New Designer Dielectric Metamaterial with Isotropic Photonic Band Gap

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Abstract—A new designer dielectric metamaterial featuring an isotropic photonic bandgap at 1550 nm wavelength designed as a finite thickness, 220 nm thick 2d slab, is fabricated in a CMOS-compatible silicon-on-insulator process. This "hyperuniform disordered solid" (HUSD) is neither crystalline nor quasicrystalline.

Keywords—Photonic band gap; hyperuniform disordered solid; hyperuniform disordered structure; HUSD; metamaterial; silicon-on-insulator; photonic band gap

I. INTRODUCTION

Until recently, the only known photonic band gap structures were photonic crystal (PC) structures consisting of regularly repeating, orderly lattices of dielectric materials [1][2]; it was generally assumed that crystal order was essential to have photonic band gaps. This longstanding assumption is now known to be false. Whole new classes of photonic band gap (PBG) structures characterized by suppressed density fluctuations (hyperuniformity) have recently been invented [3][4]. One of these new classes includes disordered structures exhibit large photonic band gaps which are both complete and isotropic [4]. This means that light propagates the same way through these new PBG structures independent of direction – a feature which is impossible for a photonic crystal.

II. SUMMARY

This new kind of disordered designer dielectric leveraging hyperuniformity and exhibiting direction-independent photonic band gaps has, for the first time, been designed, fabricated, and tested for operation at optical wavelengths in the silicon-on-insulator material system. The hyperuniform disordered structures (HUSDs) were monolithically integrated with silicon photonics vertical couplers for chip-scale testing. Standard processes from the CMOS fabrication industry and an automated test system developed for wafer-scale testing of silicon photonics chips were used to demonstrate ease of manufacture and test.

As compared to periodic or quasi-periodic photonic band gap (PBG) devices in which waveguides must always be aligned along the crystal axes, the ability to orient HUSD waveguides in any direction on the wafer and with any bending angle improves layout flexibility. As well, since periodicity is not a requirement of the hyperuniform disordered structures, the manufacturing tolerance constraints so important to the commercial viability of PBG-based photonic integrated circuits are expected to be substantially relaxed with the use of HUSDs.

Compared to the use of conventionally-clad waveguide devices, the following two advantages of using photonic band gap based waveguide devices are well-known: smaller device size leading to improved density on the wafer, and the potential to make active devices capable of modulating light with less energy per bit [5][6][7][8].

III. DESIGN, FABRICATION, AND TEST

A two-dimensional “network of walls” HUSD was designed and dimensioned for operation and testing with TE polarized light in the 1550 nm wavelength range. The structure’s dimensions were scaled in accordance with the dielectric constant of its constituent silicon for a range of wall thicknesses predicted to provide photonic band gaps ranging from 0.15 eV to ~0.24 eV, corresponding to 30% of the 0.8 eV energy of a 1550 nm wavelength photon. In addition to parameterizing the effect of wall thickness on the band gap of the structure, tiles for testing several different kinds of waveguide channels as shown in the optical micrograph in Figure 2, were included along with other passive structures.

A key feature in the design-for-test was the planar integration of the HUSD test structures with silicon photonics waveguides and one or the other of several different kinds of vertical couplers requiring only a single mask layer, as shown in Figure 2 [9][10]. An e-beam lithography and inductively-coupled plasma RIE process that was originally developed for rapid prototyping of substantially larger-scale silicon photonics...
demonstrated that the vertical grating couplers were effective at coupling light into and out of the various HUDS test structures.

Comparing the optical transmission through HUDS of structures having 80 nm thick walls and those without channel filling in lattice holes with silicon arsenide photonic crystal cavity electro-optic modulator,” *Optics Express*, vol. 19, no. 8, pp. 1700-7536, 2011.


