Single Crystalline Wurtzite GaAs Nanoneedles Epitaxially Grown on Highly Lattice-Mismatched Sapphire with Bright Luminescence

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Heterogeneous integration of dissimilar single-crystalline materials, such as III-V compound on Si or sapphire, enables functionalities and performance that cannot be achieved with single material system. Yet, lattice mismatch makes growing high quality thin film on dissimilar substrates difficult. Recently high quality nanowires have been demonstrated on substrates with large lattice mismatches [1]. However, in that case, there exists a critical nanowire diameter for a given mismatch, below which single crystalline can be obtained. This, in turn, presents an upper bound of the substrate lattice mismatch to ~15%, on which nanowires with physically meaningful diameters can be attained with the growth of three-dimensional nanostructures. In this paper, we report a completely new growth mechanism that leads to self-assembled, single crystalline GaAs nanoneedles grown on a sapphire substrate with 46% lattice mismatch. The needles exhibit a single crystalline wurzite phase, have a sharp hexagonal pyramid shape and can be scaled to micron size with growth time. The GaAs nanoneedles were grown on a (0001) sapphire substrate in a commercial MOCVD at 400°C. The growth was spontaneous without any prior substrate surface treatment. At typical growth condition, the nanoneedle shows a hexagonal base, six slanted sidewalls and a sharp tip. With one-hour growth time, the nanoneedle has a base diameter of ~600 nm and a height of ~3 μm. Furthermore, high-resolution TEM shows that the tip is ~ 3 nm wide, and the needle has a taper angle of ~11°. TEM and diffraction analysis reveals that the NN has single-crystalline wurzite structure as opposed to the normal zinc-blende GaAs structure. The effect of growth condition on nanoneedle was studied by varying the growth time. When the growth time was varied, the base dimension and height of the nanoneedle scales linearly, maintaining the same taper angle, even when the growth time was only 1.5 min. This suggests that the nanoneedle nucleates as a seed and grows with a two-dimensional thin-film deposition process on the six sidewall facets. Despite the large 46% lattice mismatch, the NN shows bright photoluminescence. A 514 nm excitation laser is focused down to a ~1.5 μm spot. With 100 μW excitation power, the NN shows emission peak at 1.519 eV at 4 K. The linewidth of the peak is 18 meV. This narrow linewidth indicates the excellent crystal quality of the NN. These high-quality GaAs NNs open an opportunity for integrating high-performance electronic and optoelectronic devices onto highly lattice-mismatched substrates.