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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 (λ=1-2μm) 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 manupulating the flow of light on a semiconductor chip. The realization of high efficiency sub-μA edge-emitting-lasers [1], high speed tera-Hertz optical switches and the routing of optical signal in all three-dimensions are but a few benifits 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 (λ=1-2μm) 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 adopt to construct a 3D crystal for its design simplicity [3-5]. Secondly, a planarization process call 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 sucessufully 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 <001> 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 λ=1.35 to 1.95μm for the near-IR crystal, suggesting the existence of a photonic bandgap in the optical λ. In the bottom panel, a similar transmission dip was observed at wavelengths λ=10-14.5μm 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.

References:

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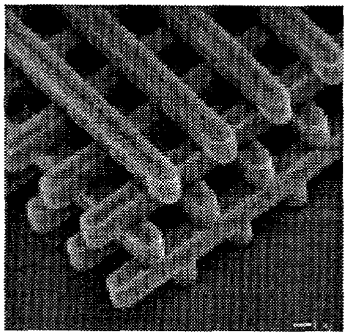

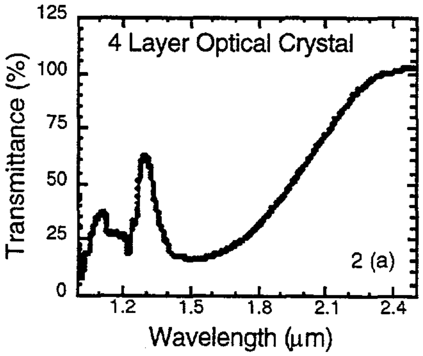
4 Layer Optical Crystal
Transmittance (%)
125
100
75
50
25
0
1.2
1.5
1.8
2.1
2.4
Wavelength (μm)
2 (a)

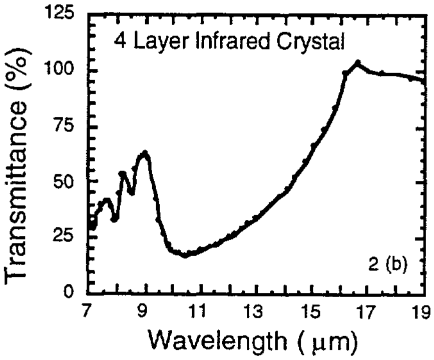
4 Layer Infrared Crystal
Transmittance (%)
125
100
75
50
25
0
7
9
11
13
15
17
19
Wavelength (μm)
2 (b)

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.