Photonic crystal and wave guide effect of ZnO nano rods

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Abstract – *The light wave guide within ZnO nano rod and photonic crystal effects in arrayed ZnO nanorods was calculated by COMSOL and 3D-finite dimension time domain(3D-FDTD) programs. Various ZnO nano photonic crystals were grown by laser interference lithography and hydrothermal method. The propagation and photonic crystal effects in ZnO nanorod was governed by shape of ZnO nanorod and arragement of ZnO nanorods, respectively.*

1. INTRODUCTION

Since photonic crystals (PCs) were reported, there has been a dramatic increase in the number of papers related to nano-scale structures, because of their unique properties, such as presence of bandgap, local field enhancement, anomalous refractive index dispersion. et al. [1,2]

Among these nano scale PCs materials, ZnO PCs have attracted considerable attention for their wide range of applications because of their outstanding electrical and optical properties. [2] The ZnO nano crystal can be used for solarcell material, gas sensing material, and UV-light diodes because it has properties of direct wide bandgap and high excitation binding energy at room temperature. The ZnO nano crystal shows the difference of physical and chemical properties depend upon morphology of nanostructure. [3-5]

In this study, we have calculated light waveguide mechanism of ZnO nanorod and photonic crystal effects of arrayed Zno nanorods. And fabricated two types of arrayed ZnO nanorods were integrated on the ZnO/Si substrate by laser interference lithography and hydro-thermal synthesis at 90°C.

2. EXPERIMENTAL PROCEDURE

The 2D nanopatterns were fabricated on a PR (SPR 510-A,ROHM HAAS electronic materials) coated ZnO/Al_2O_3(001) substrate using the LIL method, which were then used for the hydrothermal synthesis of different 2D Bravais lattices of ZnO nanostructures at 90°C.

Figure 1 shows a schematic diagram of the technique for producing nanopatterns on a PR coated ZnO/ Al_2O_3(001) substrate and the subsequent growth of ZnO nanorods through the patterned areas using a hydrothermal method.

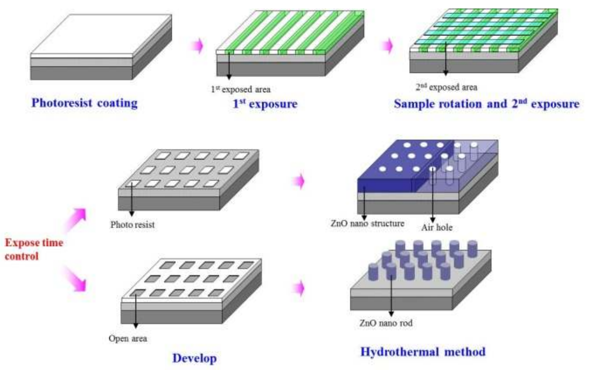

Fig. 1. Experimental procedure

Two different types of precursor solutions, A and B, were prepared to grow ZnO nanorods in the hydro-thermal process. Solution A contained 0.2 g of zinc nitrate hexahydrate dissolved in 24 mL of distilled water, and solution B contained 0.2 g of zinc nitrate hexa-hydrate and 0.25 g of sodium citrate as a surfactant in 24 mL of distilled water. A 29.2% NH4OH solution was then added into the precursor solutionsuntil the pH reached 10.9.

3. RESULTS AND DISSCUSION

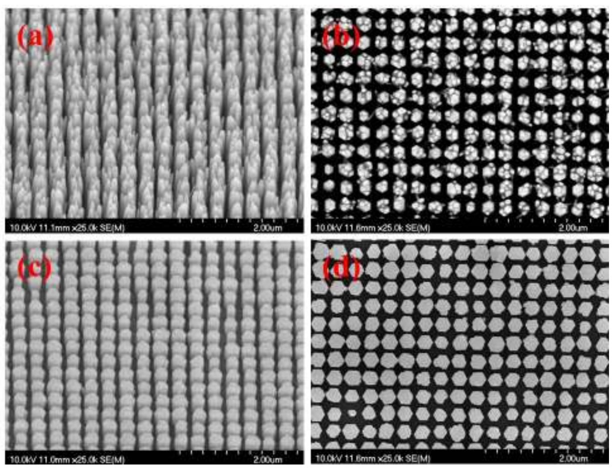

Fig. 2. Tilted and plan view SEM images of ZnO nanorods on ZnO/Al_2O_3 substrate.

Figure 2 shows the tilted and plan view of ZnO nanorods grown by laser interference lithography and hydrothermal process. The difference between theis two ZnO nanorods is the use of Na-citrate in solution B.

Needle-shaped ZnO nanorods are observed in the samples grown in solution A without Nacitrate (Figure 2 a and b) and a hexagonal-prism shaped ZnO nanorods with a flat top surface and controlled shape are observed in the sample grown in solution B with Na-citrate (Figure 2c and d).

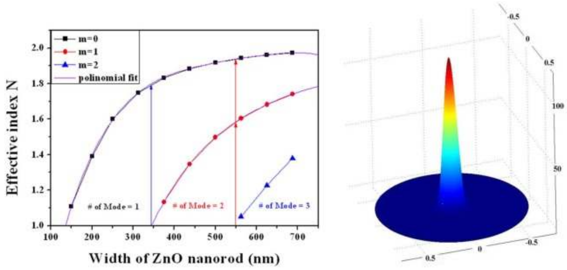

Fig. 3. The dependence of refractive index and number of modes on the width of ZnO nanorods at a wavelength of 450nm (a), simulation of light propagation in hexagonal prism shaped ZnO nanorod at width of 250nm (b).

The correlation between the width of ZnO nanorods and the number of light propagation modes was calculated by COMSOL and the results are shown in **figure 3**. Wave equation is expressed by

$$\frac{\partial^2}{\partial x^2}E(x,y) + \frac{\partial^2}{\partial y^2}E(x,y) + k_0^2[n^2(x,y) - N^2]E(x,y) = 0 \quad (1)$$

As the width of ZnO nanorod was increased, there was no significant increase of the number of modes. The single mode condition satisfies in the width of 135 to 345nm of ZnO nanorods, the multi-mode was begun at 345 nm.

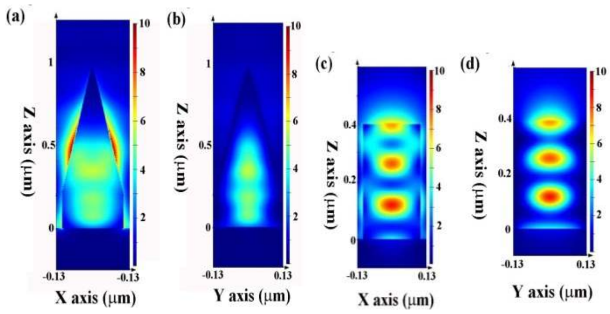

Figure 4. 3D finite-difference time-domain(FDTD) simulated longitudinal section images of light propagation in ZnO nanorods.

(a) XZ plane of needle shaped ZnO nanorods
(b) YZ plane of needle shaped ZnO nanorods
(c) XZ plane of hexagonal prism shaped ZnO nanorods
(d) YZ plane of hexagonal prism shaped ZnO nanorods

The wave guide effects of ZnO nanorods were simulated by 3D- FDTD method to investigate the mechanism of wave guide effect of ZnO nanorods. The light wave guide effect of the needle shaped and hexagonal prism shaped ZnO nanorods was shown in figure 4. Most of light in hexagonal prism shaped ZnO nanorod was propagated from bottom to top end with single mode. However, the light in needle shaped ZnO nanorod was not propagated to top end and dispersed in an inclined plane

4. CONCLUSIONS

We have fabricated two types of ZnO nano-rods including a hexagonal prism shaped and a needle shaped nanorods were integrated on ZnO/Al2O3 substrate. The ZnO nano photonic crystal was grown on patterned Al_2O_3 wafer using hydrothermal method. The light wave guide in ZnO nanorods were different from fiber wave guide. And the photonic crystal effects and light wave guide in nanorods were dominated by the arrangement and shape of nano structures, respectively.

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