Photoconductive Photonic Crystal Switch

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***Abstract*—We demonstrate a single-pole single-throw switch in W-band based on the optical illumination of a defect waveguide in a photonic crystal. Simulations show that an extinction ratio of greater than 40 dB between 89 and 101 GHz is possible. Measurements at 99 GHz confirm this extinction ratio.**

I. Introduction And Background

PHOTONIC crystals (PCs) can be used for the realization of a variety of components for communication systems such as waveguides, resonators and antennas [1]. The work presented here demonstrates the use of a high resistivity silicon (HRS) photonic crystal with a defect waveguide that can act as a millimeter-wave switch. The state of the switch is controlled by modulating the local conductivity of the silicon inside the defect waveguide through optical illumination.

II. Photonic Crystal Waveguide Design

The PC is formed from a triangular lattice of cylindrical air holes in a HRS substrate, which has previously been demonstrated to have a *TE*-like band-gap [2]. To create a band-gap in the 90 to 100 GHz range, a cylinder radius of 270 µm and a lattice constant of 900 µm is chosen for a 525 µm thick HRS substrate. A waveguide is created within the PC by omitting a row of holes (known as a W1 defect waveguide). To excite the PC W1 defect mode, 2.1 x 1.2 mm triangular tapers are introduced at the ends of the W1 waveguide, which protrude into a conventional WR-10 metal-pipe rectangular waveguide, as illustrated in Fig. 1.

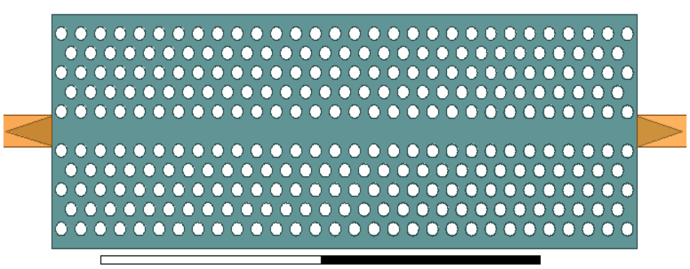

Fig. 1: Illustration of the photonic crystal with a W1 defect waveguide and triangular tapers protruding into WR-10 metal-pipe rectangular waveguides.

Simulated results of the PC across the WR-10 band were obtained using ANSYS® HFSS™ version 13.0. The HRS is modeled with ε_{reff}' = 11.64 and $tan\delta$ = 10^{-4} [3], the air cylinders are represented by a vacuum and the WR-10 waveguide walls as a perfect electrical conductor (PEC). The laser was modeled as a cluster of small spots on both sides of the W1 defect waveguide, producing a total illumination area of 2 mm^2 on both sides. The conductivity profile for this is taken from [4],[5], which had been simulated using the Silvaco™ 2D *Luminous* solver. The HFSS™ results in Fig. 2 show that the PC has a band gap from 85 to 105 GHz. Within this, the 2.1 mm W1 defect waveguide operates over the 88 to 98 GHz frequency range, having a predicted insertion loss of less than 1.5 dB across this band.

When the simulated laser illumination, having a wavelength of 808 nm and power density of 80 W/cm^2, is applied the insertion loss increases to over 44 dB. This represents a greater than 40 dB reduction in the power transmittance through the crystal.

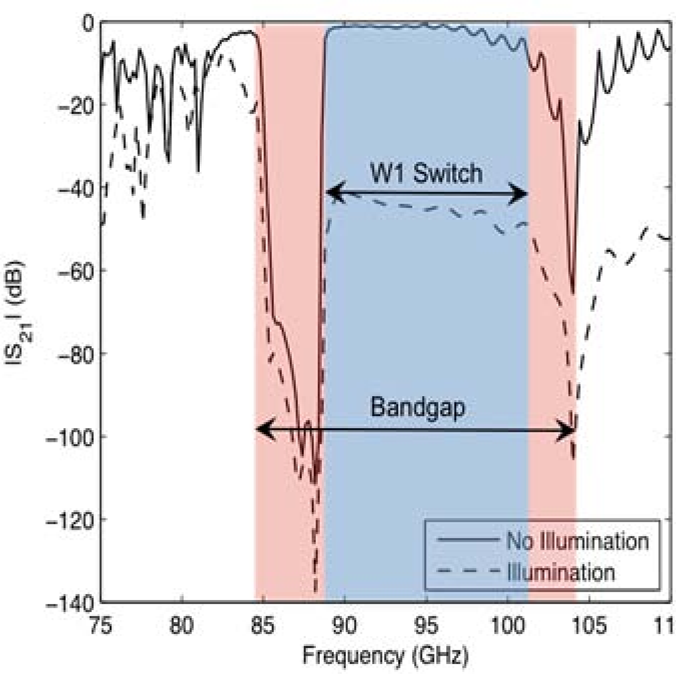

Fig. 2: Simulated results across W-Band for the switch in the 'ON' (no illumination) and 'OFF' (illuminated) states.

III. Measured Results

The PC was realized by bulk micromaching the design given in Fig. 1, into a 525 µm thick HRS wafer having a resistivity of greater than 10 kΩ.cm.

This was then measured using the setup shown in Fig. 3, which consisted of a 91.898 GHz Millitech GDM-10-0-17H WR10 Gunn diode source [6] and external isolator. The PC was inserted between the isolator and a Millitech DXP-10 Schottky barrier beam lead diode detector [6]. The PC is aligned so that it sits in the center of the rectangular

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waveguides, with the silicon coupling tapers protruding fully inside. The output of the detector is measured using a Marconi Instruments VSWR meter, having an internal variable attenuator. The laser illumination is provided by a pair of IPG Photonics PLD-33 laser diodes, which produce a spot diameter of ~1.5 mm on each side of the PC, as shown in Fig. 4.

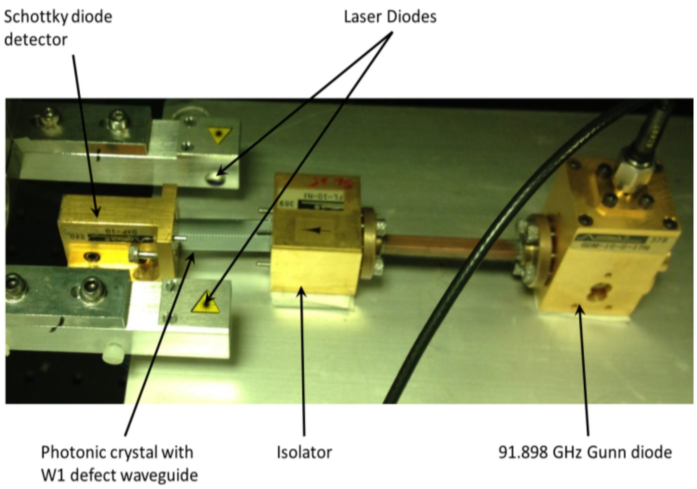

Fig. 3: Measurement setup

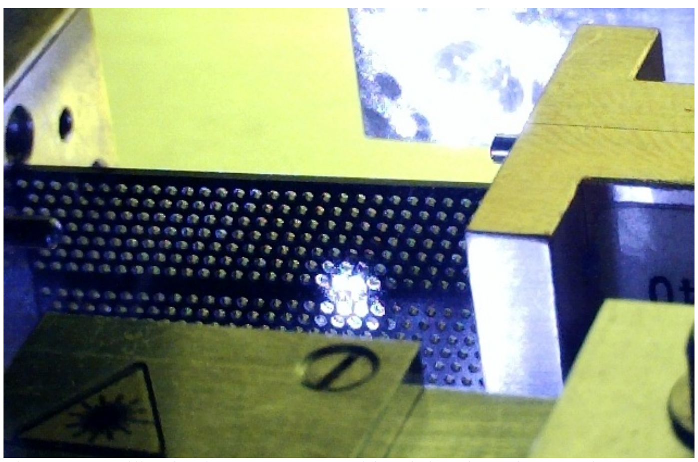
Fig. 4: Laser illumination spot on one side of the photonic crystal (as seen through an infrared/optical camera)

A reference for transmission measurements was established by removing the PC and connecting the isolator directly to the detector.

The laser current was swept from 0 to 1 A, to obtain the switching performance of the PC, with the measured results shown in Fig. 5. It can be seen that an extinction ratio of 40.1 dB exists between the ON and OFF states, which is in good agreement with the simulation data presented in Fig. 2. Fig. 5 also shows that the illuminating power required from the laser, to significantly switch the PC waveguide, is approximately a hundred milliwatts. It can be seen that as the laser power increases beyond this, the transmission drops further, as the local conductivity in the silicon increases further, but then saturates at -40.1 dB. This represents the background level of the other leakage radiation paths through the PC.

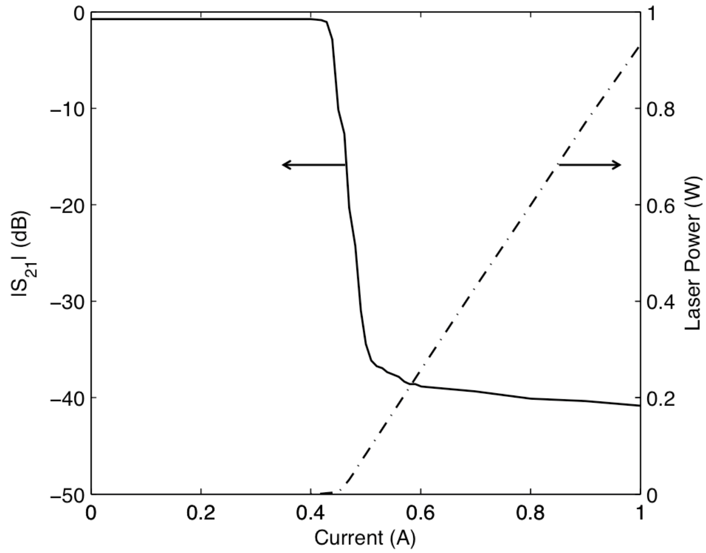

Fig. 5: Measured data showing how transmission through the W1 defect waveguide and laser power vary as the current through the laser increases.

IV. Conclusion

This works shows the potential for a photonic crystal switch based upon laser-induced photoconductivity. We have demonstrated both through simulations and measurements that a 40 dB extinction ratio can be achieved by double-sided illumination at only a single position along the W1 defect waveguide, with the prospect of large ratios if more positions are included. This offers the prospect of being able to implement higher performance switches and at greater frequencies of operation, which is currently perceived as a technological bottleneck in silicon integrated circuit technology.

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