Department of Electrical Engineering
Electronics
Computers
Communications

Technion—Israel Institute of Technology

Will Insulators Replace Semiconductors ?

Dan Ritter

Thanks to our group members

Graduate Students: Yonnie Kalahorra, Eilam Yalon, Eli Bloch, Shlomo Mehari, Kobi Greenberg, Igor Krilov, Sasha Kelrich

Crystal growth: Shimom Cohen

Technology: Arkady Gavrilov

Thanks to Technion Micro Nano Fabrication Utility

Prof. Nir Tesler, Head

Dr. Yacov Shneider, Chief Engineer

and the excellent team

Insulators as active elements

Underlying mechanism: manipulation of atoms in insulators by an electric fields or energy

In more detail: insulator to metal transition or change in resistivity

Examples: metal atoms, oxygen(vacancy), phase transition

Why? Non volatile, small

Status

- Memory chips available commercially
- Research on logic circuits using two terminal devices combined with CMOS at Technion (Kvatinsky, Kolodny, Weiser) and other universities
- Device physics not always fully understood
- Only few examples of three terminal devices

We are pleased to host today Prof. Dongmin Chen of Peking University, founder of 4DS, who will talk here today at 15:45 on

Metal Oxide Hetero Junction Nonvolatile Memory

Dongmin Chen Dean, School of Innovation and Entrepreneurship of Peking University

Dr. Chen is the Dean of School of Innovation and Entrepreneurship, Director of Science and Technology Development Office of Peking University, and a tenured full professor in the Faculty of Academy for Advanced Interdisciplinary Studies.

Dr. Chen was an adjunct Professor of the Institute of Physics, Chinese Academy of Sciences where he served as the co-director of the Beijing National Laboratory for Condensed Matter Physics from 2004 to 2009. He was a Sr. Rowland Fellow and the Head of the Nanoscale Quantum Physics Lab. at Harvard University from 1989 to 2004. His academic expertise includes nanotechnologies and advanced semiconductor process integrations, nonvolatile material and device physics, MEMS device and process, MEMS-CMOS integration; spin and quantum device physics. He co-authored more than 70 scientific publications and 150 US and international patents.

Dr. Chen is a serial entrepreneur. He is the Chief Scientist and the inventor of the Metal Oxide Heteorjunction RRAM device of 4DS Inc. in the Silicon Valley. He also co-founded Miradia Inc. in Silicon Valley in 2003 which raised 80M USD from tier-1 venture capitals. He led the development of a platform technology for MEMS-CMOS 3D integration for applications in digital micro-mirror array and motion sensors. He was responsible for the development of the IP portfolio with more than 100 international patents and has successfully licensed it to a major foundry in Asia.

Dr. Dongmin Chen is the International Adviser of WIPO GII. Dr. Chen is an Associate Editor and board member of Applied Physics letter and Journal and Applied Physics; a Sr. Associate Editor of Chinese Science Bulletin and an Associate Editor of Chinese Physics Letter. He is the Honorary Advisor and former Chairman & President of Chinese American Semiconductor Professional Association in US.

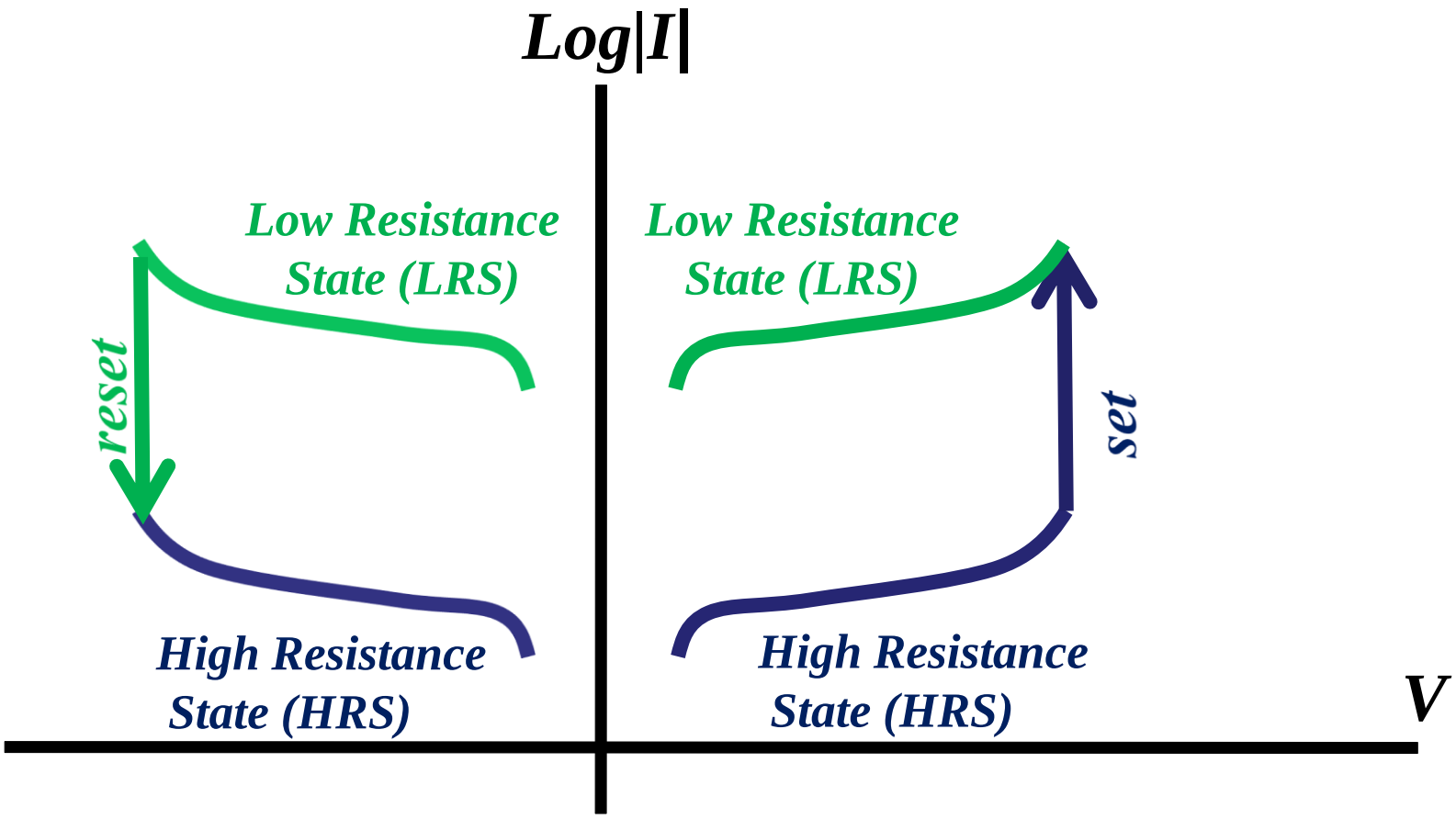
Agenda

- Highlight of our research on insulator electronics
- Review of our activity on semiconductor devices

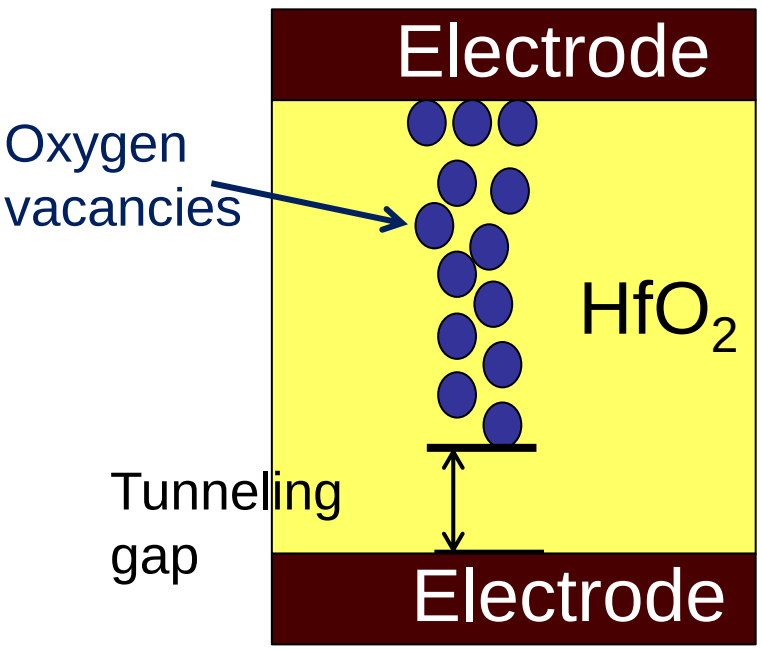
Resistive switching in hafnium oxide

- Hafnium oxide used in silicon industry as high k gate insulator
- Exhibits resistive switching
- Effect believed to be due to formation and rapture of metallic oxygen vacancy filaments

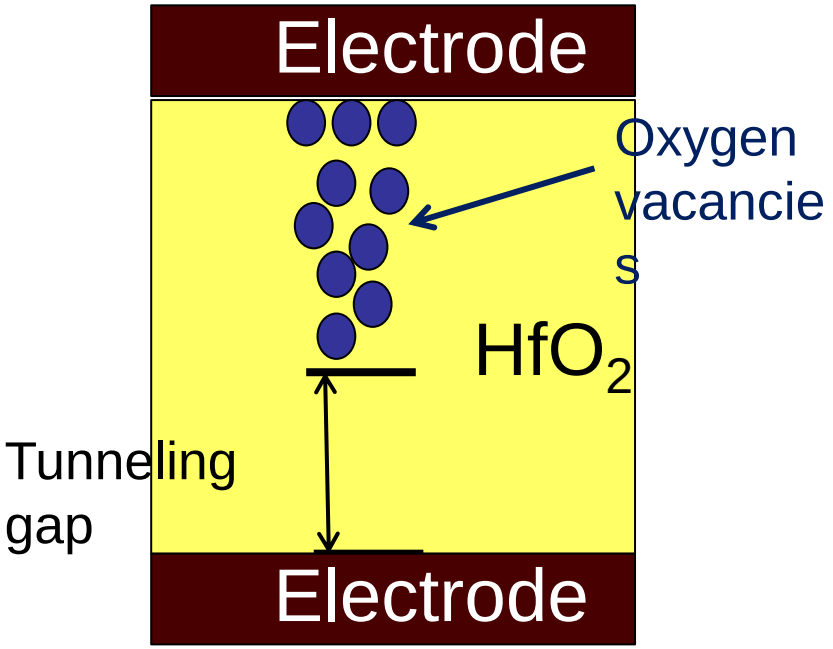
Bipolar Resistive Switching



Filament formation



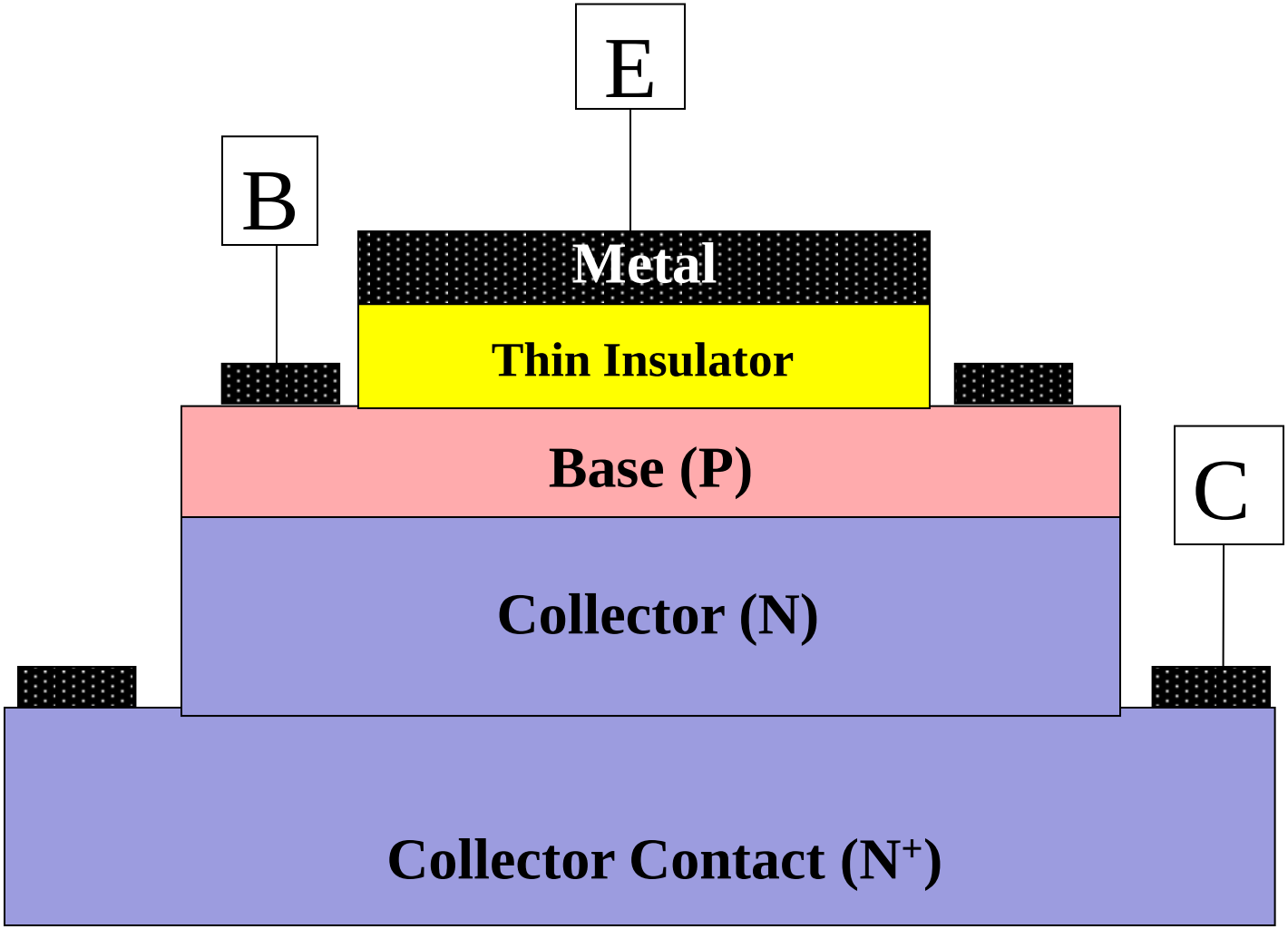
Low resistance state (LRS)



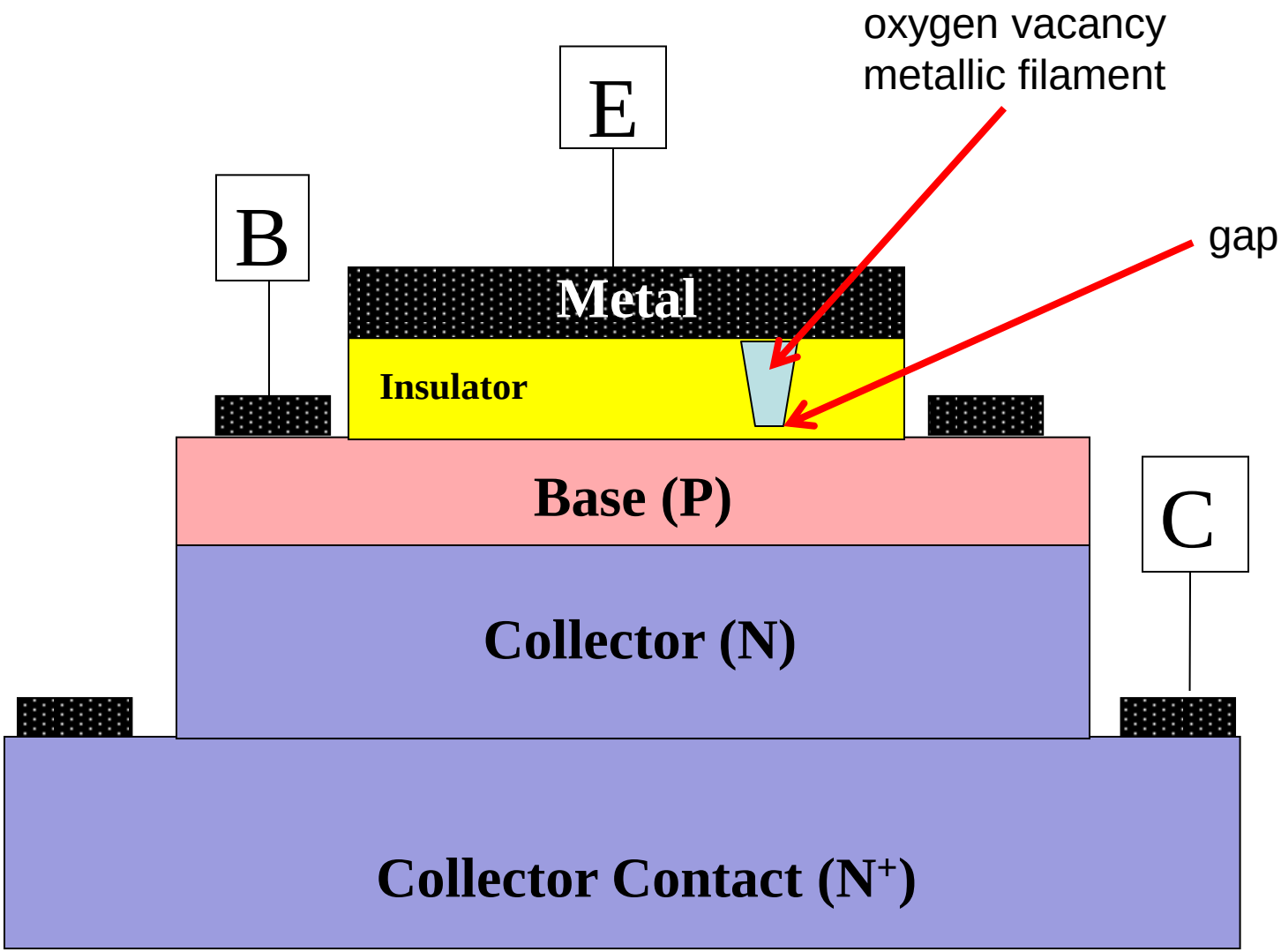
High resistance state (HRS)

The Metal Insulator Semiconductor Bipolar Transistor

A Standard NPN Bipolar Transistor



* E. Yalon et al., *IEEE Electron Device Lett.*, 33 (1) , 2012

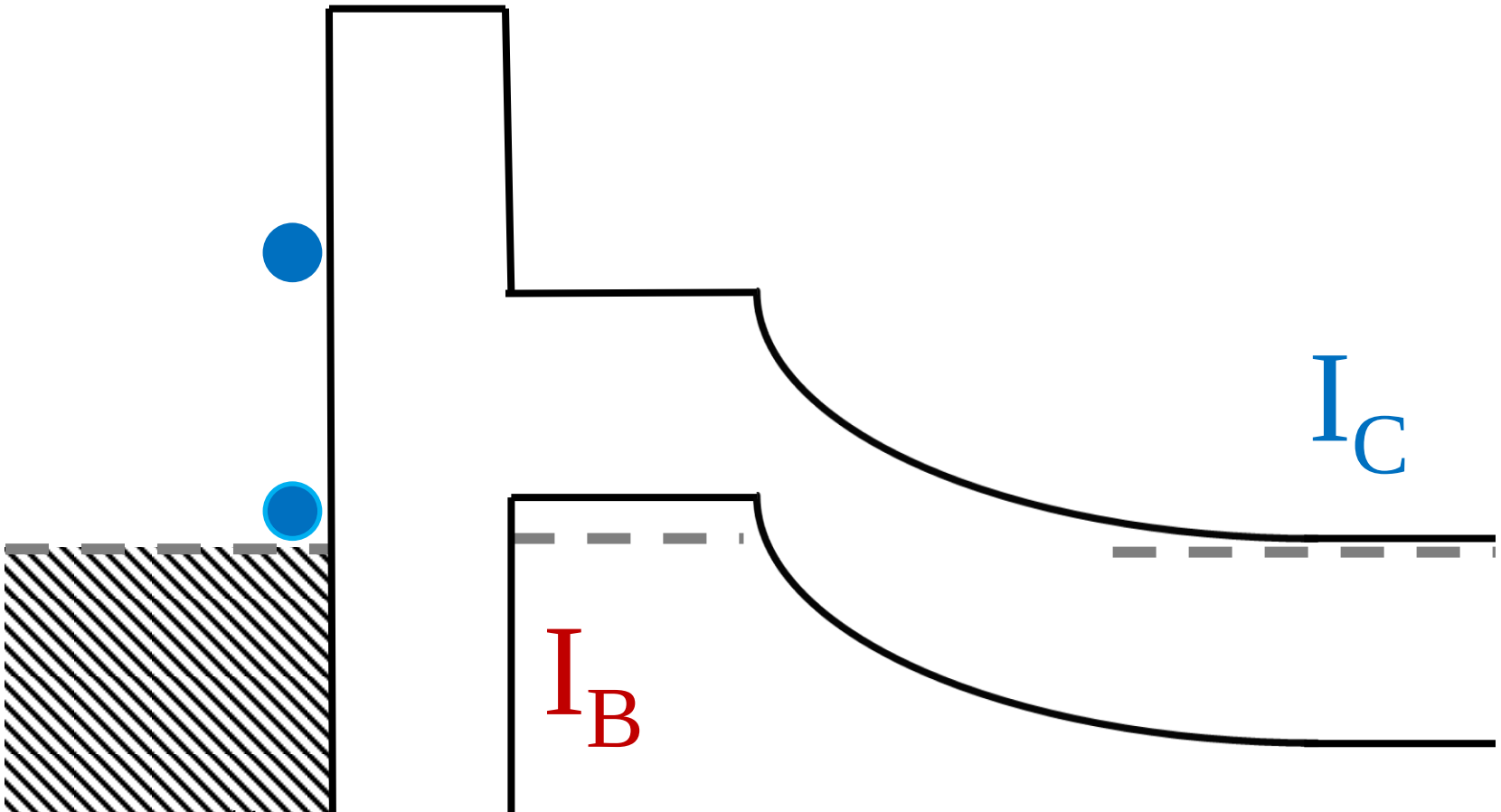


* E. Yalon et al., *IEEE Electron Device Lett.*, 33 (1) , 2012

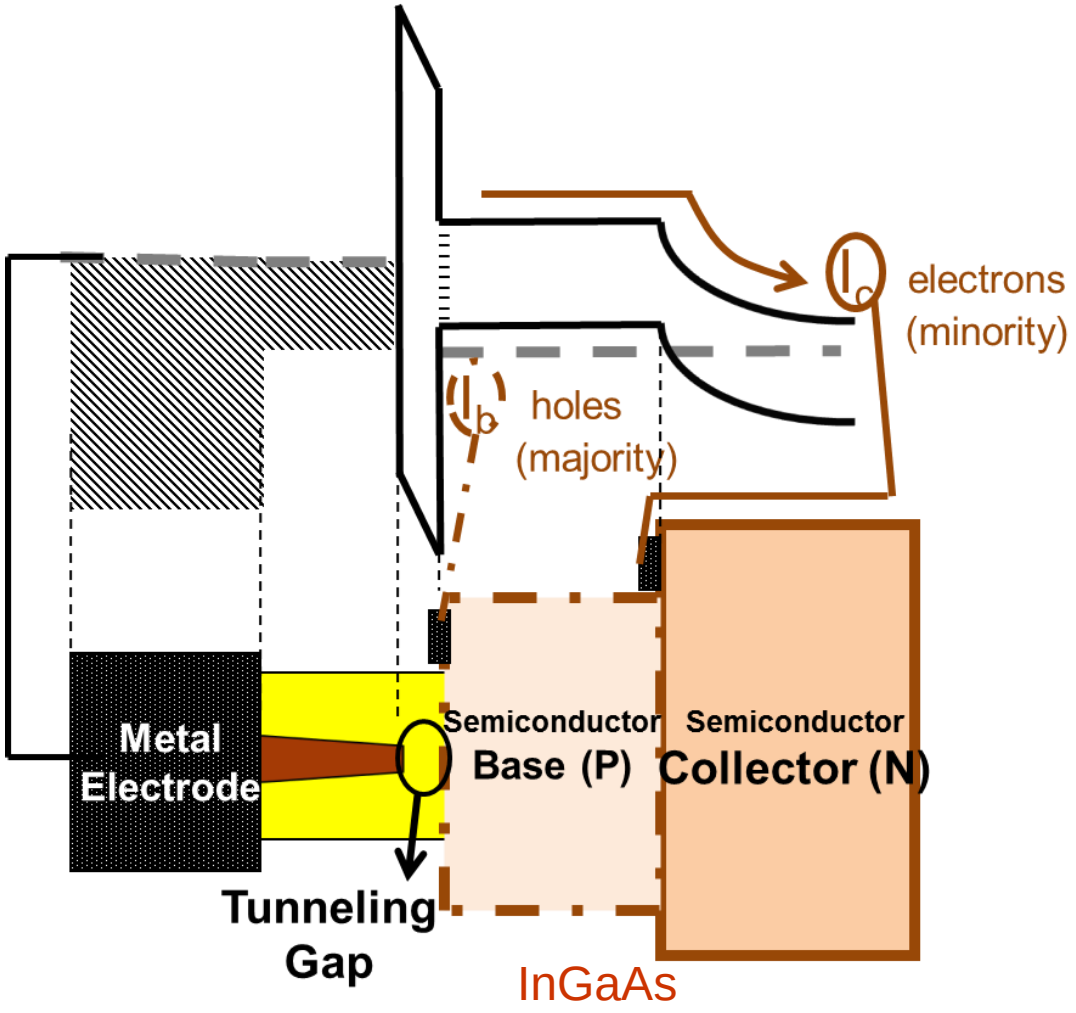
metallic filament

insulating gap

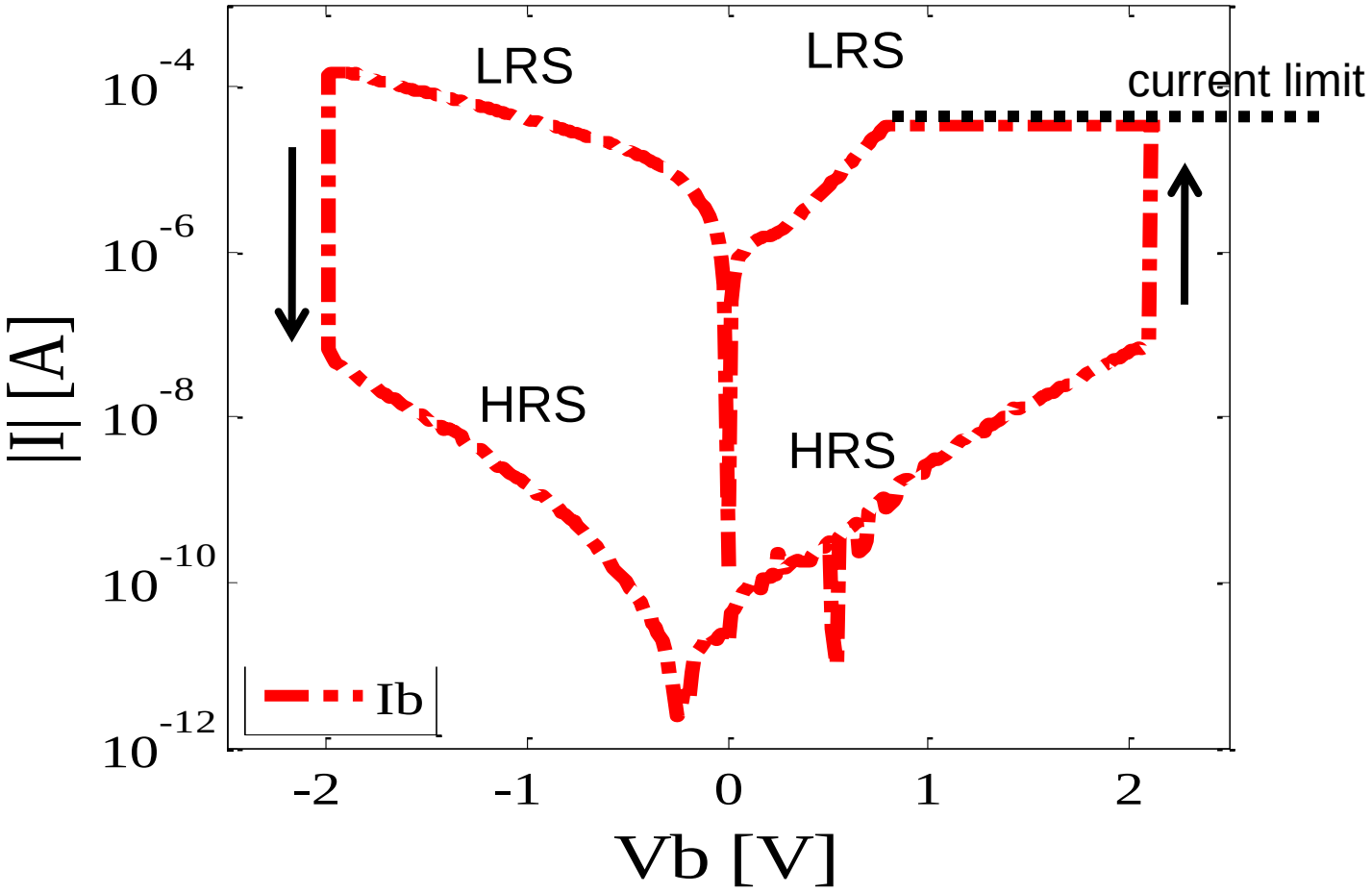
semiconductor p-n junction



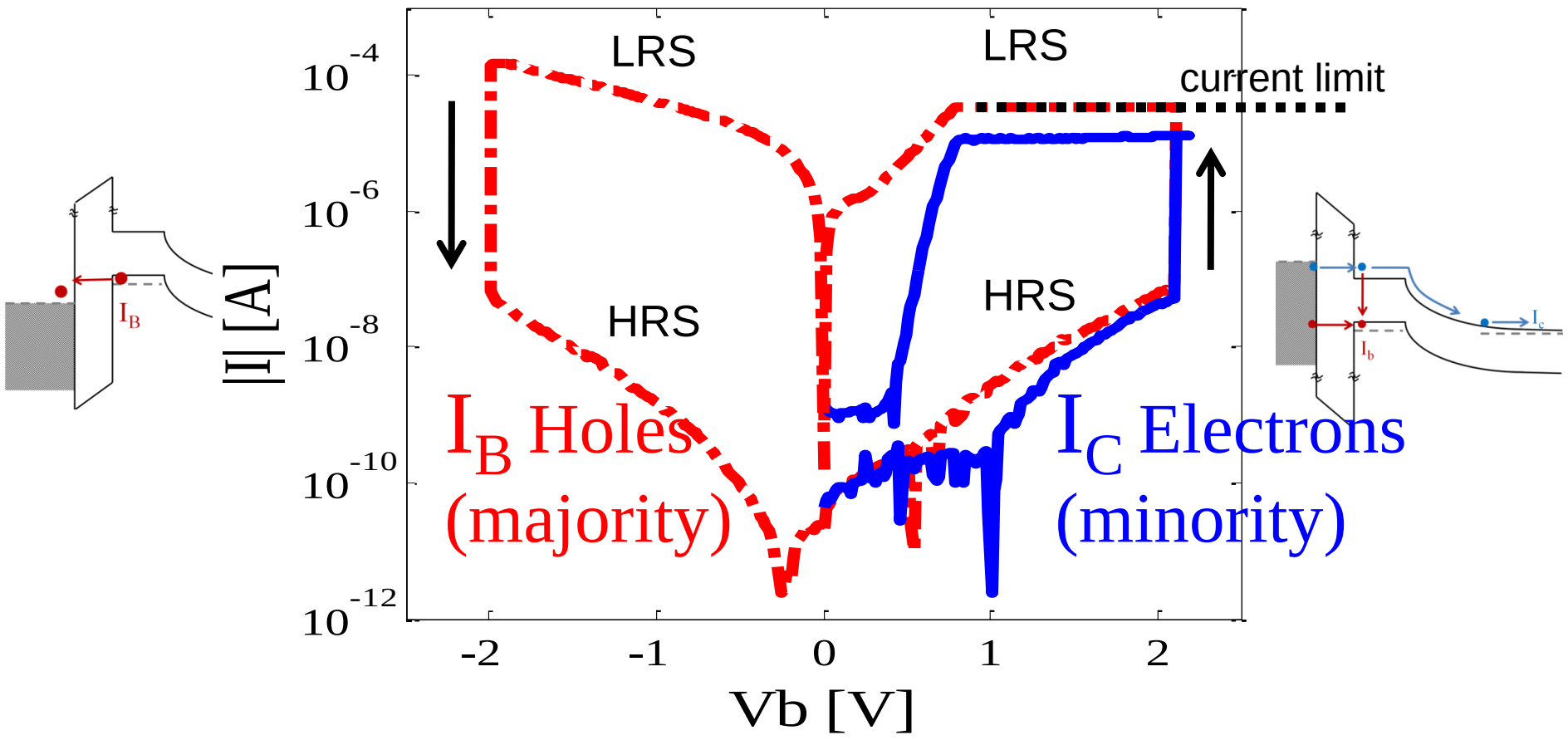
Device and band diagram



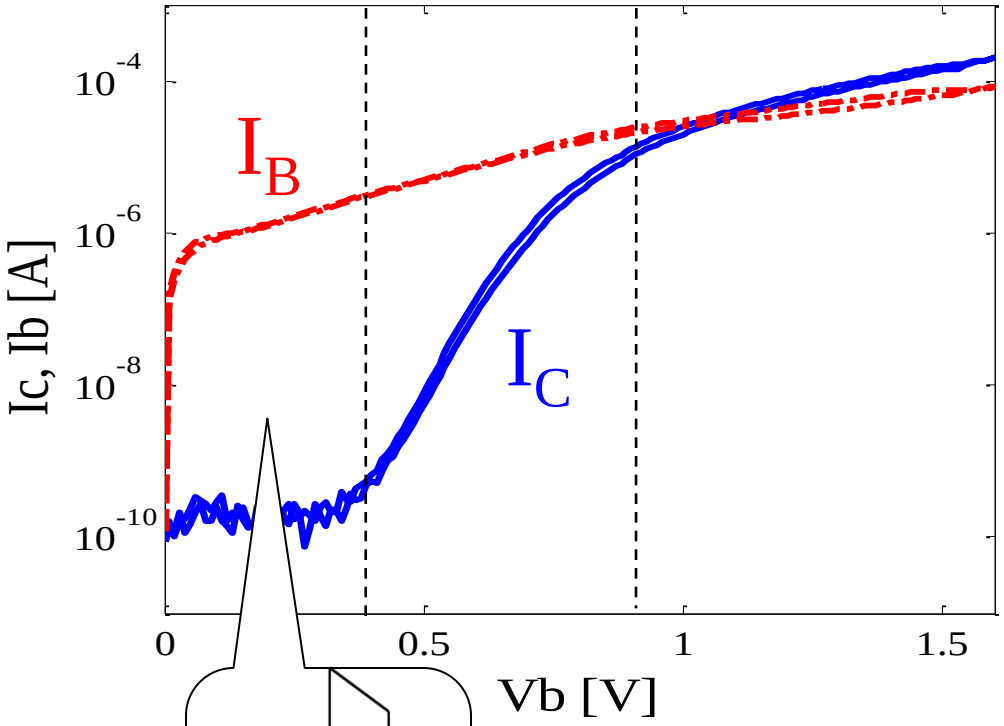
Switching characteristics of the base current (majority carriers)



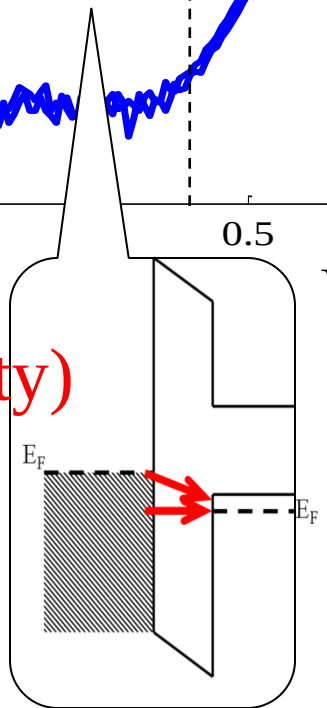
Majority and minority carriers



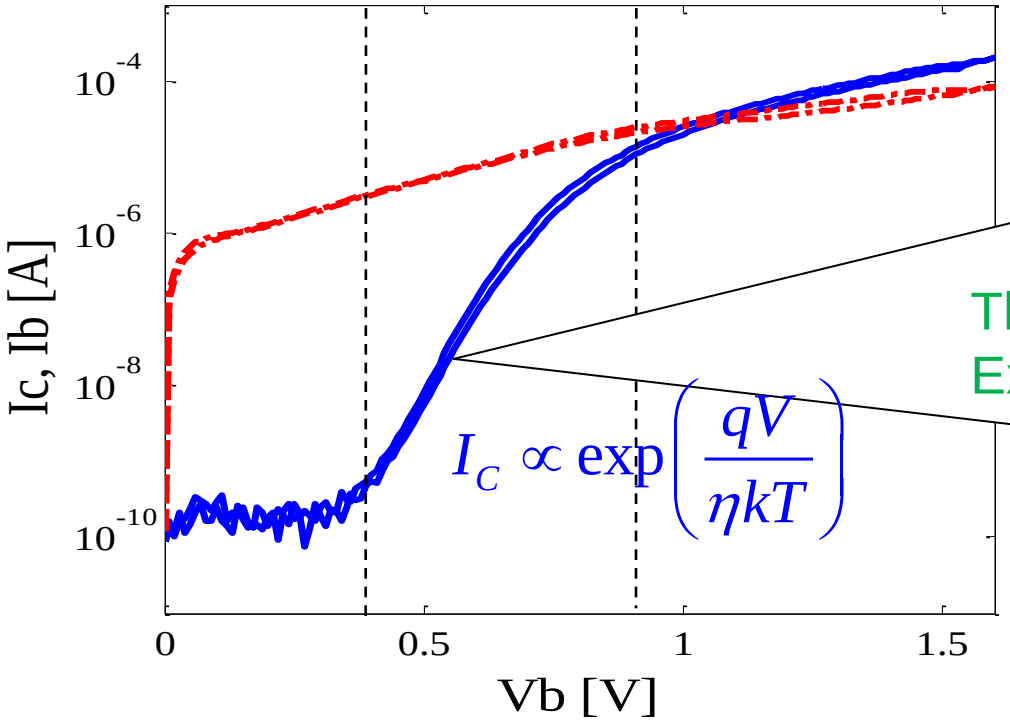
No minority carrier injection at low bias



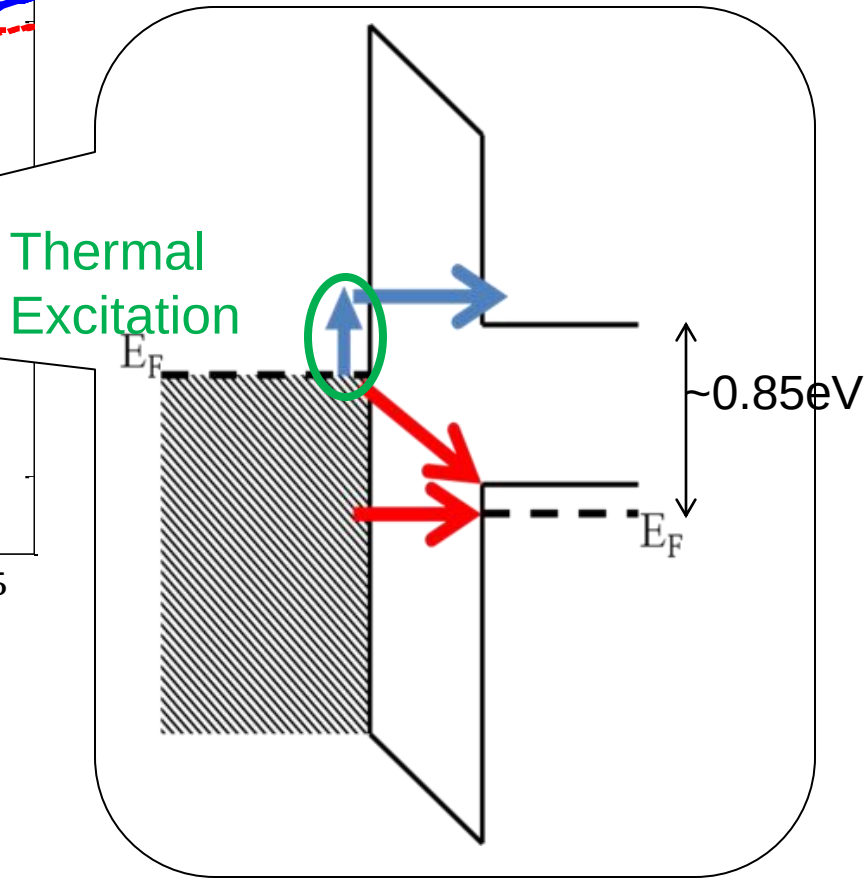
Holes (majority) current only



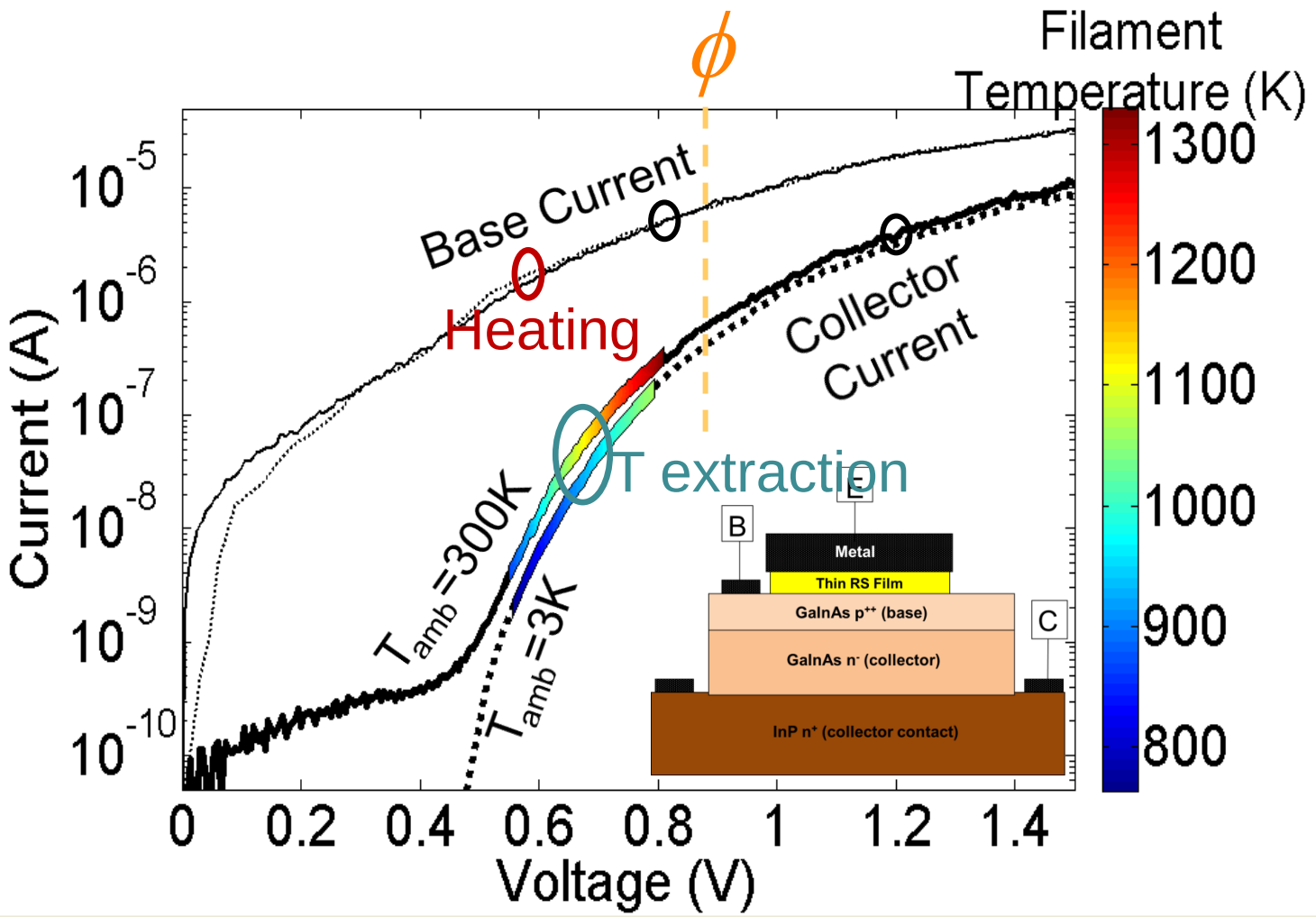
Thermal emission of minority carrier at higher bias



$$I_C \propto \exp\left(\frac{qV}{\eta kT}\right)$$



Filament temperature extracted from collector current

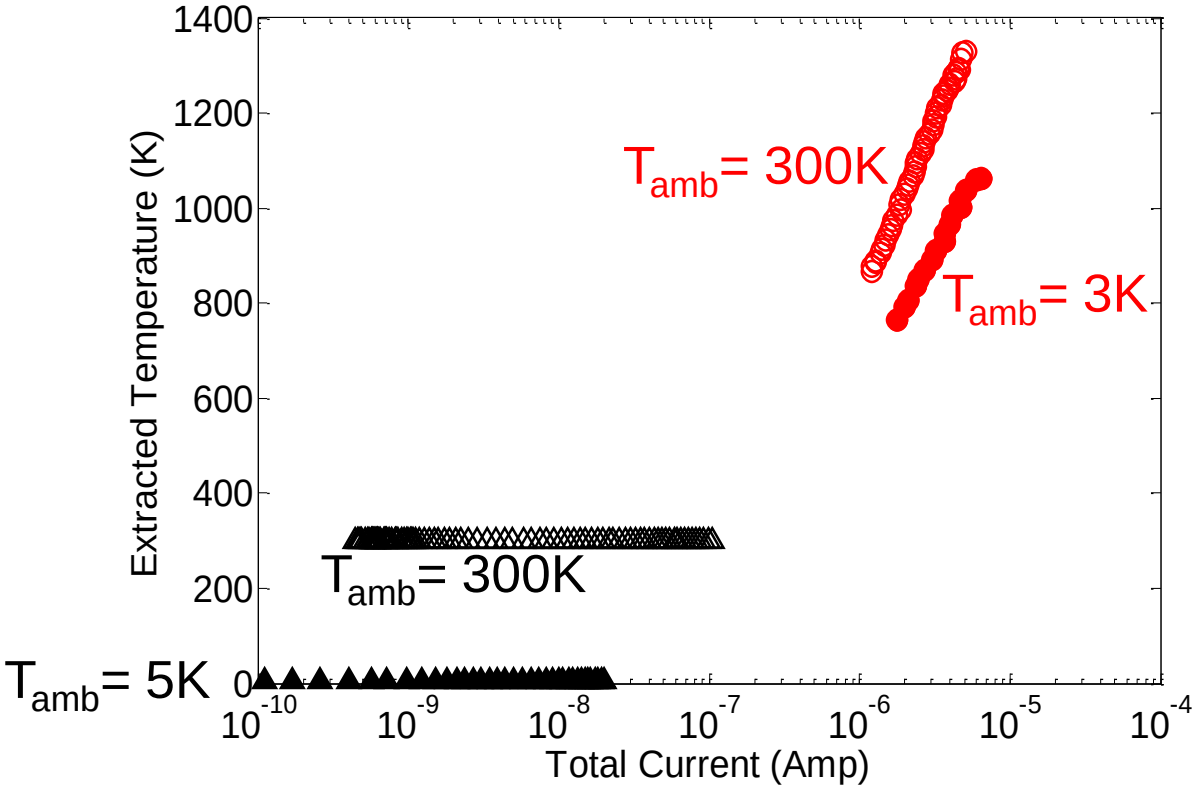


E. Yalon et al., *Nanotechnology*, 23 465201, 2012

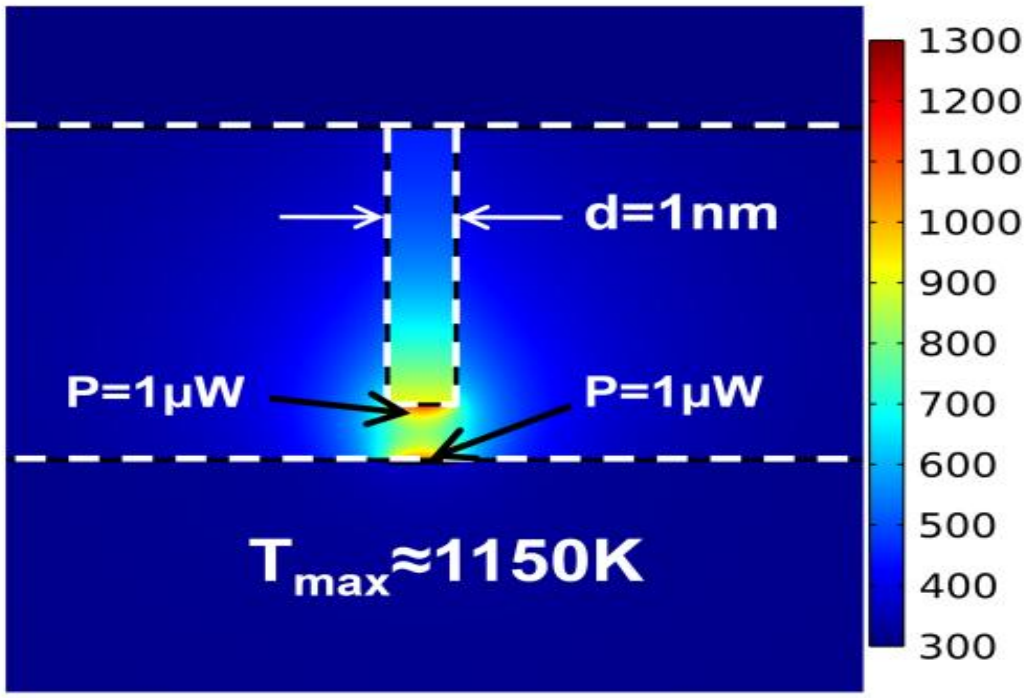
Evaluation of filament temperature

- Only experimental method
- Thermal effects play a key role in switching mechanism
- Comparison with thermal simulation reveals information on filament geometry

Extension of temperature extraction range – work in progress



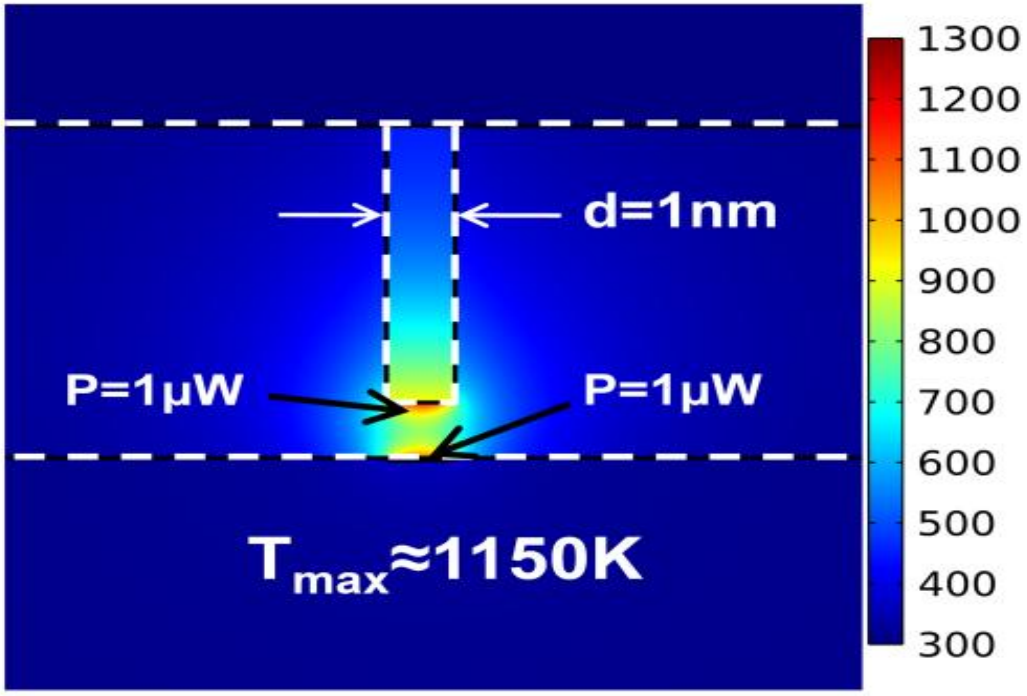
Comparison of thermal simulations with experiment reveals conductive filament diameter of about 1 nm



E. Yalon et all, submitted to IEEE Transactions on Electron Devices

Thermal simulations

- Heat input at interfaces rather than Joule heating
- Temperature dependent thermal conductivity
- Thermal interface resistance very important



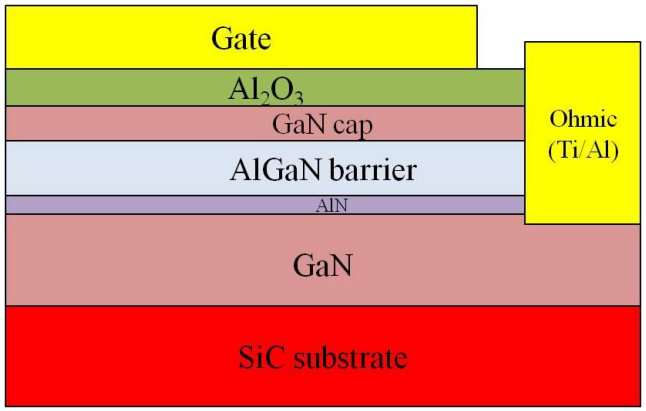
E. Yalon et all, submitted to IEEE Transactions on Electron Devices

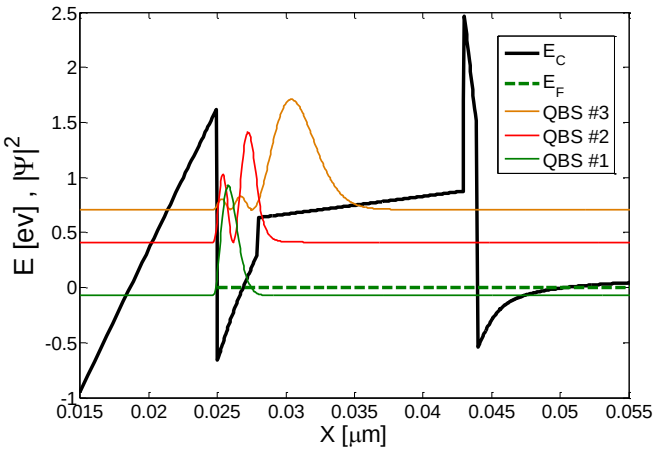
Filaments or bulk

- Bulk may be more robust (more by Prof. Chen)
- Filaments are small …

Review of research in our group on semiconductors

GaN technology for power electronics- close collaboration with industry

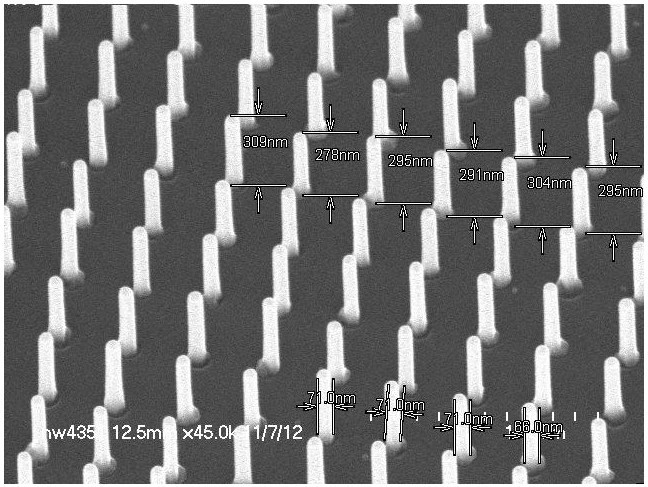


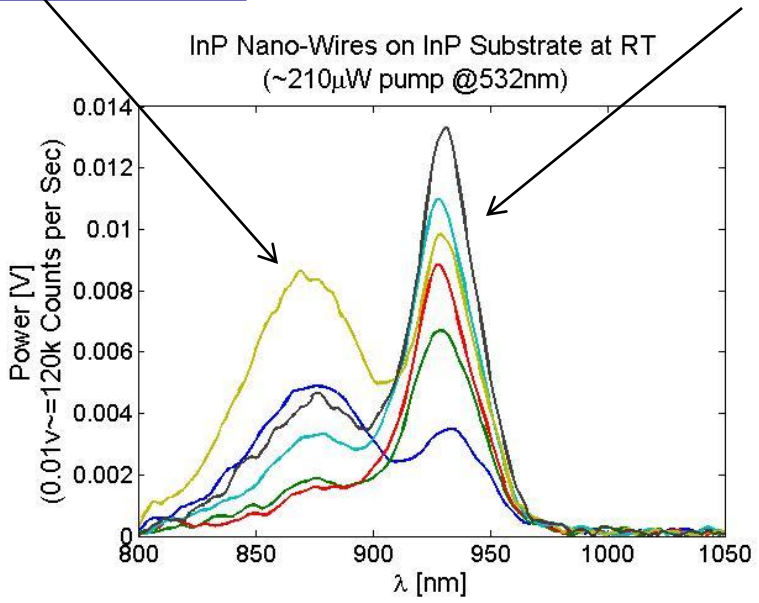


Shlomo Mehari - Comparison of Simulations and Measurements of Gate Leakage Currents in Metal/Al_2O_3/GaN/AlGaN/AlN/GaN Capacitors, submitted to TED

•Collaboration with Prof. Moshe Eizenberg, Department Material Science

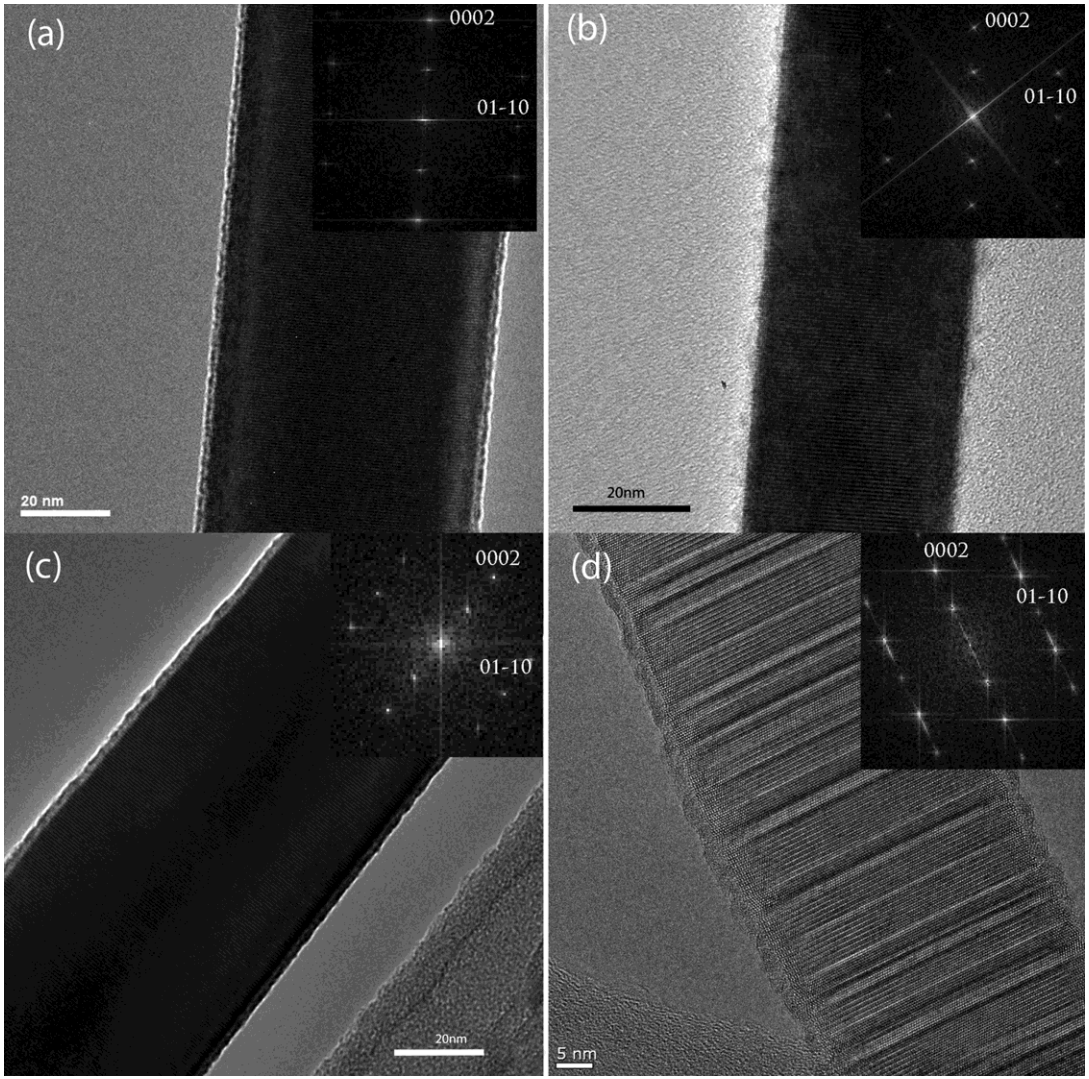
Crystal Growth of Semiconductor Nanowires



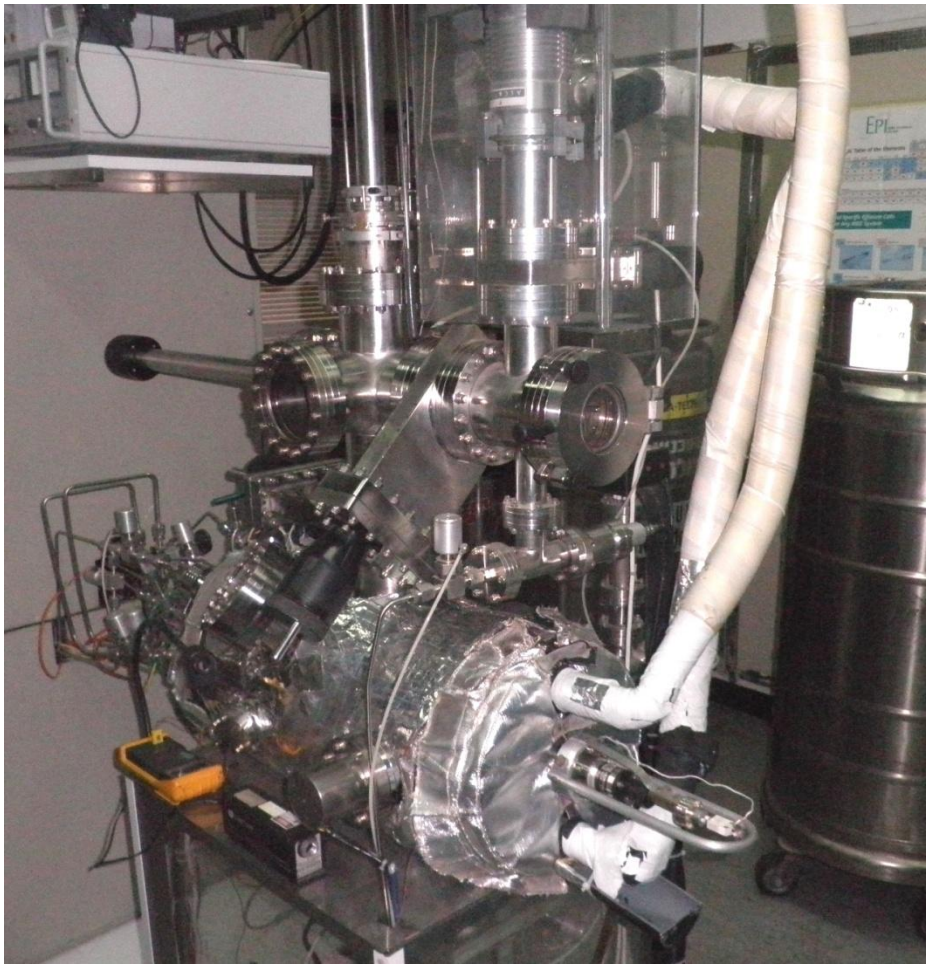


Y. Greenberg, Y. Calahorra, S. Kelrich

Pure wurtzite and mixed phase InP nanowires

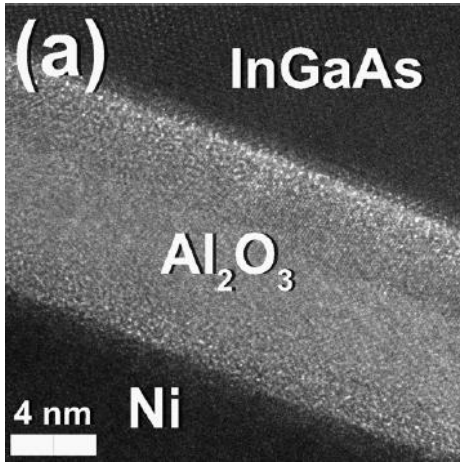


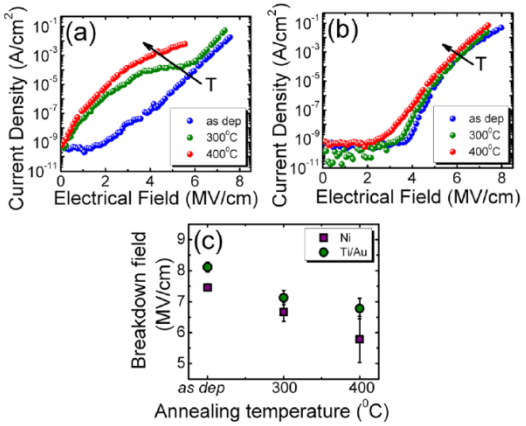
Metal organic molecular beam epitaxy (MOMBE)

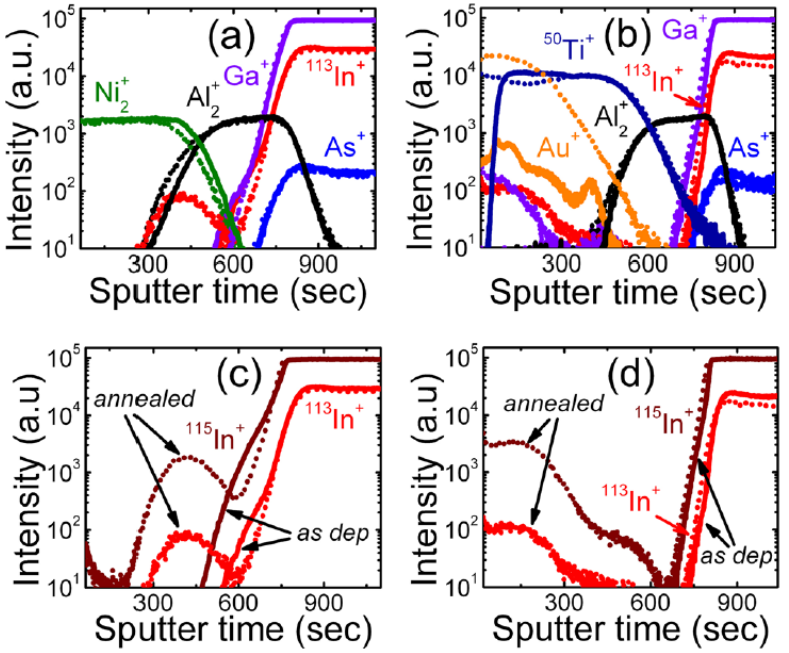


Shimon Cohen

The metal/insulator/InGaAs system – example
Indium out-diffusion: the role of the metal







Element	Pre-exponential factor, D_0 (m^2/s)	Activation energy, Q_a (kJ/mol)	Measured temperature range (°C)	Expected diffusion coefficient, D at 400 °C (m^2/s)	Ref.
Au	7.5×10^{-2}	154	700–1000	4×10^{-18}	17
Ni	1.1×10^{-4}	250	504–1240	1.3×10^{-24}	18
Ti	2×10^{-6}	260	550–800	3.9×10^{-27}	19

I.Krylov, L. Kornblum, A. Gavrilov, M. Eizenberg , and D. Ritter, *Appl. Phys. Lett*. ,**103**, 053502 (2013)

Thank you for listening