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Formation and Ordering of Nanostructures using Focused-Ion Beams

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Summary

Arrays of metallic nanostructures are of interest for a broad range of applications including magnetic memory arrays, plasmonic waveguides, nanowire seeds, and negative index materials. Although nanometer-sized metallic droplets often form on compound semiconductor surfaces during epitaxial growth, thermal annealing, and/or ion irradiation, their formation mechanisms are not well understood. In this work, we examine the formation and ordering of metallic droplets during FIB irradiation of GaAs, GaSb, and InAs surfaces as well as nanowire formation on GaSb and InSb surfaces. On GaAs and GaSb surfaces, randomly distributed Ga droplets are observed to form at a critical dose. Subsequent ion beam irradiation on GaAs results in growth, motion, and coalescence of the droplets. On GaSb/InSb surfaces, polycrystalline GaSb/InSb nanowires with Ga/In tips are formed initially, and with continued irradiation, the Ga tips of GaSb nanowires coalesce to form large droplet but coalescence is not evident in InSb case. On InAs surfaces, randomly distributed solid-phase In nano-dots are observed. Interestingly, further irradiation of GaAs and GaSb surfaces leads to motion of the Ga droplets, while on the InAs surfaces, the nano-dots apparently remain static. A higher droplet velocity is observed on GaSb than on GaAs surfaces, suggesting that droplet motion is dependent on the energetics of the Ga-substrate interface. The formation mechanism of Ga droplets on GaAs surfaces will be discussed involving Ga precipitation from a Ga-rich surface layer, followed by droplet coarsening due to ion-enhanced Ga surface diffusion. The formation mechanism of nanowires on GaSb/InSb surfaces will also be presented based upon modified vapor-liquid-solid growth mode with ion-enhanced local heating and ion-induced sublimation from the substrate acting as vapor sources.

In terms of surface patterning, we have fabricated arrays of droplets and nanowires with uniform sizes and shapes on GaAs and GaSb/InSb surfaces. On GaAs surfaces, after scanning the ion beam over the patterned areas, Ga droplets form within the pre-patterned holes. By controlling the ion beam energy, dwell time, and position, droplet arrays with various sizes, densities, and periodicities may be produced. We are in the process of developing techniques for the growth of GaN nanostructures from Ga droplet seeds by nitrogen plasma and NH_3 vapor exposure. On GaSb/InSb surfaces, site-controlled NWs are nucleated and grown directly from FIB-patterned holes. The nanowire formation is dependent on the ion dose, beam

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energy, and ion scan direction. Both single- and multiple-nanowire arrays are fabricated by controlling the patterning diameter and depth. The typical nanowire is 50∼60 nm in diameter and 300∼400 nm in length. Interestingly, by tuning ion beam spot size and pitch, highly efficient formation of highly ordered nanogrid arrays with can be realized on nearly all common semiconductor surfaces including GaAs, InAs, Si, InSb etc.