Nanolasers Directly Grown on Si

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Abstract: We report a completely new growth mode with which single crystalline InGaAs/GaAs nanopillars can be grown directly on silicon substrates at CMOS compatible temperature. Light emitting diodes, photovoltaic device and optically pumped lasers are achieved.

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1. Summary

Heterogeneous integration of III-V optoelectronic devices, Si-photonic devices and CMOS circuits is of tremendous importance because it will enable functionalities otherwise unattainable as well as expand capabilities with greatly reduced power consumption, size and weight. Despite of much research, the integration of optical gain materials onto silicon remains difficult or unscalable. One approach to overcome this problem is the hetero-epitaxial growth of low-dimensional materials. However, single crystalline growth is usually limited to films thinner than a critical thickness or to nanostructures whose footprints are smaller than a critical diameter [1].

In this talk, we will first present an overview of a new growth mechanism, with which single crystalline III-V nanopillars can be grown on substrates with a very large lattice mismatch at low temperature 400°C by metal-organic chemical vapor deposition (MOCVD). We demonstrated (In,Al)GaAs nanopillars grown on silicon, polysilicon and sapphire substrates [2-6]. We also demonstrated InP/InGaAs and InAs nanopillars on silicon substrates. All of them are single crystalline, single phase and scalable with growth time up to a few μm in diameter. Furthermore the growth temperatures and V/III ratios are all within a small range. Optically pumped InGaAs/GaAs nanopillar lasers are achieved on polycrystalline-Si and crystalline (100)-Si substrates at room temperature. Similarly, InP nanopillar lasers are also demonstrated on silicon substrate. These indicate the excellent optical properties of the material.

Nanopillar optoelectronic devices are processed by standard fabrication techniques [5]. We will discuss the performance of room-temperature operation of light emitting diodes, avalanche photodiodes and solar cells [5].

We will review our recent work of InGaAs nanopillar laser structure directly grown on a Si substrate containing metal-oxide-semiconductor field effect transistors (MOSFETs). Despite little index contrast between silicon and InGaAs, the nanopillars support helically-propagating whispering gallery modes and hence confine light strongly within a very small volume, resulting in subwavelength-sized lasers without the use of conventional plasmonic effects. Lasing data and near field mode pattern reveal that the lasing modes are novel helically propagating modes. The laser emission has a polarization perpendicular to the c-axis which we ascribe to its wurtzite crystal structure. The MOSFETs characterized before and after the nanopillar growth show nearly no difference. This result demonstrates CMOS-compatibility of nano-laser growth, serving as a proof-of-concept that such integration can be extended to more complicated CMOS integrated circuits.

This result paves a way for future heterogeneous integration of nanophotonics, in particular lasers, directly onto silicon wafers consisting of nearly completed electronic circuits.

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References