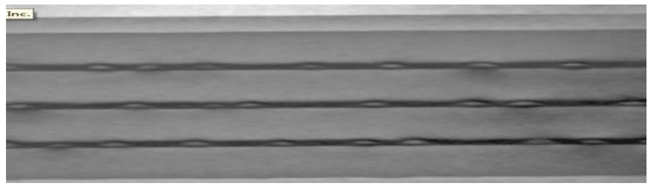

INVESTIGATION OF CURRENT LEAKAGE MECHANISMS ON INAS NANOISLAND DIODES FOR RADIATION HARDNESS

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ABSTRACT (120 words)

This research project presents the effects of thermal neutron radiation of fluences ranging from 3 to 9×10^{13} neutron/cm^2 on the electrical behaviour of quantum dot-in-a-well semiconductor samples. The samples are characterized via forward-bias and reverse-bias current densities measurement, capacitance-voltage measurement and temperature dependence measurement. After neutron irradiation of up to 9×10^{13} neutron/cm^2, the leakage current increases both in forward bias and reverse bias by an order of magnitude and two orders of magnitude respectively. Increments are expected to be due to the induced displacement damage effect. Based on ideal diode equation fitting, the ideality factor and series resistance are some of the values that increase with the increasing neutron fluence, indicating a change in the current transport mechanism as well as the doping profile. From the capacitance-voltage measurement, the capacitance is calculated to reduce by up to 6.42%, which is believed to be due to the carrier removal effect. Reduction in the doping densities of the *p*-region and *i*-region and increment in the doping densities of the *n*-region on the other hand suggests an effect of Neutron Transmutation Doping. An insight on the reverse-bias leakage current mechanism reveals that the increase in current densities is due to trap-assisted generation-recombination and Frenkel-Poole effect.

1. INTRODUCTION

All semiconductor devices suffer from electrical and structural properties degradation in the presence of defects and dislocations especially when operated in a hostile environment. It is well established that when semiconductor based devices such as silicon diode subjected to high energy electrons, protons or fast neutron radiation, the diode suffers damage as a result of high current increment. Among the possible reasons causing such damage include the displacement of atoms which created defects or traps in the mid bandgap of the diode as well as the creation of energetic free carriers in the device through ionization process. Devices exposed to high energy neutrons can be found in a variety of applications, for example; space based electronics systems, radiation detector and control system in the nuclear industry and also in medical applications.

The impact of this degradation on many safety-critical applications is a major issue and there is a need for radiation hard electronic devices. This research project study the electrical properties of semiconductor optoelectronics based devices that are capable of operating in an environment subjected to high energy particles, specifically under neutron and gamma radiation. This project will study commercial silicon diodes and diodes made from conventional bulk GaAs (group III-V) along with diodes containing stacks of InAs nanoislands /quantum dots (QD) within the GaAs intrinsic region. III-V materials are known to be more resistant to degradation when subjected to fast particles due to its heavier atomic number compared to silicon devices. However more recently, quantum dot containing devices have been shown to be even more resistant to growth defect propagation in the devices where the quantum dots appear to act as barriers to dislocation movement in epitaxial semiconductor diodes. This research aims to study the different types of QD based devices radiation hardness and to demonstrate that QD incorporated devices have a better resistance towards fast neutron and gamma rays compared to bulk III-V materials and silicon devices and may be the basis for a class of radiation hard electronic devices.

2. RESEARCH METHODOLOGY

a. Literature review of technical and scientific papers

b. Design of GaAs and quantum dot diode structures

c. Exposure of the samples to neutron radiation

d. Room temperature current-voltage measurements

e. Room temperature capacitance-voltage measurements

f. Temperature dependence current-voltage measurements

h. Result analysis

3. FINDINGS : Reverse Bias (RB) Leakage Current Mechanism

The RB leakage current mechanisms of the DWELL samples are evaluated under consideration of the results obtained in the previous sections. Neglecting the effect of non-radiative Auger recombination [30], the analytical results imply that the total current density in the RB is a result of combination of two current mechanism components given by $J_{Total} = J_{TAGR} + J_{F\text{-}P}$ where J_{TAGR} is the trap assisted generation-recombination current and $J_{F\text{-}P}$ is the 3D frenkel poole current.

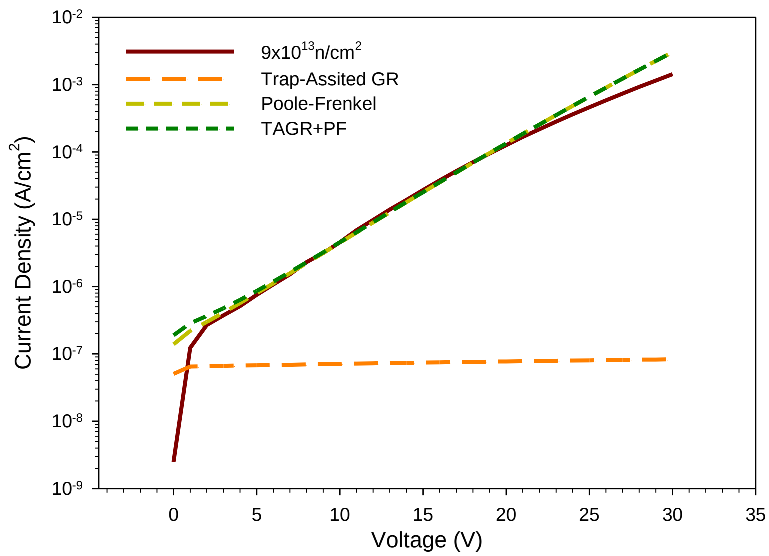

Fig. 1: RB I-V fittings of the sample subjected to $9{\times}10^{13}$ n/cm^2 with TAGR model and 3D F-P model.

According to the RB I-V fittings (shown in figure 1 and figure 2), it may be seen that both the TAGR model and the 3D F-P model demonstrate a good correlation with the RB I-V characteristics of the sample for voltage in the range of 4 to 22V. At lower voltage, it is assumed that the current is due to thermal excitation of carriers while at much higher field, the current would probably be due to field-assisted tunneling mechanism as suggested by [16]. A fit of the sample's current density against electric field profile with that model over an increasing temperature is illustrated in figure 14. Fittings are in agreement with the RB I-V characteristics over the field range of >50kV/cm. Such findings indicate that the RB leakage current mechanisms are indeed largely due to postulated mechanisms.

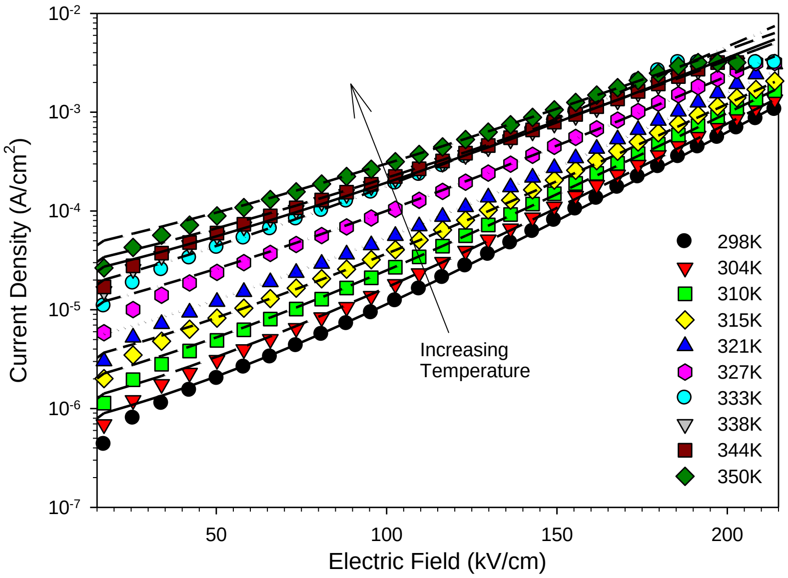

Fig. 2: Excellent fittings of the sample's RB I-V characteristic subjected to 9×10^{13} n/cm^2 with TAGR model and 3D F-P model over increasing temperature.

Values of the defect densities and the radius of the square well potential from the fittings before and after irradiation are tabulated in Table 1 below. The trap densities derived from both TAGR mechanism and F-P mechanism showed a linear correlation with increasing neutron fluence. Such condition is expected as the greater the number of fluence, the greater the probability for neutrons to interact with the device in that specific period of time. Hence, causing greater number of radiation-induced trap densities inside the bandgap of the structure. Apart from the two parameters, linear relationship with the increasing neutron fluence was similarly recorded for the square well potential which signifies a decrease in the energy band gap value.

Table 1: Trap densities and radius of square well potential of the sample before and after neutron irradiation

Sample Type	**$N_{t(TAGR)}$ (cm^{-3})**	**b (m)**	**$N_{t(FP)}$ (cm^{-3})**
Pre-irradiation	5.7×10^3	6.6×10^{-9}	2.3×10^4
3×10^{13} n/cm^2	8.0×10^3	13.1×10^{-9}	3.0×10^4
6×10^{13} n/cm^2	9.0×10^3	14.2×10^{-9}	3.5×10^4
9×10^{13} n/cm^2	9.3×10^3	14.8×10^{-9}	3.7×10^4

4. CONCLUSION

Neutron irradiation on various types of quantum dot (QD) samples under neutron fluences ranging from 3×10^{13} neutron/cm^2 to 1.44×10^{16} neutron/cm^2 were successfully conducted. Findings include increment in the forward-bias (FB) and reverse-bias (RB) leakage current of the InAs/GaAs QD samples as much as an order and 2 orders of magnitude respectively. The RB I-V temperature dependence measurements were also carried out for all samples and the samples exhibit dependence of the slope of Arrhenius plot with the applied temperature. The activation energy derived from the temperature dependence measurement showed decreasing trends with increasing applied field which signifies that the fermi level is reduced. We report that the mechanisms responsible for the I-V characteristics of the QD samples are due to both Poole-Frenkel (P-F) and trap assisted generation-recombination (TAGR). Fittings of the RB I-V characterics using P-F and TAGR model indicates good fit which proved that the current mechanisms are indeed due to the postulated mechnaisms above. As an addition, we have found out that the trap density due to TAGR and P-F increases with the increasing neutron exposure causing the carrier concentration for p^+ and p^- reduced. However, increment in carrier concentration of n substrate tells us that the possible cause of the changes in doping concentration is due to an effect of NTD.

FINANCIAL REPORT AND ASSET REPORT

Financial Summary Details

Project ID	FRGS12-081-0230
Title	Investigation of Current Leakage Mechanisms on Inas Nanoisland Diodes for Radiation Hardness
Kulliyyah	Kulliyyah of Engineering
Duration	24
Researchers	
ASSOC. PROF. DR. Nurul Fadzlin Bt Hasbullah (4527)	Principal
DR. Nahrul Khair Bin Alang Md Rashid (5928)	Co-Researcher
ASSOC. PROF. DR. Agus Geter Edy Sutjipto (4703)	Co-Researcher
PROF. DR. A. H. M. Zahirul Alam (4575)	Co-Researcher

Fund Summary

Vote Code	Description	Initial Allocation (RM)	Current Allocation (RM)	Disburse (RM)	Committed (RM)	Balance (RM)
V11000	Research Assistant (RA)	36,000.00	36,000.00	28,600.00	0.00	7,400.00
V21000	Travelling Expenses And Subsistence	8,000.00	8,000.00	2,792.25	0.00	5,207.75
V23000	Communication and Utilities	0.00	0.00	0.00	0.00	0.00
V27000	Research Materials & Supplies	15,000.00	15,000.00	30,665.98	0.00	-15,665.98
V28000	Maintenance services	500.00	500.00	0.00	0.00	500.00
V29000	Professional Services & Other Services including Printing & Hospitality, Honorarium for subjects	3,000.00	3,000.00	5,463.40	0.00	-2,463.40
V35000	Equipment	27,200.00	27,200.00	21,905.55	0.00	5,294.45
V36000	Miscellaneous Research Advancement	0.00	0.00	0.00	0.00	0.00
V37000	Travelling Research Advancement	0.00	0.00	0.00	0.00	0.00
Total		**89,700.00**	**89,700.00**	**89,427.18**	**0.00**	**272.82**

Fund Received Detail

Receive Date	Description	Receipt No	Total	Vote Code
27-06-2016	REFUND ADVANCEMENT_FRGS12-081-0230_BMMB23969	CM13016000202	272.82	A73107
Total Fund Receive			**272.82**	

Fund Received Detail Fund Disbursed Detail

Disburse Date	Description	Supplier Name	Documentre	Total (RM)	Vote Code
08-02-2013	RESEARCH ADVANCEMENT_FRGS12-0810230	NURUL FADZLIN BT HASBULLAH		10,000.00	A73107
10-02-2013	RESEARCH ADVANCEMENT_FRGS230	NURUL FADZLIN BT HASBULLAH	024671	10,000.00	A73107
13-02-2013	DISBURSEMENT OF GRANT_FRGS12-081-0230	NURUL FADZLIN BT HASBULLAH	024766	280.72	B27102
02-09-2013	LOCK IN AMPLIFIER	RAYTAG SOLUTIONS SDN BHD	027112	18,000.00	A39401
08-03-2019	Research Officer Payment Process - Group Method	BANK MUAMALAT MALAYSIA BERHAD (6175-W)	RA/2014-03	1,500.00	B29405
13-08-2014	REIMBURSEMENT FROM ADVANCEMENT TAKEN	NURUL FADZLIN BT HASBULLAH	EP14090482	12,260.04	B27505
04-11-2014	RESEARCH CLAIM - FRGS0230	NURUL FADZLIN BT HASBULLAH	EP14112113	5,425.00	B29404
04-11-2014	RESEARCH CLAIM - FRGS0230	NURUL FADZLIN BT HASBULLAH	EP14112113	2,334.24	B27103
04-11-2014	RESEARCH CLAIM - FRGS0230	NURUL FADZLIN BT HASBULLAH	EP14112113	1,900.00	B27505
Total Fund Disbursed				**61,700.00**	

HUMAN CAPITAL DEVELOPMENT

1. **One master student**
   Dhiyauddin Bin Ahmad Fauzi
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   Student ID: G1211123
   Citizenship: Malaysian
   Year of Graduation: 2015
   Thesis Title: Electrical Characterisation of Commercial Optoelectronics Diodes and Quantum Dot Based Diodes Subjected to Neutron Radiation

ACHIEVEMENT

i) Fauzi, D.A., M.D. Rashid, N.K.A., Karim, J.A., Zin, M.R.M., Hasbullah, N.F., Fareed, O.A.S., "*Electrical performances of commercial GaN and GaAs based optoelectronics under neutron radiation*", (2013), IOP Conference Series: Materials Science and Engineering, 53 (1), art. no. 012029.

Fauzi, D.A. ; Alang, N.K. ; Rashid, M. ; Omar, N.I.C. ; Hasbullah, N.F. ; Zin, M.R.M., "*Effects of High Neutron Fluence on The Electrical Characteristics of InAs Quantum Dot Structures*", (2013), IEEE 4th International Conference on Photonics (ICP) 2013, vol., no., pp.227,229, 28-30 Oct. 2013.

A journal paper was accepted in Tier 1 ISI journal, IEEE Transaction of Nuclear Science

ii) Bronze medal award. (IIUM's Research, Invention and Innovation Exhibition 2014)