

## Three-Dimensional Silicon Photonic Crystals

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### Abstract

In this work, we report the realization of a series of silicon 3D photonic crystals operating in the infrared (IR), mid-IR and most importantly the near-IR ( $\lambda=1-2\mu\text{m}$ ) wavelengths. The structure maintains its crystal symmetry throughout the entire 6-inches wafer and holds a complete photonic bandgap.

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A three-dimensional (3D) photonic crystal is an optical analogous of a semiconductor that is useful for controlling and manipulating the flow of light on a semiconductor chip. The realization of high efficiency sub- $\mu$ A edge-emitting-lasers [1], high speed tera-Hertz optical switches and the routing of optical signal in all three-dimensions are but a few benefits of 3D photonic crystals.

In this work [2], we report the realization of a series of silicon 3D photonic crystals operating in the infrared (IR), mid-IR and most importantly the near-IR ( $\lambda=1\text{-}2\mu\text{m}$ ) wavelengths. The structure maintains its crystal symmetry throughout the entire 6-inches wafer and holds a complete photonic bandgap. This demonstration opens the door for Si-based photonic crystal devices that is compatible with the well-developed Si microelectronics processes and is suitable for the large-scale photonic integration.

Our approach takes advantage of two recent breakthroughs. Firstly, a layer-stacking scheme is adopted to construct a 3D crystal for its design simplicity [3-5]. Secondly, a planarization process called Chemical-Mechanical-Polishing is recognized to be the key process for repetitive fabrication of layer structures that constitute the topology of a 3D photonic crystal. With these new approaches, silicon photonic crystal structures were successfully fabricated. A scanning-electron-microscopy image of such a layer-by-layer 3D photonic crystal built on silicon substrate is shown in Fig.1(a). The structure has a diamond lattice symmetry.

The transmission spectrum of light propagating along the  $\langle 001 \rangle$  direction of the 3D crystal, i.e. normal to the substrate, is shown in Fig.1(b) for both near-IR and IR photonic crystals. In the top panel, a strong transmittance dip is observed at  $\lambda=1.35$  to  $1.95\mu\text{m}$  for the near-IR crystal, suggesting the existence of a photonic bandgap in the optical  $\lambda$ . In the bottom panel, a similar transmission dip was observed at wavelengths  $\lambda=10\text{-}14.5\mu\text{m}$  for the IR photonic crystal.

Experimental results taken from a 3-D single mode cavity (with a modal volume of  $\sim 1\lambda^3$ ), thermal emissivity data and the modified spontaneous emission spectrum will also be described.

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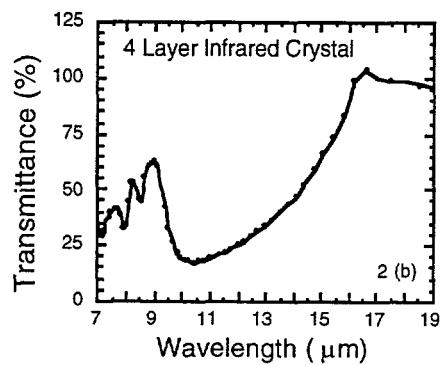
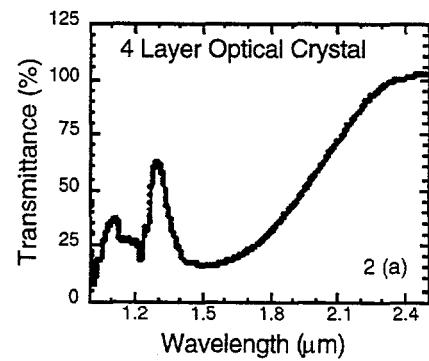
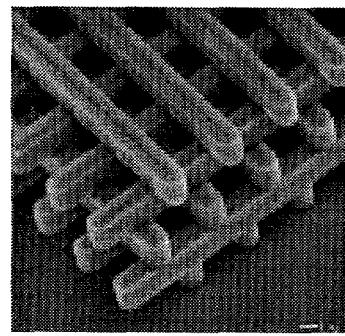


Fig.1 A SEM image of a 5-layer infrared 3D photonic crystal.

Fig.2 (a) Transmission spectrum taken from an optical 3D photonic crystal; 2 (b) spectrum taken from an infrared 3D photonic crystal.