Design and Fabrication of a 100 GHz Channel-Drop Filter

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Abstract— We have designed and are fabricating a novel passive mm-wave spectrometer based on a Photonic Band Gap (PBG) channel-drop filter (CDF). There is a need for a compact, wide-band, versatile and configurable mm-wave spectrometer for applications in mm-wave communications, radio astronomy, and radar receivers for remote sensing and nonproliferation. The CDF spectrometer was designed to operate in the frequency range of 90-130 GHz. We have manufactured a single proof-of-principle channel-drop filter. The manufacturing process involved etching the rods on a silicon wafer and then bonding them to metallic plates. The initial testing results for the filter will be presented here. Research is also underway to explore alternative configurations of the CDF, including one with metallic rods.

I. Introduction and Background

Performing the analysis of millimeter (mm) wave spectrum is essential for many applications in communications, radio astronomy, and radar receivers for remote sensing and non-proliferation [1]. It is desired that the mm-wave detection spectrometer be wide-band, compact, easy to operate, and configurable. The spectrometers which are currently available at mm-waves rely on one of the following concepts. It is either a heterodyne spectrometer, or a Fabri-Perot, or a more sophisticated mm-wave dispersive grating or a dispersive prism. The main disadvantage of the most popular heterodyne spectrometer is the noise which is introduced into the device by the mixer, and which reduces the sensitivity of the system. The Fabri-Perot system is hard to operate in real-life conditions, since it has to be tuned to determine the frequency of the incoming system. The quasi-optical systems, such as a dispersive grating or a prism, are bulky and employ a large array of detectors (100 detectors or more). Since space and aircraft systems are essentially purchased by the pound, this ultimately implies a higher system cost. We have proposed to employ a novel Photonic Band Gap (PBG) channel-drop filter (CDF) [2] for construction of a mm-wave spectrometer, which would satisfy all the above requirements.

The idea of a PBG CDF relies on the intrinsic property of PBG structures to filter frequencies. PBG structures are periodic structures of dielectric rods. PBG structures possess a band gap, which is a range of frequencies where the electromagnetic waves cannot propagate through the structure and are reflected. If a defect in the form of a different size rod is introduced into the structure, then a certain frequency in the middle of the band gap will be allowed to propagate. This property is exploited to create a channel drop filter.

II. Results

The PBG CDF consists of two parallel photonic crystal waveguides. The waveguides are the defects in a square lattice of rods in the form of rows of removed rods (see Fig. 1(a)). Regular metallic waveguides (for example, WR8 at 100 GHz) can be connected to PBG waveguides, and the power will transmit from one waveguide into another. The PBG waveguides are coupled by two micro-cavities. The cavities are formed by rods of varying diameters, which are different from the diameters of the rods in the overall structure. The power from the input waveguide will exit directly into the main output waveguide (Port 2 in Fig. 1(a)) at all the frequencies within the band gap except for the one supported by the micro-cavities. The frequency supported by the micro-cavities will resonate and couple into the separate output waveguides (Port 4 in Fig. 1(a)). The sample electric field pattern at the resonant frequency is shown in Fig. 1(b). The sample transmission characteristics of the CDF, namely the signals at Port 2 and Port 4, are shown in Fig. 1(c). The unwanted signal at Port 4 is 20 dB below the signal at the channeled resonant frequency. The channeled frequency can be tuned by adjusting the size of the rods at the center of the micro-cavities. Placing the detector at the output channel Port 4 provides an opportunity for detection of the frequency of interest.

If multiple CDFs with different frequencies are stacked in series then this system will act as a spectrometer. The spectrometer will determine if the unknown spectra contains the set of given frequencies. For example, in the framework of this project, we have designed a version of a PBG CDF spectrometer which can be employed for the detection of the spectra of methyl chloride. Methyl chloride (with Cl^{35}) exhibits three distinct spectral lines at mm-waves, at 237 GHz, 262 GHz, and 288 GHz at atmospheric pressure. The designed PBG CDF spectrometer consists of an input waveguide, main output waveguide, and three separate channel waveguides. Each separate channel waveguide interacts with the main waveguide by means of a filter representing two coupled resonant cavities in a PBG structure. The interaction is fine-tuned by adjusting the sizes of the coupling rods, so that the signal at each frequency of interest is totally coupled into the corresponding waveguide. The unknown spectra will be collected by an antenna and coupled into the main waveguide. The frequencies of 237 GHz, 262 GHz, and 288 GHz will be sampled by the detectors at the output waveguides. If a signal is detected at all three channels, then it can be concluded that the methyl chloride is present and produces the spectral lines.

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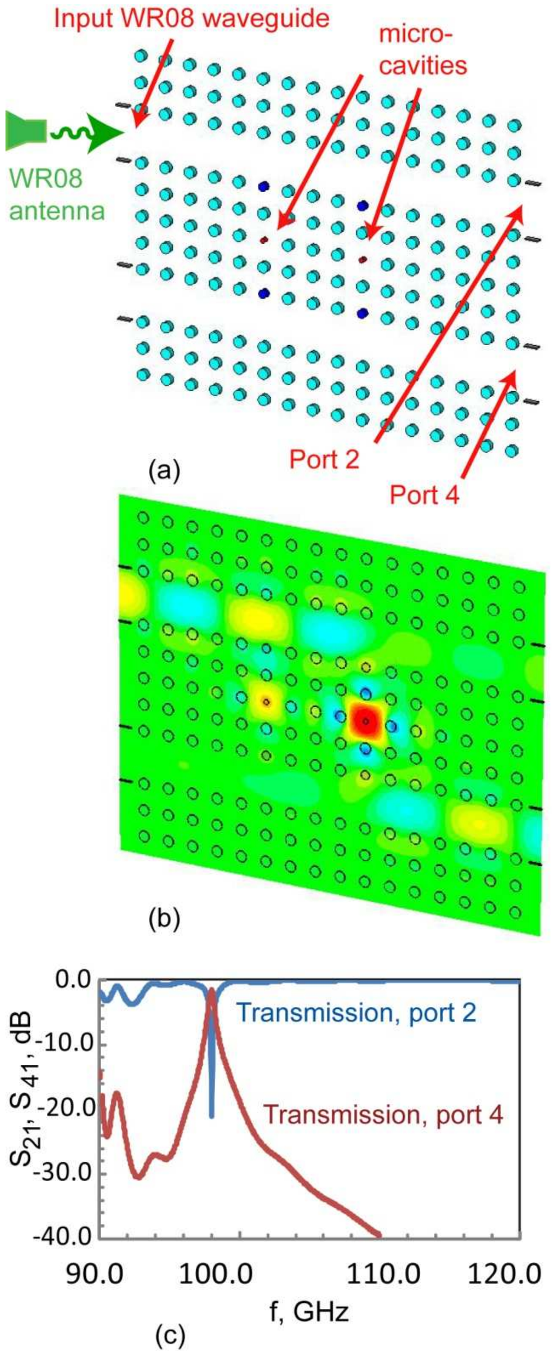

Fig. 1 The schematic of a channel-drop filter (a); the electric field pattern for a specific frequency which is being channeled into a separate output waveguide (Port 4) (b); transmission through the CDF into the main output (Port 2) and into the separate output channel (Port 4).

To develop the principles for fabrication of the CDFs at mm-waves and simplify the proof-of-principle experiment, we have designed a version of the PBG CDF spectrometer to operate at a frequency of 98.5 GHz. The transmission characteristics for this particular filter are shown in Fig 1(c).

III. Work in Progress

The channel-drop-filter designed to operate at 98.5 GHz is currently in fabrication. The rods are being etched on a 6 inch diameter, high-resistivity (resistivity of 1000 Ωcm) silicon wafer. Next, the rods will be bonded in between two metalized plates. We plan to test the filter in our mm-wave laboratory, determine the transmission characteristics and compare them to our simulation. The test results will be reported in the conference presentation.

We are also exploring the alternative configurations for a CDF at mm-waves, in particular one with metallic rods. The filter with metallic rods is conceptually easier to fabricate via conventional electroforming. However, metallic filters are more complicated from the design point of view, and we believe that there are certain drawbacks in the expected performance of the metallic filter. The main design difficulty comes from the fact that the metallic PBG resonators have much higher diffraction Q-factors than PBG resonators with similar configurations of dielectric rods. Therefore, the two resonant micro-cavities must be designed to operate at higher-order modes in order to achieve significant cross-talk between the two micro-cavities and also between the micro-cavities and the input and output waveguides (Fig. 2). As a consequence, manufacturing of the metallic CDFs requires higher tolerances than manufacturing of the dielectric structures. From the performance point of view, the main difficulty is relatively high ohmic losses in metals at mm-waves, which results in a small transmitted signal at the filtered frequency. We are exploring different configurations of micro-cavities operating at different higher-order modes which may help us mitigate the problem of losses.

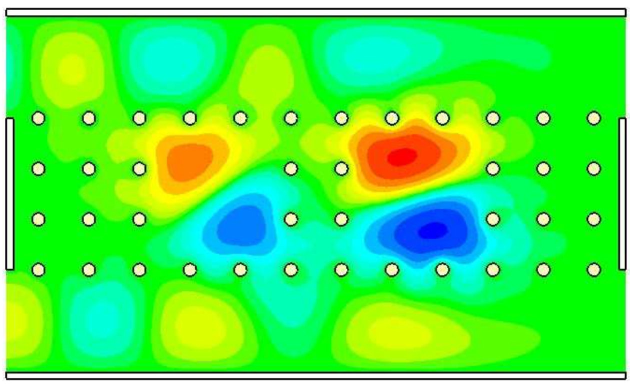

Fig. 2 The electric field pattern snap-shot in a channel-drop filter with metallic rods operating in a higher-order (the TM_{11}-like) mode.

References

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