Improved infrared photoluminescence characteristics from circularly ordered self-assembled Ge islands

Samaresh Das[1], Kaustuv Das[2], Raj Kumar Singha[1], Santanu Manna[1], Achintya Dhar[1], Samit Kumar Ray[1*] and Arup Kumar Raychaudhuri[2]

Abstract

The formation of circularly ordered Ge-islands on Si(001) has been achieved because of nonuniform strain field around the periphery of the holes patterned by focused ion beam in combination with a self-assembled growth using molecular beam epitaxy. The photoluminescence (PL) spectra obtained from patterned areas (i.e., ordered islands) show a significant signal enhancement, which sustained till 200 K, without any vertical stacking of islands. The origin of two activation energies in temperature-dependent PL spectra of the ordered islands has been explained in detail.

Introduction

The confinement of charge carriers in low-dimensional Ge/Si heterostructures allows one to increase the efficiency of the radiative recombination, making the indirect gap group-IV semiconductors attractive for optical devices. Owing to the type-II band alignment [1], Ge dots form a potential well only for holes, whereas the electrons are weakly confined in the vicinity of the Ge dots, i.e., by the tensile strain field in the Si cap induced by Ge quantum dots (QDs) [2,3]. The resulting recombination energy depends strongly on size, shape, strain, and composition of the QDs leading to a wide emission energy spectrum. Therefore, intensive effort is currently undertaken to prepare arrays of identical" QDs, which emit in a resonant mode [4]. Infrared (IR) photoluminescence (PL) at room temperature has been reported by vertical ordering of Ge islands in three-dimensional stack of 10-20 periods [5,6].

To improve the lateral ordering of QDs, one of the strategies is to convert the stochastic nucleation process into a deterministic one by directing nucleation on the predefined surface sites, using a combination of self-assembly and surface pre-patterning [7-10]. In general, the 2D Ge dot arrays reported so far have considerably larger inter-dot distance, thus lateral coupling is quite weak. The IR PL emission from randomly distributed islands is reported to be quenched at a relatively low temperature [2,11], because of thermal dissociation of excitons. In this article, we report the superior IR PL characteristics, which exist up to a temperature as high as 200 K, owing to lateral coupling in circularly ordered Ge islands on pre-patterned Si (001) substrates.

Experimental

Ge QDs were grown by solid source molecular beam epitaxy (MBE) on focused ion beam (FIB) patterned (FEI HELIOS 600 dual beam system) substrates. The Si (001) substrate surface was patterned with two-dimensional periodic hole arrays using an FIB with Ga^+ ion energy of 30 keV and a beam current of 21 pA. Arrays of about 50 × 50 holes of diameter in the range of 100-200 nm and depth varying from 20 to 50 nm were fabricated at a fixed volume per dose (0.15 μm^3/nC). The hole spacing and pitch were varied from 50 to nearly 200 nm and 50 to 600 nm, respectively. After removing Ga contamination from the surface, Ge QDs were grown using solid source MBE (Riber Supra 32) system using an electron gun for the deposition of thin buffer layer (approx. 5 nm) of Si with a growth rate of 0.4 Å/s, and a Knudsen cell for Ge deposition followed by a 2-nm Si cap layer. The Ge growth rate was kept constant at 0.5 Å/s at a substrate temperature of 580°C. PL spectra

* Correspondence: physkr@phy.iitkgp.ernet.in
[1]Department of Physics and Meteorology, Indian Institute of Technology Kharagpur, Kharagpur 721302, India