New Insights into Surfactant and Doping Effects in GaAs Nanowire Growth

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GaAs-based nanowires (NW) have evolved as prosperous materials for advanced Si-integrated device applications in photonics, electronics and quantum technologies. Much of this progress is owed to very dedicated growth methods, where key challenges lie in the realization of scalable NW arrays with high uniformity, structural integrity and excellent control of aspect ratio, doping, and heterostructure formation.

In this contribution, we highlight our recent progress in both the catalyst-free vapor-solid (VS) and self-catalyzed vapor-liquid-solid (VLS) growth of GaAs NWs by molecular beam epitaxy (MBE), with a focus on the role of dopants and surfactants. By using selective area epitaxial (SAE) processes, we first illustrate how in periodic NW arrays Si dopants influence growth dynamics and array homogeneity. In particular, we show improved array homogeneity under high Si doping that is well explained by strongly altered twin formation probabilities that drive the facet-mediated growth along the growth direction [1]. Employing the catalyst-free VS-process we directly demonstrate clear n-type doping behavior in these Si-doped GaAs NWs [2], resolving the long-standing problem of exclusively reported p-type conduction of MBE-grown GaAs NWs when Si doping is performed under more common VLS-type processes.

Adding traces of antimony (Sb) to the growth of undoped or Si-doped GaAs NWs results in very peculiar, hitherto unexpected growth behavior. Especially, depending on the amount of Sb, both surfactant and anti-surfactant action is found, as seen by transitions between growth acceleration and deceleration characteristics [3,4]. For threshold Sb-contents up to 3-4%, adatom diffusion lengths are increased manifold compared to Sb-free GaAs NWs, evidencing significant surfactant effect and strong enhancement in aspect ratio [3]. Microstructural analysis reveals substantial reduction in twin defect density – nearly 10-fold over only small compositional range (1.5–6% Sb), exhibiting much larger dynamics as found in VLS-type GaAsSb NWs [4]. Also, only phase-pure ZB domains are found in GaAsSb NWs as opposed to mixed-phase in Sb-free GaAs NWs, evidenced by narrow, single peak emission in photoluminescence (PL) spectroscopy. Furthermore, we show how to overcome the growth limiting effects of Sb in VLS-type GaAsSb NWs under very high Sb molar fractions. By carefully tuning growth parameters, it is possible to realize quite long (>7µm) GaAsSb NWs without tapering and with Sb-content of ~20-30%.

Ultimately, we apply the combined effects of Si-doping and tuning of Sb-content to realize very high aspect-ratio GaAsSb NW laser structures vertically integrated on Si. We close this talk by discussing results of optically pumped lasing, particularly highlighting low lasing thresholds (~2-10 µJ/cm2) under wide Si-doping densities as well as tailoring emission to longer wavelengths (~1-1.15 µm).

References

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