Xiuling Li Research Group at UIUC

- Our group's general interests are in the area of semiconductor materials and devices. We focus on developing innovative semiconductor structures and device concepts through both bottom-up and top-down approaches to bring lasting impact to the field of semiconductor nanotechnology, electronics, and photonics; and possibly to medicine. Our group has pioneered the development of several platform nanotechnologies including the lateral selective epitaxy of planar nanowire arrays for 3D III-V transistors, the metal-assisted chemical etching (MacEtch) method for damage-free highly anisotropic etching of versatile semiconductor materials and structures, and the self-rolled-up membrane (S-RuM) technology for miniaturization of passive electronic devices.
- Prof. Xiuling Li received her B.S. degree from Peking University and Ph.D. degree from the University of California at Los Angeles. Following post-doctoral positions at California Institute of Technology and University of Illinois, as well as industry experience at a startup company EpiWorks, Inc., she joined the faculty of the University of Illinois in 2007 as an Assistant Professor in the Department of Electrical and Computer Engineering. She was promoted to Associate Professor with tenure in 2012, and to Professor in 2015. She is an IEEE fellow, and a recipient of the NSF CAREER award, DARPA Young Faculty Award, ONR Young Investigator Award, Distinguished Lectureship at IEEE Nanotechnology Council etc. She has published > ~135 referred journal papers and holds 12 patents with another 12+ patents pending. Among her synergistic activities, she is a deputy editor of Applied Physics Letters and the lead PI of a NSF RET site grant. She currently serves as the Vice President of Finance and Administration for IEEE Photonics Society.

http://mocvd.ece.illinois.edu

Research Interests

- Semiconductor materials and devices
- Metalorganic chemical vapor deposition (MOCVD)
- III-V compound semiconductor
- Nanotechnology
- Nanowires
- Metal-assisted chemical etching (MacEtch)
- Nanoelectronics
- Nanophotonics
- Photovoltaics
- Self-rolled-up membrane (S-RuM)
- RFIC miniaturization
- van der Waals epitaxy of 2D TMDCs

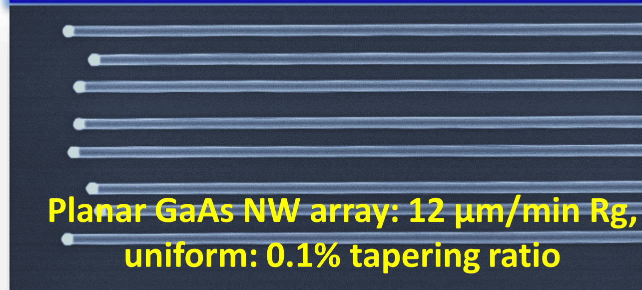
Research Interest and Recent Developments (1/4)

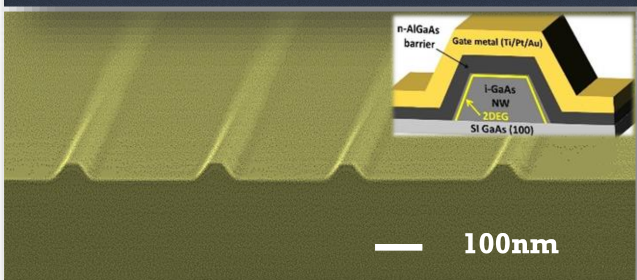
Planar III-V nanowire array for beyond Si CMOS and Future RF Electronics:

- Nanowire has long been regarded as a promising architecture for beyond Si CMOS logic and future III-V RF electronics, as well as next generation optoelectronic applications. The challenges have been the controllability and manufacturability. Our discovery of parallel arrays of planar III-V nanowire growth mode opens up a new paradigm of crystal growth: selective lateral epitaxy and consequently in situ lateral junctions. Technologically, in-plane nanowire configuration is perfectly compatible with existing planar processing technology for industry. Chip-scale transistors (HEMTs) with record DC and RF performance are demonstrated, with a clear path to reach THz for high speed applications.

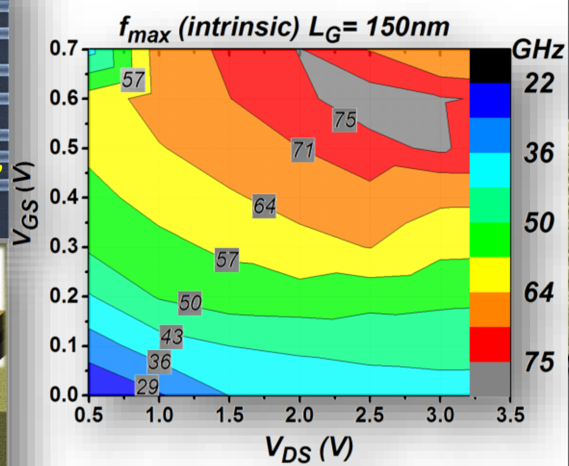
3D III-V Electronics: Planar III-V Nanowires via VLS for High Performance and Scalable FETs

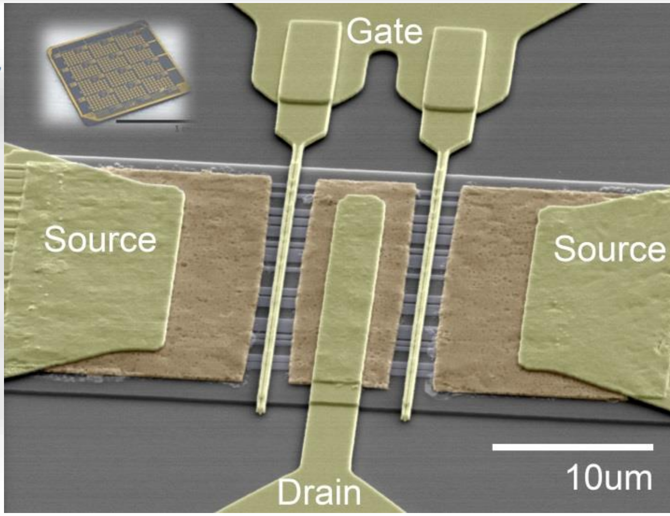
MOCVD epitaxial, self-aligned, defect-free, transferable, high-μ



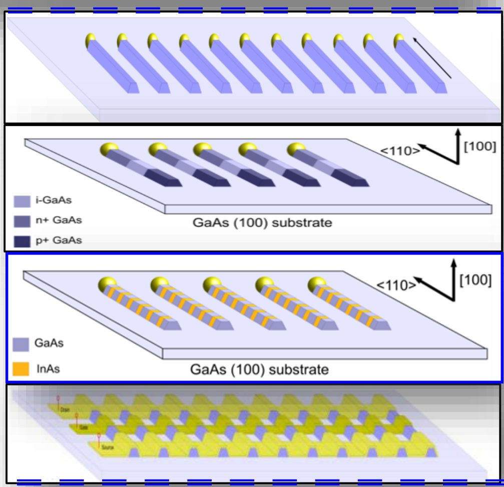


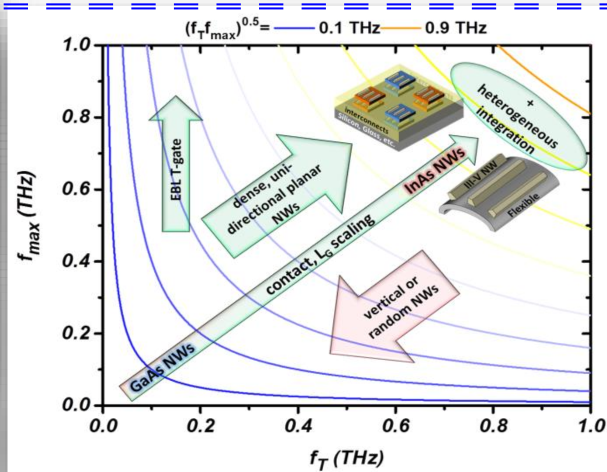
Chip-scale fully-fabricated AlGaAs/GaAs NW array HEMT RF layout and performance





VLS Planar III-V NW FETs roadmap





Related publications:

- *Fortuna et al. Nano Lett. 2008.*
- *Fortuna et al. IEEE EDL, 2009.*
- *Fortuna et al.* Semi.. Sci. Technol. 2010
- *Miao and Li, IEEE EDL, 2011.*
- *Dowdy et al., IEEE EDL, 2012.*
- *Dowdy et al. Nanotech, 2013.*
- *Miao et al. Nano Lett. 2013.*
- *Dowdy et al. Opt. Mater. Express, 2013.*
- *Zhang et al. Solid State Electronics, 2014.*
- *Zhang et al. Nano Lett. 2014.*
- *Miao, Chabak, et al. Nano Lett. 2015 (cover).*
- *Chabak et al. IEEE EDL 2015.*
- *Zhang et al. IEEE EDL 2015.*

http://cen.acs.org/articles/92/web/2014/12/Record-Breaking-Nanowire-Transistors.html

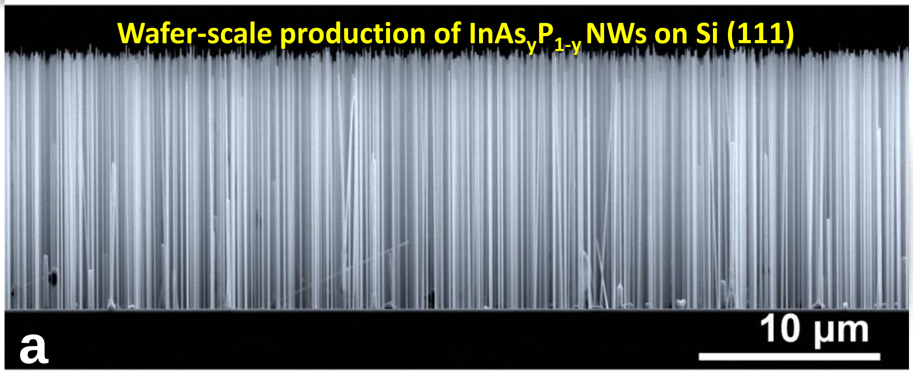
Research Interest and Recent Developments (4/4)

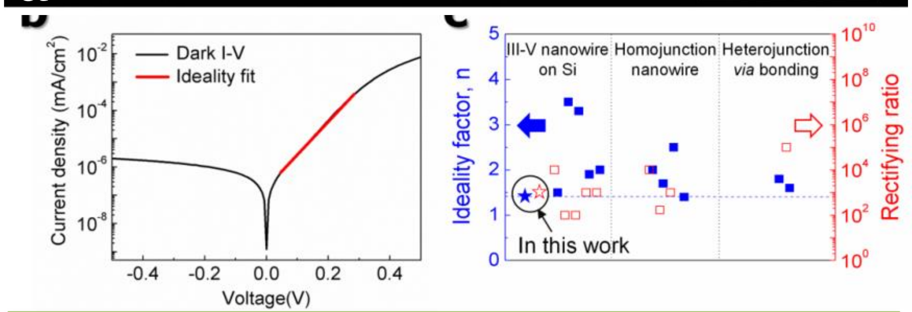
MOCVD Epitaxial Heterogeneous Integration III-V, Si and layered van der Waals 2D Substrates.

- The quintessential challenge of heterogeneous integration of III-V thin films on silicon and other foreign substrates has been the lattice matching restriction. Owing to the small hetero-interfacial areal footprint of a nanowire on a substrate and the free sidewall facets, it has been well-demonstrated that semiconductor nanowires are amenable to direct and high quality heteroepitaxial crystal growth of materials with highly mismatched lattice constants and coefficients of thermal expansion. We have achieved site-controlled selective area epitaxy by metalorganic chemical vapor deposition (MOCVD) and characterization of GaAs, InAs, InGaAs, GaP, GaAsP nanowires on GaAs, silicon, as well 2D van der Waals surfaces including graphene, MoS2, and BN. These unconventional epitaxial growth modes her lab pioneered are positioned to bring translational impact on nanoelectronics and nanophotonics, including III-V gate-all-around transistors and multi-junction tandem solar cells.

Breaking the Lattice Match Barrier: Vertical III-V Nanowires for Heterogeneous Integration

III-V NWs on Si by seed-free, pattern-free direct epi

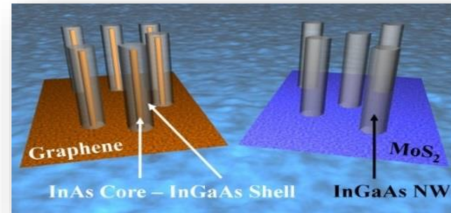


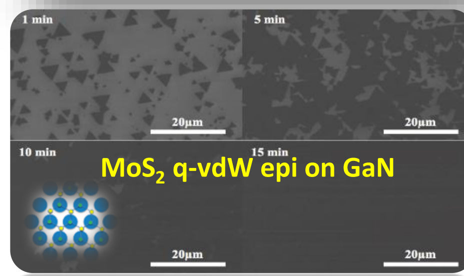


- *Shin et al.* Nano Lett. 2011; Nanotech. 2012; Cryst. Growth Design, 2012; ACS Nano, 2012, 2013.
- *http://news.illinois.edu/news/11/1108nanowires_XiulingLi.html*

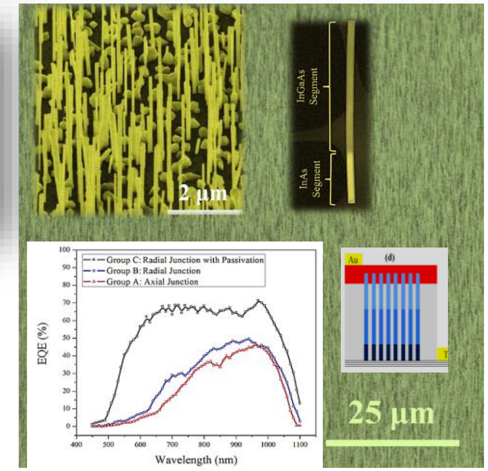
vdW epitaxy and solar cells

vdW epi driven phase segregation





Single phase InGaAs NWs on SLG

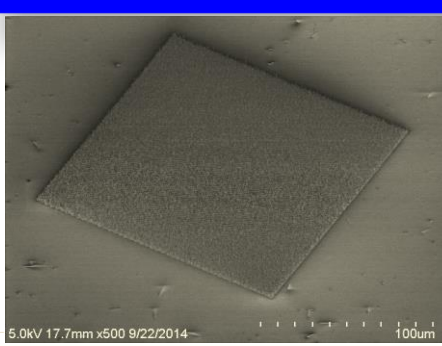


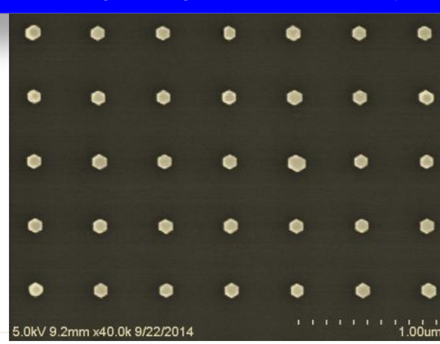
InGaAs NWs on SLG Solar Cells

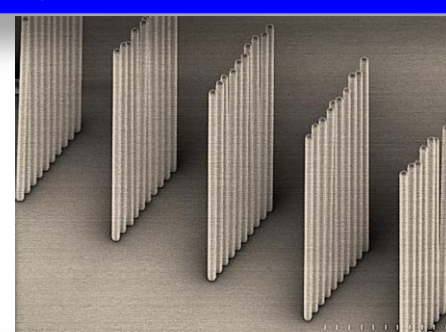
Related Publications:

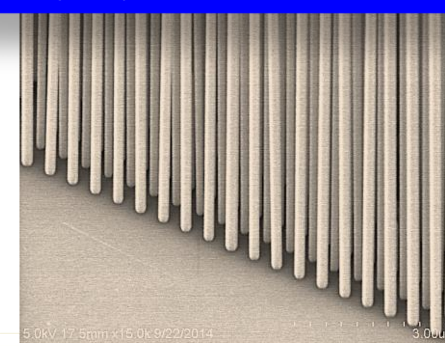
- *Mohseni et al. Nano Lett. 2013; Adv. Mater. 2014.*
- *Bassett et al. Appl. Phys. Lett. 2015.*
- *http://news.illinois.edu/news/13/0422nanowires_XiulingLi.html*
- *http://www.compoundsemiconductor.net/article/91799-enhancing-performance-of-iii-v-nanowires.html*

Selective Area Epitaxy: GaAs, InAs (shown), GaP, InGaP, GaAsP NWs on Si (111)









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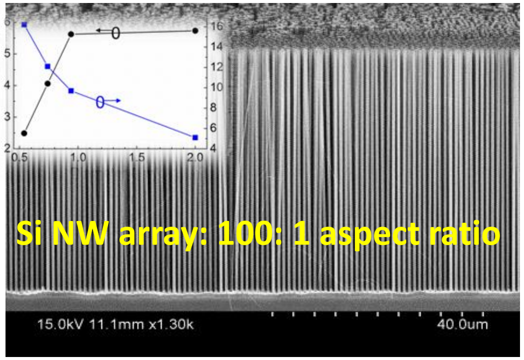
Research Interest and Recent Developments (2/4)

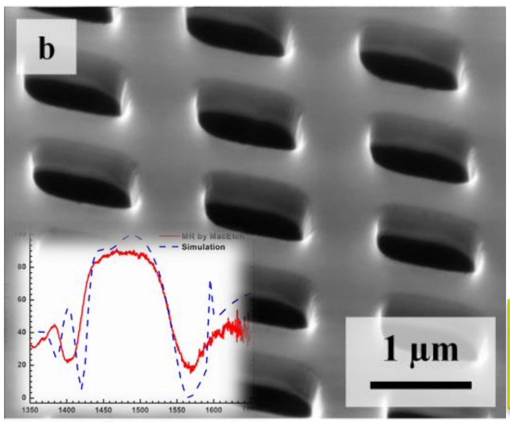
Wet Etch, Dry Etch, and Now MacEtch for Semiconductors:

- From transistors to lasers, etching is an important step in the device fabrication process. Metal assisted chemical etching (MacEtch) is an unorthodox anisotropic wet etching method, that defies the isotropic nature of wet etch through local catalysis effect and enables site-controlled semiconductor nanostructure fabrication with unpresented aspect ratio (> 100:1) and versatility. This innovative etching method has profound impact to semiconductor fabrication, not only because of the readily achievable extraordinary aspect ratio, but also the absence of ion-induced damage. Since our first paper published in 2000 on porous silicon formation using MacEtch followed by catalyst-site-specific etching, the frontier of this technology continues to advance from investigating the fundamental mechanism, properties, and applications, to extending its applicability to other semiconductors, including germanium, III-As, III-P, III-N, SiC, and oxides, as well as heterostructures. Inverse-MacEtch (i-MacEtch) allows the formation of atomically smooth sidewalls and magnetic-field guided MacEtch (h-MacEtch) enables 3D control of the etching trajectory. The simplicity, versatility, manufacturability, and realistic potential of MacEtch to replace and enhance dry etch methods position this technology for future generation of 3D transistros, through-silicon-vias, trench memory, thermoelectric, detectors, and photovoltaic devices.

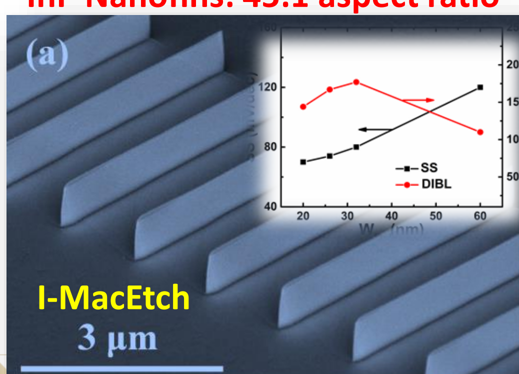
Metal-assisted chemical Etching (MacEtch) for Semiconductor Nanostructured Photonics, Electronics, and Energy



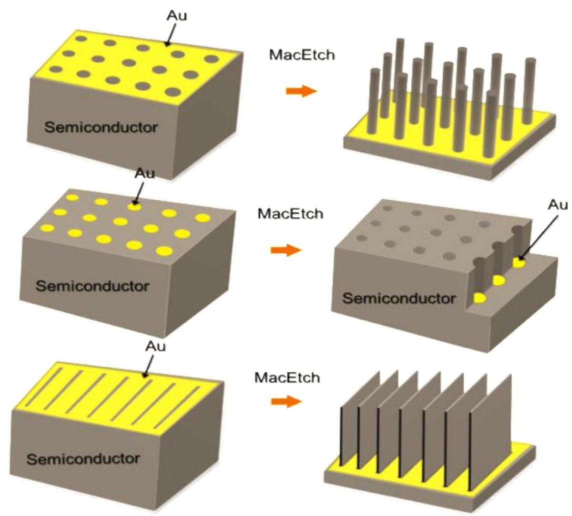
Si membrane reflector



InP Nanofins: 45:1 aspect ratio



Defying textbook definition of wet etch, MacEtch is an anisotropic wet etching method that could potentially replace or improve dry etch for various electronics, photonics, and energy applications.



Selected Publications :

- *Li and Bohn, APL **2000**;*
- *Chun et al. APL, **2008**; Chern et al. Nano Lett. **2010**;*
- *DeJarld et al. Nano Lett. **2011**; Shin et al., IEEE J. Photovoltaics **2011**;*
- *Li, COSSMS, **2012 (review)**;*
- *Balasundaram et al. Nanotech. **2012**;*
- *Shin et al. Nanotech. **2012**;*
- *Mohseni et al. JAP, **2013**;*
- *Kim et al. Nano Lett. **2014**.*
- *Song et al. IEEE EDL **2016**.*
- *Kim et al. Adv. Func. Mater. 2017.*
- *Kong et al. ACS Nano 2017.*
- *Kim et al. ACS Appl. Mater. Interfaces 2018.*

Mechanism: local electrochemical reaction (metal: cathode; anode: semiconductor)
Applicability: Si, Ge, GaAs, InGaAs, InP, GaN, Ga_2O_3 homo- hetero-junctions, single, poly

	Wet Etch	Dry Etch	MacEtch
Directionality	Isotropic	Anisotropic	Anisotropic
Aspect Ratio	Low	Medium	High
Ion Induced Damage	None	Mild to Severe	None
Crystal-Orientation Dependence	Some	Weak	Weak
Etch Rate	Fast	Slow	Fast
Sidewall Smoothness	Smooth	Not Smooth	Smooth or Rough
Chemical Selectivity	Good	Poor	Depends
Cost	Low	High	Low

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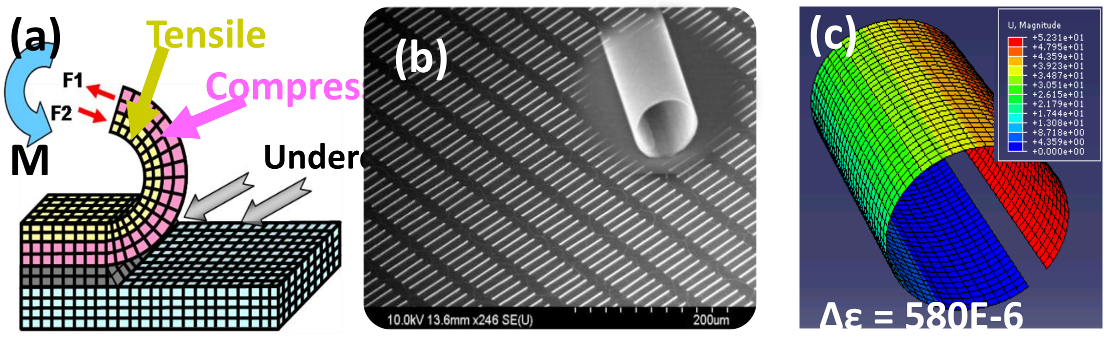
Research Interest and Recent Developments (3/4)

Self-Rolled-up Membrane (S-RuM) Nanotechnology for Extreme Passive Electronics Miniaturization and Medicine:

- The overarching physical principle of S-RuM nanotech is strain-driven spontaneous deformation of 2D membranes into 3D architectures. Complex 3D structures enable advanced functionalities that are otherwise out of reach. S-RuM inductors have been demonstrated with a footprint that is 10 – 100 times smaller than the 2D counterpart and capable of operating at high frequencies (> 20 GHz). By stacking two S-RuM inductors in-plane or vertically to form transformers, near unity coupling coefficients and unprecedentedly-high turn-ratios have been achieved. Through global and local strain engineering, S-RuM filters, transmission lines, antennas with ultra-high frequency (including THz) and bandwidth can all be enabled. S-RuM technology promises to break the constraints of size, weight, and performance (SWAP) of RFICs and even millimeter wave communications. The unique form factor can also bring translational impact to wearable and flexible IoT devices and other exciting opportunities including the guiding and accelerating neuron cell growth using S-RuM for neural regeneration.

Strain-induced Self-Rolled-up Membrane (S-RuM)-Enabled Extreme SWaP Electronics, Photonics, and Biology



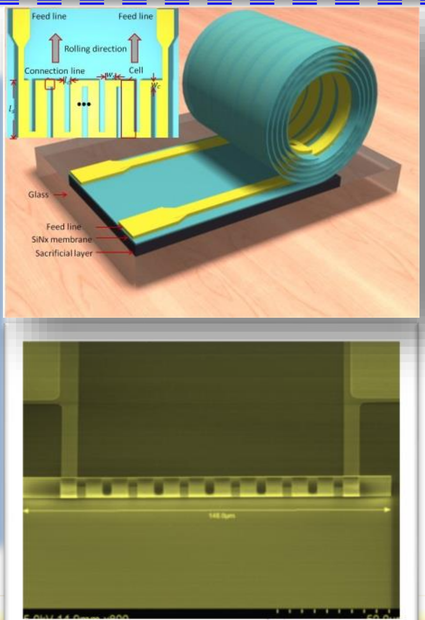
Related publications:

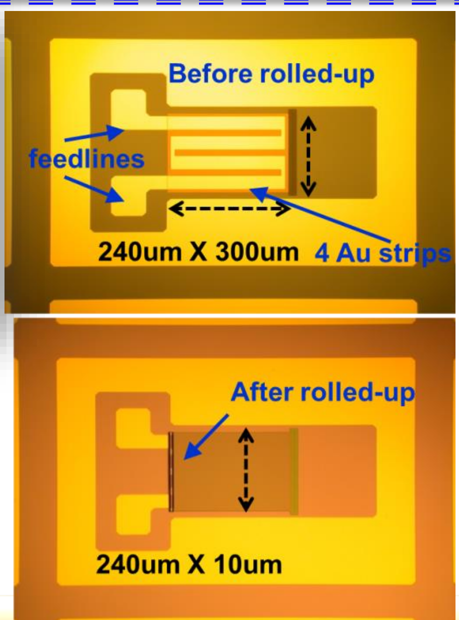
- *Chun and Li, IEEE Tnano, 2008; Li, J. Phys. D 2008.*
- *Chun et al. JCG, 2008; APL, 2010; Nano Lett. 2010.*
- *Miao, Chun and Li, Springer, 2011.*
- *Li, Adv. Opt. Photonics, 2012.*
- *Huang et al. Nano Lett. 2012; Nano Lett. 2014.*
- *Froeter et al. Nanotech 2013; ACS Nano 2014.*
- *Yu et al. Sci. Rep. 2015; APL 2015.*
- *http://www.rdmag.com/news/2012/12/engineers-roll-inductors-save-space*
- *http://www.rdmag.com/videos/2014/11/microtubes-create-cozy-space-neurons-grow*

Formation: CMOS compatible 2D processing for 3D structures via spontaneous strain relaxation

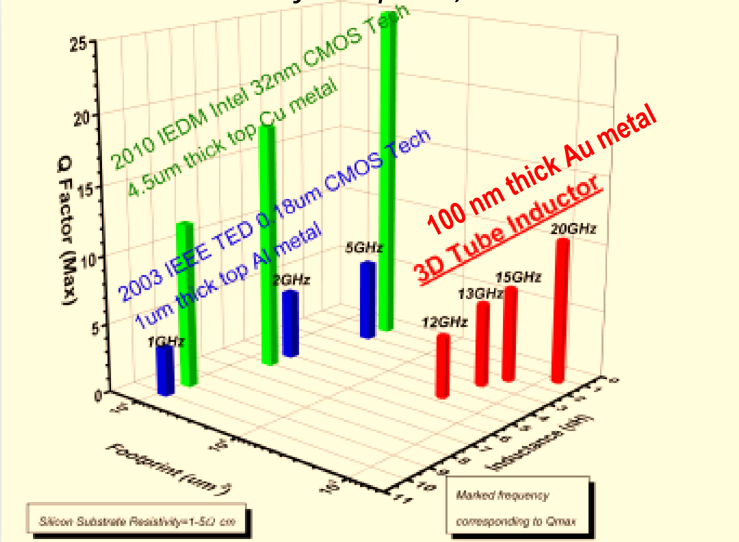
Functionality: extreme reduction in size and weight, and performance (SWaP) enhancement of devices; and guiding, accelerating, and monitoring neuron cell growth

S-RuM inductor: high frequency and 10 – 100X smaller





• *Yu et al. Scientific Reports, 2015.*



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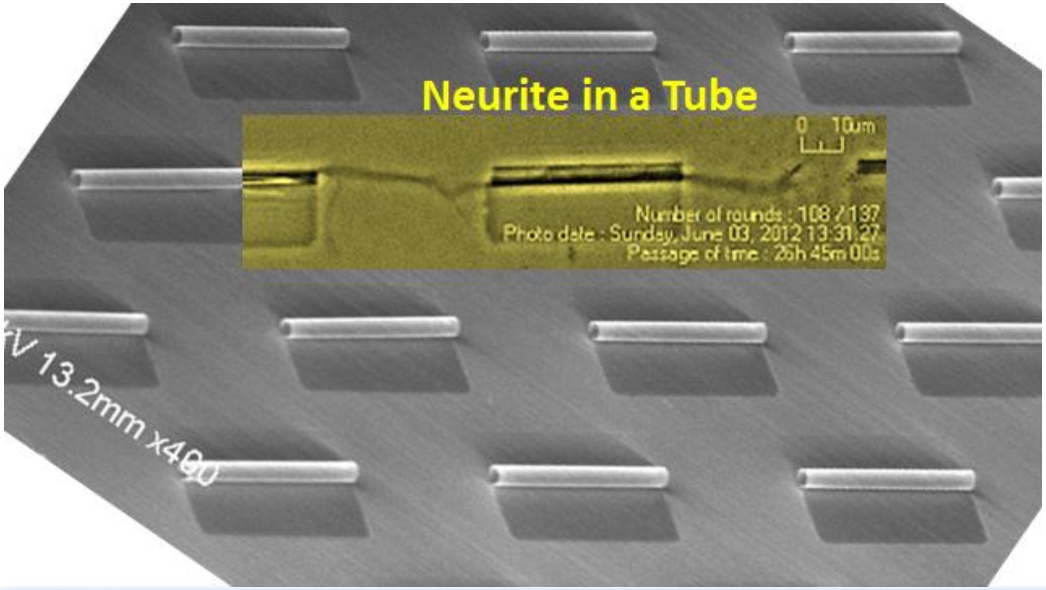
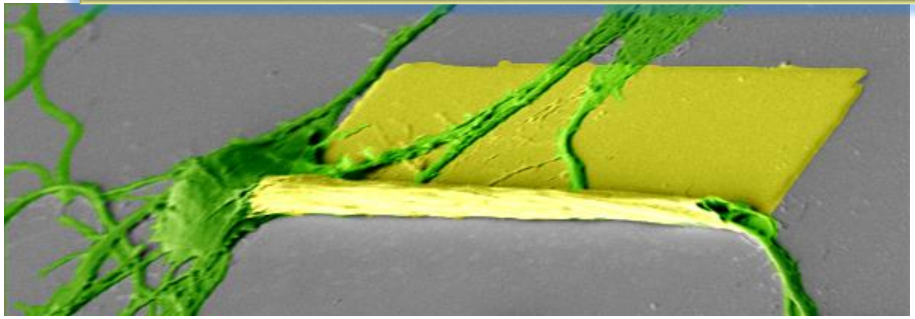
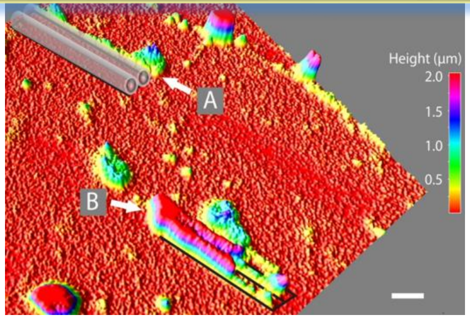
Strain-induced Self-Rolled-up Membrane (S-RuM)-Enabled Neuron Cell Growth, Acceleration, and Monitoring

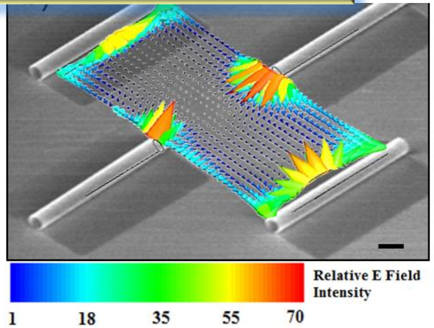


- Neuron cells (axon) actively search for and extend their growth process through the SiN_x microtubes.
- Record increase (20x) of growth rate inside the microtubes compared to the bare glass slide.

➢ Bio-compatible · bio-conformal · 3D adhesion · Electrostatic adhesion







- P. Froeter, Y. Huang, O. V. Cangellaris, M. U. Gillette, J. C. Williams and X. Li, "Toward Intelligent Synthetic Neural Circuits: Directing and Accelerating Neuron Cell Growth by Self-Rolled-Up Silicon Nitride Microtube Array," ACS Nano, 8 (11), 11108 (2014).
- http://news.illinois.edu/news/14/1111neuronmicrotubes_XiulingLi.html
- http://cen.acs.org/articles/92/web/2014/11/Silicon-Nitride-Microtubes-Direct-Neuron.html