**분과초청IV1**

# 2차원 광자결정 레이저

# Two-Dimensional Photonic Crystal Lasers

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## ABSTRACT

Room-temperature continuous operation of two-dimensional photonic crystal lasers is achieved at 1.6 $\mu$m by using InGaAsP slab-waveguide triangular photonic crystal on top of wet-oxidized aluminum oxide.

The main difficulty in the realization of photonic bandgap (OBG) structures has been the nontrivial difficulties in nanofabrication, especially for 3-dimensional PBG structures. Recently, 2-D PBG structures have attracted a great deal of attention due to their simplicity in fabrication and theoretical study as compared to the three-dimensional counterparts [1]. Recently, air-guided 2-D slab PBG lasers were reported by Caltech group [2]. However, this air-slab structure is mechanically fragile and thermally unforgiving. Therefore, a new structure that can remove this thermal limitation is dearly sought after for 2-D PBG laser to have practical meaning. In this talk, we report room-temperature continuous operation of 2-D photonic bandgap lasers that are thermally and mechanically stable.

An electron micrograph of a wafer-fused photonic bandgap laser is shown in Fig. 1. The lattice constant is 450 nm and the radius of holes is ~135 nm. This 2D photonic bandgap laser is built on a thin InGaAsP slab waveguide structure. Strong optical confinement in vertical direction is provided by total internal reflection at high-index InGaAsP/low index Al2O3 (or air) interface. In the horizontal plane, 2D triangular photonic crystal mirrors are formed by drilling holes. To provide a low index layer below the high-index InGaAsP active material that has small surface recombination velocity, the AlAs (n=3.4) layer is wet-oxidized into $Al_2O_3$ (n=1.5) after the wafer fusion process. To locate the active layer near an anti-node of the slab, 100-nm thick layer is added on top of the active material which consists of six compressively strained (0.6%) InGaAsP quantum wells. The resultant thickness of slab is 320 nm, which supports a fundamental mode and one higher mode for TE polarization. For TM polarization, only one fundamental mode is allowed. The compressive strain at the quantum wells splits the heavy hole band and light hole band and the coupling to the TM mode is greatly discouraged. In the drilled region with $r/a$=0.3, a photonic bandgap for the TE-like polarization is found from 1395 to 1803 nm for a lattice constant of $a$=450 nm.

After the wafer fusion process between InGaAsP material on InP substrate and 100-nm thick $As_{0.98}Ga_{0.02}As$ on GaAs substrate, the InP substrate is removed by wet etching using HCl:H2O (4:1). Then the wafer fusion process the photonic crystal structure is patterned by electron beam lithography. Using Ar/$Cl_2$ chemically assisted ion beam etching techniques, we drilled the holes through the $As_{0.98}Ga_{0.02}As$ layer. Then, the $As_{0.98}Ga_{0.02}As$ layer is changed to $Al_2O_3$ by wet oxidation.

The laser cavities are optically pumped normal to the structure using a 980-nm InGaAs laser focused to a spot size of ~10 $\mu$m. Photoluminescence is collected from the top using the same optics used for pumping. The cavity has 21 un-drilled holes in diagonal direction. Room temperature CW lasing is observed with incident threshold power of 10 mW. Below and above threshold spectra are shown in Fig. 2. The lasing wavelength is 1604 nm with linewidth of ~0.35 nm (limited by the resolution of our spectrometer) and red-shifts at a rate of 1.2 nm/mW due to thermal effects. The surface emission profile changes from a featureless bright hexagon below threshold to a distinct lobed pattern as shown in Fig. 3(a) where the physical boundary of the cavity is indicated for reference. This pattern indicates that the 2D oscillation is highly directional in the plane and that the cavity resonance is sustained mainly by a pair of mirrors facing each other. Polarization measurement demonstrates clear polarization dependence above threshold as in Fig. 3(b).

We believe this simple and robust structure prepared by wafer fusion and wet-oxidation processes should be applicable to wide range of photonic bandgap structures.

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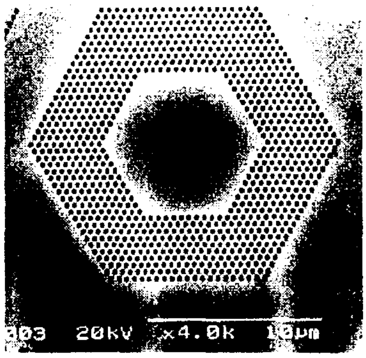

**Fig.** 1 SEM picture of photonic laser

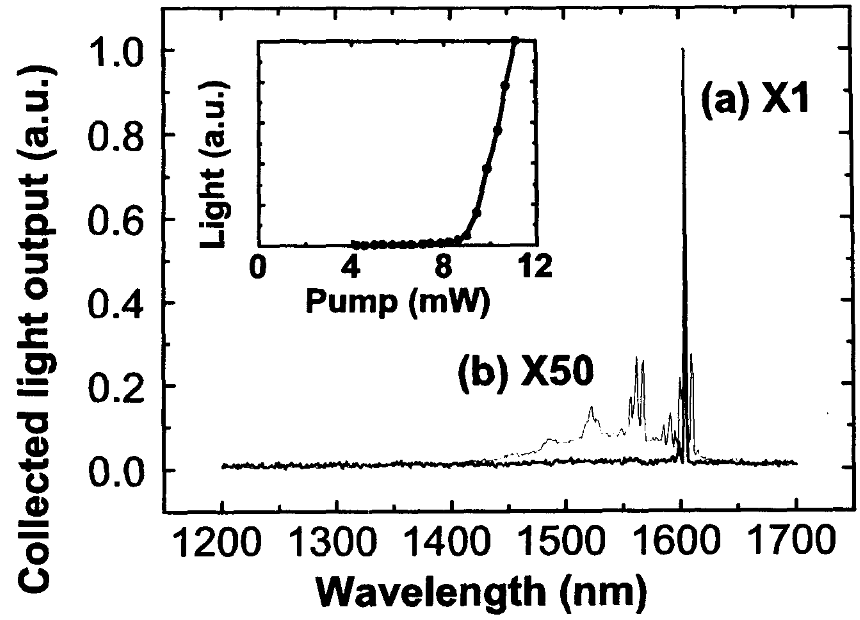

Fig. 2 (a) Above and (b) below threshold spectra and L-L curve (inset).

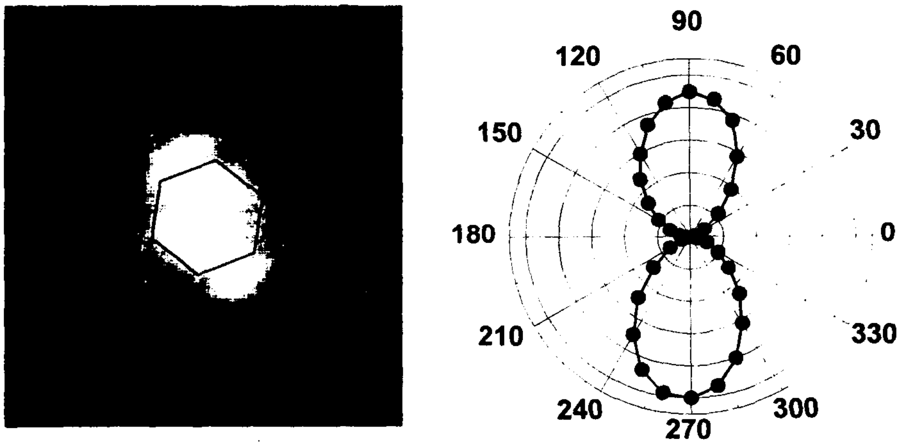

Fig.3 (a) Near field pattern of a PBG laser.
(b) Polarization characteristics.

## REFERENCES

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