Metal-assisted chemical Etching (MacEtch)

Metal-assisted Chemical Etching (MacEtch) is a novel nanofabrication method we have discovered (Appl. Phys. Lett. 77, 2572 (2000) and Patent US#6,790,785.) originally to produce porous silicon and then developed to produce extremely high aspect ratio semiconductor nanostructures including Si, Ge, GaAs, InGaAs, InP, SiC, GaN, Ga2O3 homo- and hetero-junctions. It uses noble metal (such as Au, Pt and Ag) deposited on the surface of a semiconductor (e.g. Si) as a catalyst to catalyze the hole (h+) generation from an oxidant (such as H2O2) in an acidic (or basic) solution (such as HF) to induce local oxidation (Si + 4h+ --- Si4+) and reduction (2H+ + 2e- --- H2) reactions. This results in the removal of semiconductor materials without net consumption of the metal. Under controlled consitions, the reactions occur only at the interface between metal and the semiconductor, under controlled etching conditions. As a result, metal descends into the semiconductor as the semiconductor is being etched right underneath, acting as a negative resist etch mask. When the catalyst metal is patterned in any shape and dimension, the pattern can be engraved into the semiconductor to produce micro and nanostructures including arrays of pillars for energy harvesting and storage, vias for photonic crystals, and arbitrary shape and patterns for applications including metamaterials. MacEtch is essentially a wet etching method yet produces anisotropic high aspect ratio semiconductor micro and nanostructures without incurring lattice damage.

Variations of MacEtch include:

- Forward MacEtch (**MacEtch**)
- Inverse MacEtch (**I-MacEtch**)
- Self-Anchored-Catalyst MacEtch (**SAC-MacEtch**)
- Magnetic-field guided MacEtch (***h*-MacEtch**)

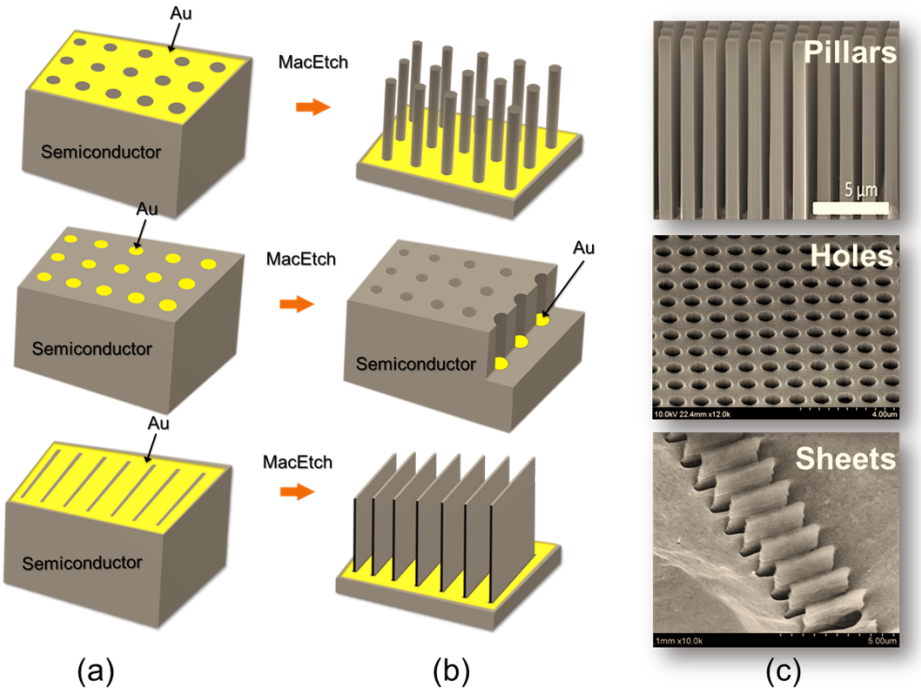
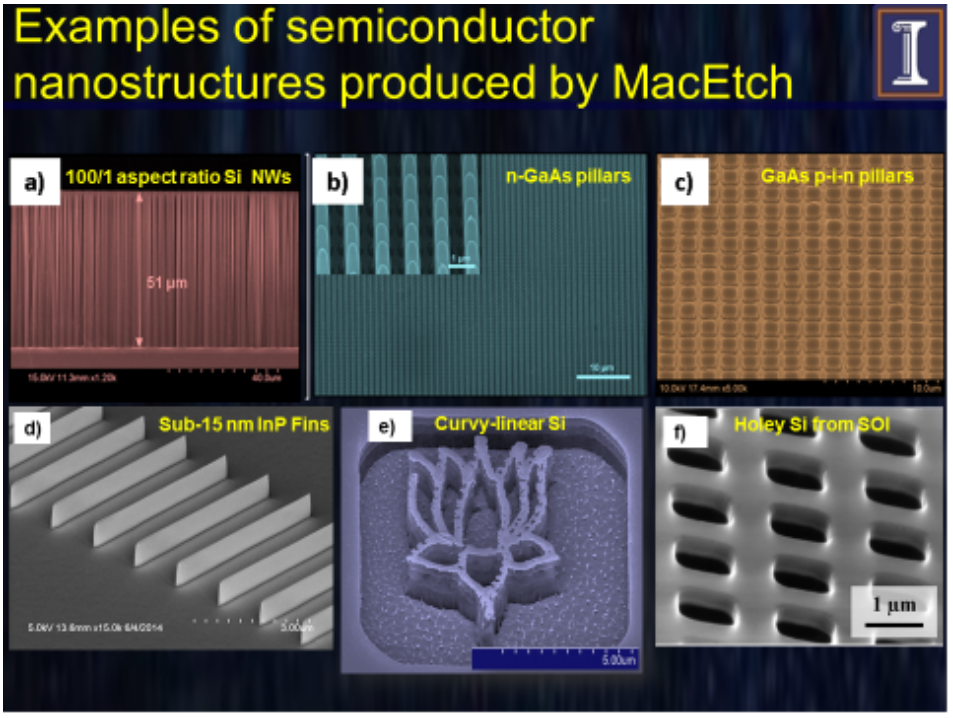


Illustration of MacEtch Mechanism and Capabilities: (a) pillar array formation from a Au mesh pattern; (b) hole arrays formation from Au disk pattern; and (c) vertical sheet array formation from a Au slit pattern.



- **Our Publications on MacEtch:**
  - **H.-C. Huang, M. Kim, X. Zhan, K. Chabak, J. D. Kim, A. Kvit, D. Liu, Z. Ma, J.-M. Zuo, and X. Li, "High Aspect Ratio Ga2O3 Fin Arrays with Low-Interface Charge Density by Inverse Metal-Assisted Chemical Etching," ACS Nano, accepted. DOI: 10.1021/acsnano.9b01709.**
  - **J. D. Kim, M. Kim, C. Chan, N. Draeger, J. J. Coleman, and X. Li, "CMOS Compatible Catalyst for MacEtch: Titanium Nitride Assisted Chemical Etching in Vapor Phase for High Aspect Ratio Silicon Nanostructures," ACS Appl. Mater. Interfaces, accepted (2019).DOI: 10.1021/acsami.9b00871**
  - **M. Kim, H.-C. Huang, J. D. Kim, K. D. Chaback, A. R. Kumar, W. Zhou, and X. Li, "Nanoscale Groove Textured beta-Ga2O3 by Room Temperature Inverse Metal-assisted Chemical Etching and Photodiodes with Enhanced Responsivity," Appl. Phys. Lett. 113, 222104 (2018).[pdf]**
  - **M. Kim, S. Yi, J. D. Kim, X. Yin, J. Li, J. Bong, D. Liu, S-C. Liu, A. Kvit, W. Zhou, X. Wang, Z. Yu, Z. Ma, and X. Li, "Enhanced performance of Ge photodiodes via monolithic antireflection texturing and *a*-Ge self-passivation by inverse metal-assisted chemical etching," ACS Nano, 12 (7), pp 6748-6755 (2018).[pdf]**
  - **J.D. Kim, M. Kim, L. Kong, P. Mohseni, S. Ranganathan, J. Pachamuthu, W.K. Chim, S.Y. Chiam, J.J. Coleman, and X. Li, "Self-Anchored Catalyst Interface Enables Ordered Via Array Formation from Sub-micron to millimeter Scale for Poly- and Single-Crystalline Silicon," ACS Appl. Mater. Interfaces, 10 (10), pp 9116â€"9122 (2018). [pdf]**
  - **L. Kong, Y. Song, J.D. Kim, L. Yu, D. Wasserman, W.K. Chim, S.Y. Chiam, and X. Li, "Damage-Free Smooth-Sidewall InGaAs Nanopillar Array by Metal-Assisted Chemical Etching," ACS Nano, 11 (10), pp 10193-10205 (2017).[pdf]**
  - **J. D. Kim, P. K. Mohseni, K. Balasundaram, S. Ranganathan, J. Pachamuthu, J. J. Coleman, and X. Li, "Scaling the Aspect Ratio of Nanoscale Closely-Packed Silicon Vias by MacEtch: Kinetics of Carrier Generation and Mass Transport," Adv. Func. Mater. 27, 1605614 (2017).[pdf]**
  - **Y. Song, P. K. Mohseni, S. H. Kim, J. C. Shin, T. Ishihara, I. Adesida, and X. Li, "Ultra-High Aspect Ratio InP Junctionless FinFETs by a Novel Wet Etching Method," IEEE Electron Dev. Lett. 37 (8), pp 970-973 (2016). [pdf]**
  - **S. H. Kim, P. K. Mohseni, Y. Song, T. Ishihara, and X. Li, "Inverse Metal-Assisted Chemical Etching of InP Produces Smooth High Aspect Ratio Nanostructures," Nano Lett. 15 (1), pp 641-648 (2015). [pdf]**

- K. Balasundaram, P. K. Mohseni, Y-C Shuai, D. Zhao, W. Zhou, and X. Li, ''Photonic crystal membrane reflectors by magnetic field-guided metal-assisted chemical etching'', Appl. Phys. Lett. 103, 214103 (2013). [pdf]
- P. K. Mohseni, S. H. Kim, X. Zhao, K. Balasundaram, J. D. Kim, L. Pan, J. A. Rogers, J. J. Coleman, and X. Li, ''GaAs pillar array-based light emitting diode fabricated by metal-assisted chemical etching'', J. Appl. Phys. 114, 064909 (2013). [pdf]
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