Characteristics and fabrication of nanohole array on InP semiconductor substrate using nanoporous alumina

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Abstract

Uniform arrays of nano-sized pore produced in porous alumina were transferred into InP substrates by inductively coupled plasma reactive ion etching (ICP-RIE). We observed a significant enhancement in the light output from InP substrate with nanohole arrays on the surface. Photoluminescence intensity of triangular arrays of air cylinders on InP substrate showed an enhancement up to 3 times compared with that from a raw InP substrate without such structure. The ICP-RIE technique using nanoporous alumina mask can be used as a prospective method in the fabrication of nanostructure materials for increasing the light output from semiconductor light emitting devices.

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1. Introduction

Formation of uniform nanohole arrays on semiconductor substrate can be variously used in applications of photonic and electronic devices. Lithographic techniques have been extensively used to fabricate electrical and optical devices of controlled dimension. But, there are many limits in fabrication of nanostructure devices with uniform nanometer size over a large area using conventional lithographic techniques. Formation of nanohole with nanometer dimension on semiconductor substrate is very important for fabrication of nanostructure devices in applications of nanotechnology. The nanoporous alumina with uniform channels of nanometer dimension has been intensively studied as a transfer mask for pattern with nanometer size into the semiconductor substrates [1–4]. Especially, the nanoporous alumina has been widely used as a template in order to grow other materials, such as nanodots [5–7], carbon nanotubes [8], and nanostructures [9]. Fabrication of pore array on semiconductor substrate may provide alternative approach for fabrication of a photonic bandgap crystal and for selective growth to fabricate low-dimensional structure [2]. In this work, we fabricated nanoholes on the surface of InP semiconductor substrate by inductively coupled plasma reactive ion etching (ICP-RIE) using nanoporous alumina mask. The property of light output of the substrate with nanohole was studied by photoluminescence (PL).

2. Experiments

The nanoporous alumina masks were prepared from an aluminum foil (99.99%, 100 μm thickness) by a two-step anodization method [10]. Anodization of Al electrode was performed by applying a constant DC voltage of 40 V in 0.3 M oxalic acid solution of 3 °C, described in detail elsewhere [6,11]. For the preparation of the alumina mask with through-hole, the remaining aluminum substrate was
removed in a saturated HgCl₂ and the barrier layer at the bottom of the cylindrical channels was etched out in an aqueous 5 wt% phosphoric acid at 30 °C subsequently.

The alumina mask with through-hole was placed onto a p-type InP substrate as a masking layer for advancing dry etching process. Then, this alumina mask/InP substrate was subsequently placed on the cathode electrode of ICP-RIE system. Under the fixed flow rate ratio (7:8:9) of Cl₂, CH₄, and H₂ gases, the sample etching was conducted under ICP source power of 1500 W and the RF bias power of 100 W for 30 s. In that condition of ICP-RIE, InP substrate was commonly etched at a rate of 1.89 μm/min. After etching by ICP-RIE, the alumina mask bonded on InP substrate was dissolved out in mixture solution of phosphoric acid and chromic acid for several hours at 65 °C. The morphologies of the alumina mask and the etched InP surface were observed by using a field emission scanning electron microscope (SEM). PL characterization of the sample was measured by the optical pumping of Ar-ion laser with the excitation wavelength of 514 nm in the room temperature.

3. Results and discussion

Well-ordered nanoporous alumina masks with through-hole play very important role in forming structure of nanohole on InP substrate. The SEM image of an oblique-view of the nanoporous alumina mask with through-hole is shown in Fig. 1. The SEM image clearly shows the straight parallel through-hole arrays of the alumina mask perpendicular to the substrate. The nanoporous alumina mask was prepared at anodization voltage of 40 V in 0.3 M oxalic acid solution. Considering the difference of growth rate dependent on anodization voltage and type of electrolyte, thickness of the alumina mask was controlled by anodization time [6]. The thickness of the alumina mask fabricated for the anodizing time of 5 min is about 250 nm.

The SEM image of top-view of the nanoporous alumina mask prepared at 40 V in 0.3 M oxalic acid solution is shown in Fig. 2(a). The cell size and the pore density of the mask are 110 ± 5 nm and ~0.9(±0.1) × 10¹⁰ cm⁻², respectively. The close-packed hexagonal cell size and pore diameter of alumina is dependent on the anodic voltage, type and temperature of electrolyte [12,13]. The InP substrate covered with the nanoporous alumina mask was exposed for 30 s in a mixed gas ambient by ICP-RIE. After ICP-RIE process, the SEM image of a top-view of the alumina mask bonded on the InP substrate are shown in Fig. 2(b). The pore diameter of the mask is 45 ± 5 nm. The pore diameter of the alumina mask was adjusted within the range of the hexagonal cell size by chemical etching time. The alumina mask shows high tolerance to ion bombardment induced by ICP-RIE in the Mixed gases of Cl₂, CH₄, and H₂.

After etching for 30 s by ICP-RIE, the alumina mask bonded on InP substrate was dissolved out in chemical etching solution. After removal of the alumina mask, the SEM image of the nanoholes formed on surface InP substrate is shown in Fig. 3. The SEM image in Fig. 3 clearly shows that uniform arrays of nano-sized pores produced in anodic alumina were transferred into InP substrate by ICP-RIE. The average pore diameter and the

![Fig. 1. SEM image of the nanoporous alumina mask prepared at the anodization voltages of 40 V in 0.3 M oxalic acid.](image1)

![Fig. 2. SEM images of top-view of (a) the nanoporous alumina as prepared and (b) top-view of the nanoporous alumina mask after etching for 30 s by ICP-RIE.](image2)

![Fig. 3. SEM image of top-view of nanohole array formed on p-type InP substrate for 30 s by ICP-RIE.](image3)
The property of light emission from InP substrate with nanohole was studied by PL intensity. In Fig. 4, room temperature PL spectra show the PL peaks at 932 nm from InP substrates band-to-band transition. The PL properties of triangular arrays of air cylinders with nanohole on InP substrate show an enhanced intensity compared with that from InP substrate without such structure. After all, the PL intensity from InP substrate with nanoholes showed 3 times enhancement compared with that from a raw InP substrate without such structure. Nanoholes formed on the surface of InP substrate may have resulted in the enhancement of PL intensity. Therefore, the light from InP substrate seems to be enhanced either through the surface roughness of InP substrate or the ordered nanohole arrays such as two-dimensional photonic crystal structure.

4. Summary

Uniform arrays of nano-sized pores produced in anodic alumina were transferred into InP substrate by inductively coupled plasma reactive ion etching (ICP-RIE). Using the alumina mask, nanohole arrays with 40 nm diameters were formed on InP substrate. The Photoluminescence intensity from on InP substrate with nanoholes showed 3 times enhancement compared with that from a raw InP substrate without such structure. The ICP-RIE technique using nanoporous alumina mask can be used as a prospective method in the fabrication of nanostructure materials for increasing the light output from semiconductor light emitting devices.

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