Pattern transfer to GaAs substrates and epitaxial growth of GaAs nanostructures using self-organized porous templates

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GaAs nanostructures were grown on patterned GaAs (111) B substrates with molecular beam epitaxy. Nanopatterns were achieved by patterning a thin film of silicon dioxide (SiO_2) grown on the substrate surface with a self-organized porous alumina template. Growth of patterned nanostructures took place through the holes in the SiO_2 film. The authors obtained two kinds of nanostructures: nanopillars and nanodots. The majority of nanopillars had two kinds of tops, i.e., hexagonal flat top and pyramidal top, as observed with a scanning electron microscope. High resolution transmission electron microscopy studies showed epitaxial relationships between the nanostructures and the substrates. Photoluminescence measurements of nanopillars showed the photoluminescence peak shifted to a higher energy compared to films grown under the same condition. © *2016 American Vacuum Society*. [http://dx.doi.org/10.1116/1.4943920]

I. INTRODUCTION

Lithographic techniques used to produce nanostructures often result in structural degradation. The arrays of nanostructures in direct growth provide alternatives for realizing unique electronic and optical properties of semiconductors. These nanostructures are potentially building blocks for future optical, electronic, and photonic devices.[1–5] Superlattices, axial, and radial heterostructures[6] can be realized in nanowires and can potentially be used in nanowire based devices.[7] Those devices require position and size control of the nanowires, which can be obtained through nanopatterning and controlled growth. Direct growth of nanostructures by MBE mostly involves gold nanodots as a catalyst.[8] Various patterning and templating methods were derived from this approach, by creating gold nanodot arrays on a substrate surface with gold nanodot solution,[9] nanosphere lithography,[10] chemical e-beam lithography (EBL),[11] gold deposition mask on porous alumina templates,[12] etc. Wu *et al*. used alumina templates for the deposition of gold nanodots, which was then used as a catalyst for the growth of nanowires.[8] The problem with gold-catalyzed method of growth is that there can be gold impurity states deep into the band gap of GaAs, which affects its optical properties.[13] Mei *et al*. grew GaAs nanodots using MBE, with alumina templates as growth masks, which require templates to be very thin.[14] Otherwise the templates will lead to shadowing effect for the growth of nanostructures. Thin alumina templates are very fragile and therefore not suitable for use as a growth masks. Among other techniques utilized to produce templates, nanopatterning of SiO_2 films deposited on the substrate surface has been done with EBL for growing nanostructures.[15] This technique of nanopatterning using EBL has the disadvantage of high cost, which is prohibitive when used for large areas.

We report on the patterning of a SiO_2 film on GaAs (111) B substrates using alumina templates. The growth of patterned GaAs nanostructures (nanopillars and nanodots) takes place selectively through the holes in the SiO_2 film with MBE. The morphology of nanostructures was studied using SEM. The crystal structure and epitaxial relationship of GaAs nanopillars with the GaAs substrate were studied using a transmission electron microscopy (TEM). The optical properties of the nanopillars were studied with low temperature photoluminescence (PL) measurements. To verify that the emission was indeed from the nanopillars, we also measured the spectra for GaAs substrate and an MBE-grown GaAs film.

II. EXPERIMENTAL DETAILS

The schematic of the pattern transfer and growth of the nanostructures are shown in Fig. 1. A thin film of SiO_2 of approximate thickness of 45 nm was deposited on Si doped n-GaAs (111) B (carrier concentration = $0.8–4 \times 10^{18}\,\mathrm{cm}^{-3}$) substrate using Trion Technology Orion plasma enhanced chemical vapor deposition technique. We used tetra ethyl ortho silicate (TEOS) as the liquid source of SiO_2 deposition. Helium was the carrier gas for TEOS. The deposition parameters for the SiO_2 film were: total pressure 750 mTorr; substrate temperature = 300 °C; O_2 flow rate = 60 standard cubic centimeter per minute (sccm); RF power = 100 W; TEOS flow rate = 60sccm; and deposition time = 50 s. A Gaertner Scientific Corp. L117 ellipsometer was used to measure the thickness of the SiO_2 film.

The alumina templates were fabricated with a two-step anodization procedure from aluminum foils of 99.999% purity.[16,17] The Al foil was cut into small square pieces, which can be called Al substrates. It was cleaned and annealed at 400 °C for 4 h. In the first anodization process, the Al substrate was anodized in a 0.3 M oxalic acid solution at 40 V at room temperature for 3 h. A thin oxidized layer was obtained, which was removed by immersing the Al substrate in the mixture of 6 wt. % phosphoric acid

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