SET devices.

ACKNOWLEGDEMENTS

The research reported in this document was performed in connection with contract DAAD17-03-C-0115 with the U.S. Army Research Laboratory. The views and conclusions contained in this document are those of the authors and should not be interpreted as presenting the official policies or position, either expressed or implied, of the U.S. Army Research Laboratory or the U.S. Government unless so designated by other authorized documents. Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof. The U.S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation hereon.

REFERENCES

Berman, D., 1998: The aluminum single-electron transistor for ultrasensitive electrometry of semiconductor quantum-confined systems, Electrical Engineering and computer science, MIT, 1-137 pp.

Karre, P. S. K., 2007: Focused ion beam technologies for room temperature operating single electron transistors, EE, Michigan Technological University, 176 pp.

Karre, P. S. K., P. L. Bergstrom, G. Mallick, and S. P. Karna, 2007: Room temperature operational single electron transistor fabricated by focused ion beam deposition Journal of Applied Physics, 102, 1-4.

Kastner, M. A., 2000: The single electron transistor and artifical atoms. Ann. Phys. , 9, 885-894.

Shin, J., P. Bhattacharya, H.-C. Yuan, Z. Ma, and G. Váró, 2007: Low-power bacteriorhodopsin-silicon n-channel metal-oxide field-effect transistor photoreceiver. Opt. Lett., 32, 500-502.

Stoeckenius, W., 1994: From membrane structure to bacteriorhodopsin. J. Membrane Biol., 139, 139-148.

Vsevolodov, N., 1998: Biomolecular electronics an introduction via photosensitive proteins