Defying Textbook Definition of Wet Etching: Anisotropic Metal-Assisted-Chemical-Etching

Defying the textbook definition of wet etching (isotropic in nature), metal assisted chemical etching (MacEtch), fundamentally a wet but directional etching method, can produce anisotropic high aspect ratio semiconductor micro and nanostructures without incurring lattice damage. Figure 7.5.1 illustrates the MacEtch process to form pillar arrays, where the metal mesh pattern descends into the semiconductor, removing the semiconductor along the way and leaving behind a 3D semiconductor pattern that is the inverse of the metal pattern. The metal catalyst can be chemically removed from the semiconductor surface after MacEtch.

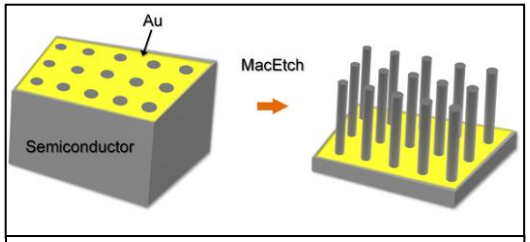

Figure 7.5.1: Illustration of the MacEtch process to produce semiconductor pillar arrays. The Au mesh pattern descends into the semiconductor by removing materials directly underneath, leaving behind an array of semiconductor pillars.

MacEtch of Si has been widely accepted and practiced as a method to produce high aspect ratio structures such as nanowire arrays. However, MacEtch of III-V materials to produce periodic nanostructures, especially in high aspect ratios, has hardly been explored until now. The main challenge of MacEtch of III-V is the inherently small differential etch rate with and without metal presence under common MacEtch conditions. Through the right combination of oxidant, acid, and temperature, our recent work[3] successfully demonstrated that ordered arrays of high aspect ratio GaAs nanostructures can be formed using Au-MacEtch. Figure 7.5.2 shows an array of GaAs pillars formed by immersing a n^+-type GaAs wafer coated with an Au-mesh pattern in an MacEtch solution consisting of $KMnO_4$ and H_2SO_4 at 40°C for 5 minutes. Although only n-type GaAs MacEtch is demonstrated here, MacEtch should work for other III-V material types and dopings, as well as heterostructures, as long as the right condition for deferential etching with and without metal can be found.

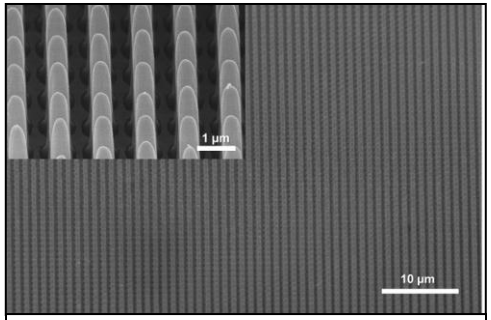

Figure 7.5.2: SEM images (inset: zoomed-in view) of an array of GaAs pillars formed by MacEtch.

In summary, MacEtch is a simple and efficient semiconductor etching technique that is capable of producing high aspect ratio semiconductor nanostructures beyond just Si. These high aspect ratio structures can potentially transform the fabrication of device structures that are currently fabricated by dry etch or bottom-up growth and assembly techniques. Examples include periodic nanostructures for photonic crystals, light trapping structures for LEDs and solar cells, 3D transistors, thermoelectric devices with roughened sidewalls, and nanowire batteries with greater energy density. MacEtch also brings affordability and possibly new device concepts for nanostructure based photonic and electronic devices.

"Formation of High Aspect Ratio GaAs Nanostructures with Metal Assisted Chemical Etching," M. T. DeJarld, J. C. Shin, W. Chern, D. Chanda, K. Balasundaram, J. A. Rogers, and X. Li, *Nano Lett.,* 11, 5259-5263 (2011).