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InP Based 2-Dimensional Photonic Band Structure —Fabrication by Anodization Method and Design—

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We have investigated the possibility of InP based 2-dimensional (2D) photonic band structure theoretically and experimentally. We aimed at utilizing low damage triangular microrods and grids formed by an anodization method for this structure. Photonic band gaps and birefringence for lightwaves inside the 2D plane were predicted from a vector wave analysis in which the shape of triangular index potentials was taken into account.

The photonic band structure is a kind of periodic microstructure of dielectric and/or semiconductor materials.[1,2] It is of great interest owing to its potential for the absolute control of light emission and propagation in photonic devices. Although the effect might be more remarkable in higher dimensional (2D, 3D) structures, most experiments have been concerned with 1D one (planar cavity)[3,4] because of the complicated fabrication process and serious surface recombination problem of 2D and 3D structures made of semiconductors. Although some authors have demonstrated the 2D and 3D structures,[5,6] they have very large dimensions designed for microwaves. In this study, we examined the anodization etching of InP[7] as a new fabrication technique of 2D structure for lightwaves.

For the experiment, we prepared (111)A n-InP substrates ($N_d = 1 \sim 5 \times 10^{18}$ cm^{-3}) and setup shown in Fig. 1. The substrate surface was etched by 15 % HCl solution at room temperature with current injection and no optical pumping. As shown in Fig. 2, a lot of triangular rods and grids were automatically formed with current density of 45 and 15 mA/cm^2, respectively. As illustrated in Fig. 3, the rods and grids were perpendicular to the surface and the triangle orientation was determined by the crystal orientation. In addition, we observed no degradation of intensity and width of photoluminescence spectra even after deep etching (> 10 μm). From these results, we confirmed that, by controlling the size of rods and grids and arranging them periodically with some etching mask,[8] this method will be applicable to the fabrication of low damage 2D photonic band structure.

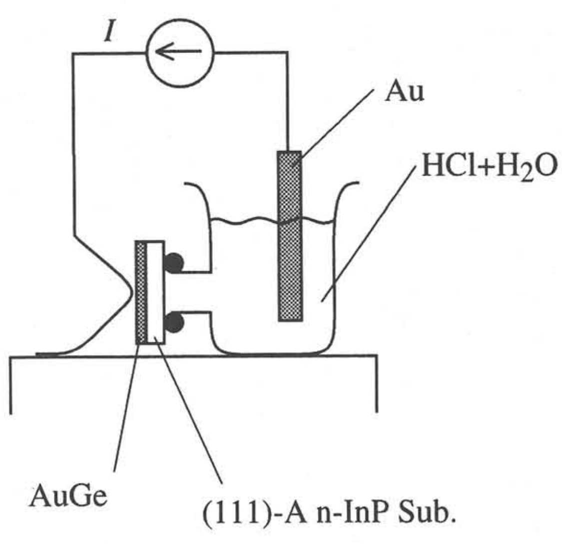
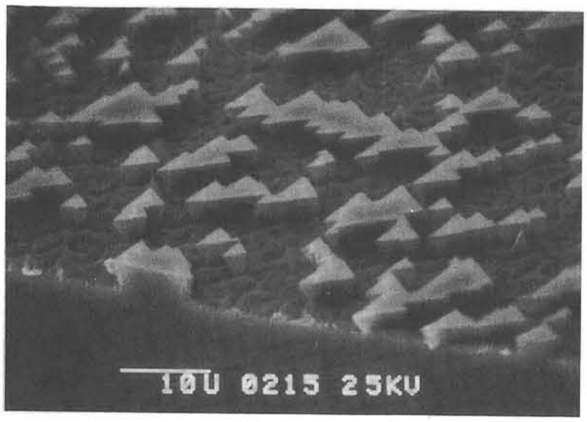
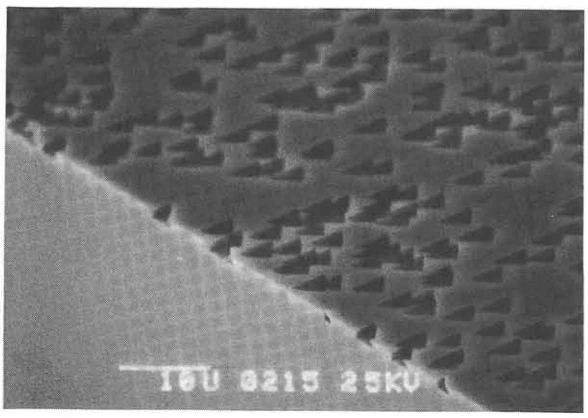


Fig. 1 Experimental setup of anodization etching of InP wafers[7]

Next we calculated 2D photonic band diagrams using a vector wave analysis.[9,10] In this analysis, the shape of triangular index poteintial was taken into account by the numerical Fourier transform the triangular shape. To verify the calculation program, we first calculated the diagram for a 2D structure with circular grids and the triangular lattice, as shown in Fig. 4. Here, a is the lattice constant, c is



(a)



(b)

Fig. 2 SEM views of (111)A n-InP substrate surface anodized with current density of (a) 45mA/cm^2 and (b) 15mA/cm^2. No etching masks were used.

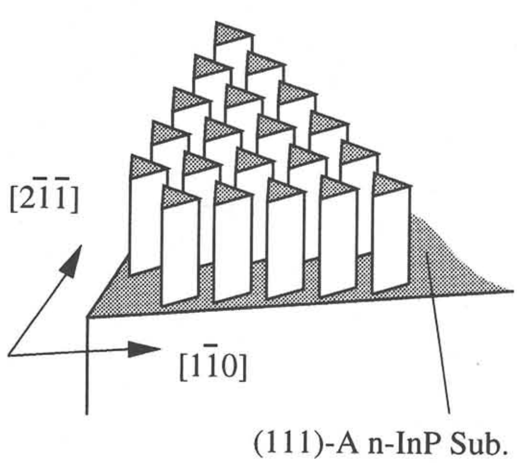


Fig. 3 Schematic structure of etched InP

the vacuum velocity of light, and the filling factor f of grids is assumed to be 0.907. One can see that dispersion curves are splitfor TE and TM waves. This implies the birefringence of the structure. As predicted in the previous report[7], the circular grids maintain an absolute photonic gap in which normalized optical frequency ω/c is absent around $2\pi/a$ for any wavenumber k. Although we calculated the diagram also for circular rods with various f, we could not find such absolute gap.

The calculation model simulating the triangular rods and grids is shown in Fig. 5. We considered the same triangular lattice as in Fig. 4 and two types of index potentials, Type I and II. They will be experimentally obtained by changing the orientation of the etching mask against the crystal orientation. Fig. 6 shows the diagram for Type I rods with $f = 0.275$. One can see the birefringence similar to the circular grid case. However, though the photonic gaps exist for both waves, they are not overlapping at a certain ω. We could not find the overlapping of the gaps for Type I and II with any f. Thus, this structure inhibits the propagation of either polarization or splits polarizations of incident wave, but cannot absolutely inhibit light emission.

In summary, we have proposed the anodization of InP as a low damage fabrication technique of 2D photonic band structure for lightwaves. From the band calculation, we found that the triangular rods formed by this technique have photonic gaps that can be used only for propagation control of incident wave. For the control of emission, the combination of electron quantum confinement in quantum-wells and optical quantum confinement in this structure will be effective.

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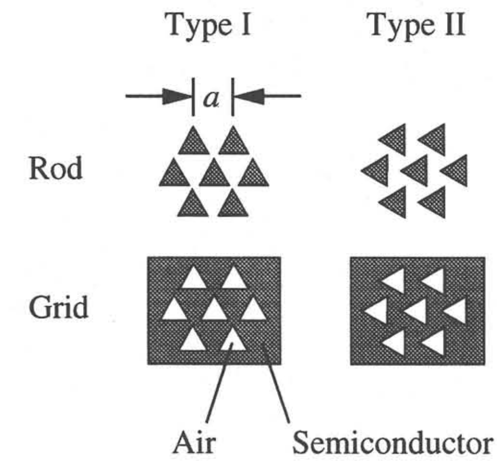

Fig. 5 Calculation model for 2D photonic band structure with triangular index potentials. Brillouin zone is same as described in Fig. 4

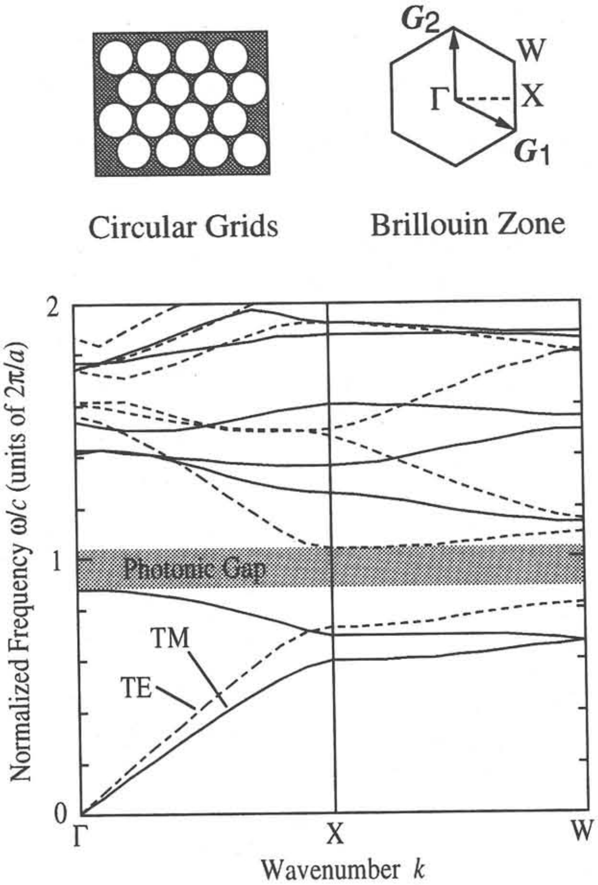

Fig. 4 Calculation model for 2D photonic band with triangular lattice and circular grids, and obtained band diagram.

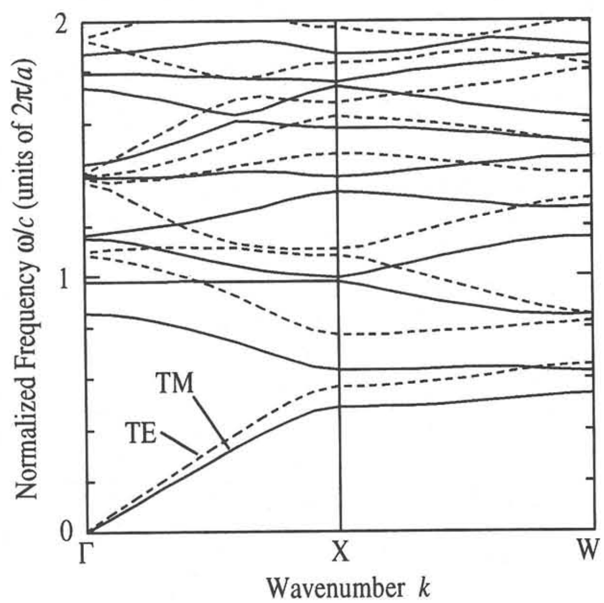

Fig. 6 Calculated band diagram for Type I triangular rods.