Nano Vacuum Channel Transistors (NVCT)

Oleksandr Novytskyy  
*Boise State University*

Ranajoy Bhattacharya  
*Boise State University*

Jessica Carlson  
*Boise State University*

Adam Croteau  
*Boise State University*

Addie Higgins  
*Boise State University*

*See next page for additional authors*
Authors
Oleksandr Novytskyy, Ranajoy Bhattacharya, Jessica Carlson, Adam Croteau, Addie Higgins, John McClarin, David Vogel, and Jim Browning
INTRODUCTION
The goal of Nano Channel Vacuum Transistor (NVCT) research is to develop and characterize three-terminal vacuum transistor devices that operate in ultra-high vacuum (UHV) and withstand temperatures up to 400 °C. This process includes designing driver systems, implementing automated Data Acquisition (DAQ) hardware, and using data to determine approximate lifetime, maximum operating conditions, and identify causes of device failure.

EXPERIMENTAL SETUP

Preliminary Testing Vacuum Chamber
- Capable of reaching pressures as low as 10^-7 Torr using a Varian VacIon 300 StarCell Ion Pump.
- Devices are powered using a driver circuit that provides a constant square pulse from 0-40V at a low duty cycle of 20%.
- Gate voltage is pulsed at a fixed amplitude.
- LabVIEW control program takes periodic I-V curves observe the degradation of the device over hundreds of hours.
- LabVIEW monitors arcing from the gate to the emitter as charge builds in the gate dielectric. If multiple arcs occur, the system shuts down to prevent further damage and to allow for failure analysis.

LIFETIME TESTING

Lifetime tests are performed to analyze long term behavior and failure conditions of the devices.

- Devices are heated up to 400 °C.
- The gate voltage is pulsed at a fixed amplitude.
- LabVIEW control program takes periodic I-V curves observe the degradation of the device over hundreds of hours.
- LabVIEW monitors arcing from the gate to the emitter as charge builds in the gate dielectric. If multiple arcs occur, the system shuts down to prevent further damage and to allow for failure analysis.

RESULTS & ANALYSIS

- The vertical emitter devices turned on at approximately 17 V.
- Emitter-collector current at a pulsed gate voltage of 40 V ranged from 20 uA to 65 uA, but some devices where the anode was positioned closer to the emitter produced up to 250 uA.
- Gate leakage current started in the 1 mA range - very high due to the large distance between anode and emitter array.
- As the device experienced repeated gate-emitter arcing, leakage current increased to the 50-120 mA range due to the gradual destruction of the gate dielectric (insulator).
- Many devices failed before making it to lifetime testing due to repeated arcing.

CONCLUSION
- By using a high vacuum chamber and a source measure unit, I-V curves for three-terminal vertical field emitter devices were observed.
- However, due to the separation of the emitter and the non-ideal external collector, the devices suffered from high gate leakage current.
- The collected data is important for fabrication of future three-terminal devices that will have a collector built-in.
- The long-term goals for these devices is to reduce gate leakage current, prevent gate-emitter arcing, create a built-in collector, and to decrease collector-emitter spacing to the nanoscale range.
- Ideally, future I-V characteristics will replicate trends shown in Figure 6, as opposed to those shown in Figure 2.
- Finalized NVCT devices are intended to operate in the high temperature and radioactive environment of a nuclear reactor.

TEST PROCEDURE

When testing transistor devices inside a vacuum chamber, the following sequence of steps is followed:
1. Clean vacuum chamber with isopropanol and place devices inside.
2. Turn on turbo pump and wait for the pressure to drop below 10^-6 Torr.
3. Set the temperature control to desired temperature.
4. Lower the gate connection pin onto the gate pad.
5. Use the EasyEXPERT software to power the collector to 100 V.
6. Sweep the gate voltage, and measure the output emitter-to-collector current to generate I-V curve. Repeat until experiments are complete.
7. Turn off the temperature controller and wait for the temperature to drop to room temperature.
8. Turn off the turbo pump and open the nitrogen gas valve to coat the vacuum chamber with nitrogen.
9. Remove devices from chamber and place into their protective packaging. Separate any destroyed devices for failure observation.

Material support for this work is provided by the Air Force Office of Scientific Research under grant FA9550-18-1-0436.