An ultrawideband photonic crystal antenna

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Index Terms

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Non-controlled Indexing

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AN ULTRAWIDEBAND PHOTONIC CRYSTAL ANTENNA

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Abstract

We present the development of a novel ultrawideband antenna structure that uses photonic crystals as a substrate to reflect the energy normally trapped within a substrate into free space. Photonic crystals are three-dimensional periodic structures that exhibit spatial three-dimensional filter properties. In order to achieve an ultrawideband photonic crystal, two photonic crystals with different periodicities are stacked in tandem. The stop band of the photonic crystal is used as a distributed reflector of a short pulse that is generated at the surface of the crystal by photoconductively switched planar antennas.

Introduction

Photonic crystals (PCs) are three dimensional periodic structures that exhibit pass and stop bands in their frequency response.[1] In the most general case, the PC can be fabricated using any host material that can be made to have a spatial periodicity on the order of the wavelength. For example, the original PCs were fabricated by drilling periodically spaced air holes in a host dielectric. [2] Typically, the stop band width is approximately 20% of the center frequency. For applications as an ultrawideband antenna substrate, where ultrawideband (UWB) is defined as bandwidths exceeding 25% of the center frequency,[3] a single periodicity air/dielectric PC cannot cover the entire bandwidth. Currently, PCs are being fabricated using dielectrics and placing metal spheres at the periodic lattice sites to increase the bandwidth of the stop bands beyond 25%.[4] In the work described in this paper, the focus is on PCs fabricated with air holes embedded in a dielectric host.[5] The UWB-PC is achieved by stacking two PCs with different periodicities in tandem.[6] The overall response is the superposition of the component responses in given directions.

Recently, Brown, *et. al.* showed that one application of PCs is their use as efficient substrates for narrowband antennas.[7] A standard narrowband antenna printed on a substrate radiates a fair amount of energy into the substrate.[8] Because the periodicity in the PC provides a

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region in space where the wave impinging on the crystal is reflected, the energy radiated into the substrate is reflected into free space. This will only occur when the excitation frequency overlaps in frequency with the stop band of the PC. For narrowband antenna structures, the overlap of the stop band with the excitation frequency is easily achieved (typically stop band widths are 20% of the center frequency). The challenge of the problem addressed in this work is extending the narrowband antenna concept to UWB antennas.

Experimental Set-up

The UWB bursts of electromagnetic energy are generated using photoconductively switched planar antennas.[9] The optical pulse train is derived from a 76 MHz repetition rate, mode-locked titanium-sapphire laser operating at a wavelength of approximately 730 nm, which generates pulses on the order of 0.2 psec. The optical pulse is focused between two coplanar lines, which are printed on a low-temperature-grown gallium arsenide (LTG-GaAs) substrate, to locally generate electron/hole pairs. The recombination time in the LTG-GaAs substrate is short (~0.7 psec), therefore the current pulse generated on the coplanar lines is short, providing a large, instantaneous bandwidth. The coplanar lines then feed an exponentially tapered, coplanar horn antenna. Conventionally, these antennas are used as a traveling wave antenna, where the photoconductively generated current pulse propagates down the transmission line and radiates from the horn in an endfire configuration. In this work, although the transmitter and receiver are identical structures, the transmitter is placed at an angle to the receiver. The photoconductively generated electrical pulse at the surface of the LTG-GaAs transmitter will act as a current source which radiates into the substrate and away from the substrate colinear with the direction of the optical beam, as shown in Figure 1.[10] On the other hand, the receiver is used as an endfire antenna in the standard configuration. The antennas are placed in a pump/probe configuration to maximize the energy through the LTG-GaAs substrate propagating away from the receiver. When a PC backing is used, the energy will be redirected towards the receiver. The measurements are done directly in the time domain so that the interaction between the electromagnetic pulse and the PC substrate can be measured.

A detailed description of the fabrication process of the PC can be found in Ref. [5]. The two crystals fabricated in this work had a plate thickness of 0.25" (L-crystal) and 0.225" (M-crystal), respectively. The frequency responses of the PCs are shown in Figure 2. Figure 2(a) is the L-crystal and Figure 2(b) is the M-crystal. The stop band is the region where the transmission is reduced. For example, in Figure 2(a), the region between 16 and 19 GHz is called a stop band.

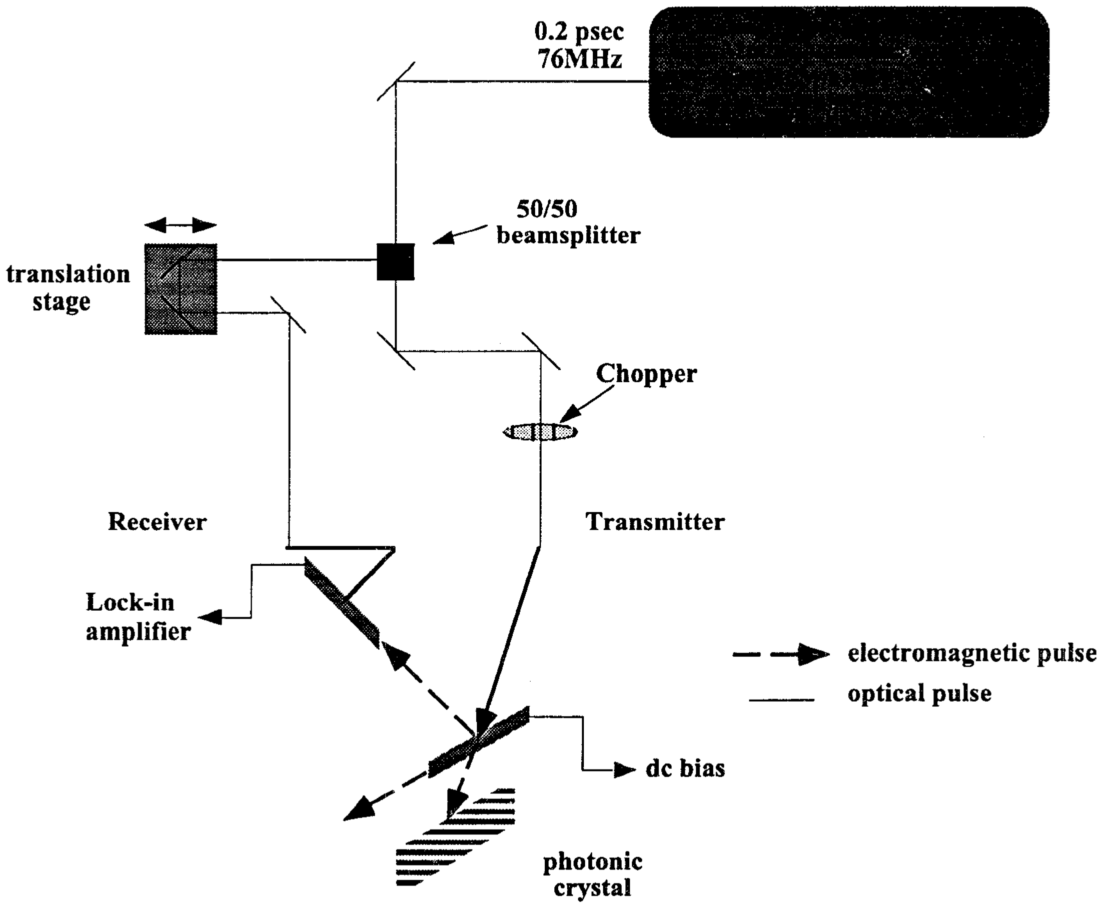

Figure 1. Experimental set-up used to photoconductively generate UWB electromagnetic bursts of energy. The transmitter is used in a broadside configuration to determine the effects of placing a substrate near the transmitter to reflect the energy that is radiated through the LTG-GaAs substrate.

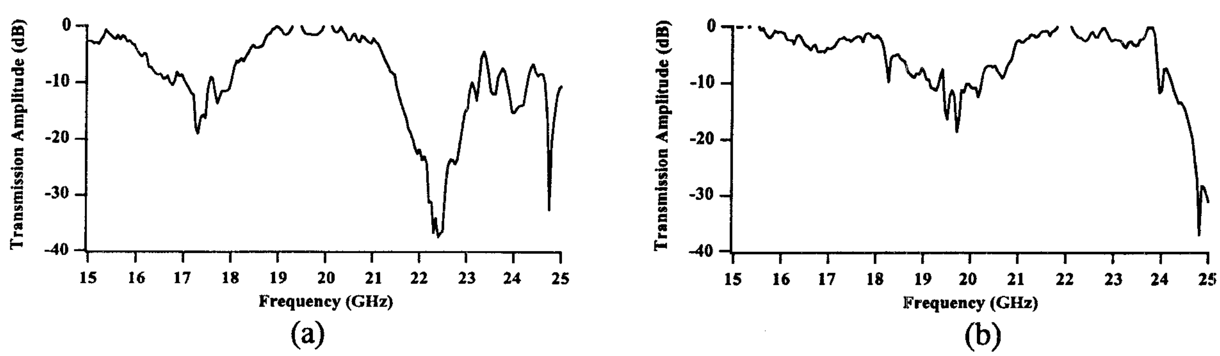

Figure 2. Frequency response of the component crystals in the UWB-PC. (a) The frequency response of the L-crystal and (b) the response of the M-crystal The measurements are performed using a network analyzer sweeping from 15 to 25 GHz. The UWB-PC response is the superposition of the individual crystal responses.

Results

A measurement is taken without a substrate to determine the effects of the LTG-GaAs substrate on the electromagnetic pulse. As expected, the response in the time domain is the superposition of multiple reflections between the front and back faces of the LTG-GaAs substrate, shown in Figure 3 as the solid line. In order to understand the effects of the PC backing, the PCs were placed 1 cm away, parallel to the face of the LTG-GaAs substrate as shown in Figure 1. The results of the PC substrate are shown in Figure 3. The solid line is the reference (no PC backing), the dashed line is the M-crystal-backed antenna and the markers are the response of the L-crystal-backed antenna. For the first 100 psec in Figure 3 (Region I), the response without the PC, the M-crystal-backed and L-crystal-backed responses are identical. This is the transit time of the pulse from the generation point to the PC and back towards the receiver. After 100 psec, the L-crystal and M-crystal responses remain the same for another 100 psec (Region II). Recent experiments have shown that the reflection of a pulse from a PC has two components.[11] The first component is a replica of the input pulse which reflects from the air/PC interface. The second component is the multiple reflections in the PC due to the periodicity of the structure. A similar response is seen here. The periodicity in the different PCs does not contribute to the response until approximately 200 psec (Region III), where the L-crystal and M-crystal responses deviate from one another. Note that for the PC-backed response (both M-crystal and L-crystal), the signal in the time domain increases in the late time response due to the reflection of the energy from the stop bands of the respective PCs.

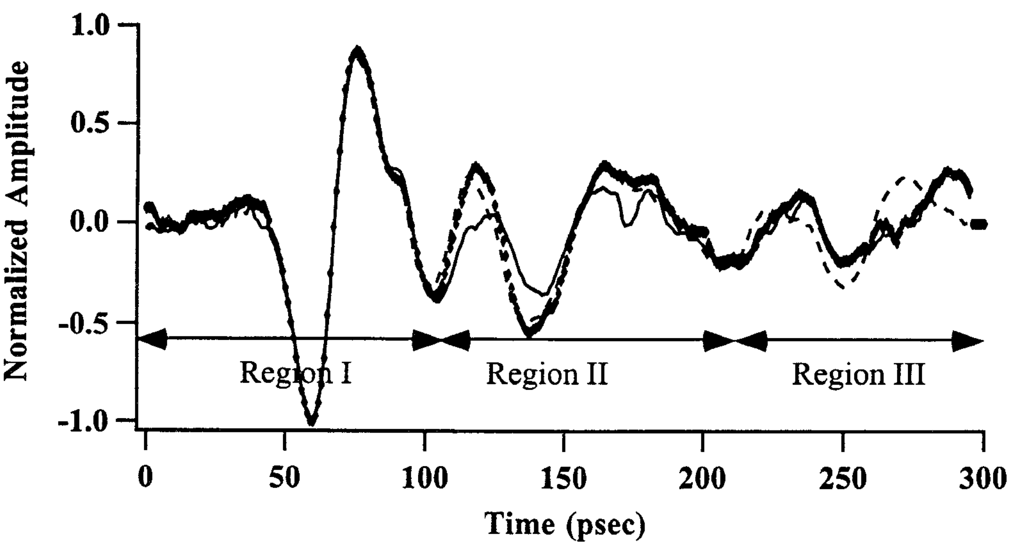

Figure 3. Response of the antenna with the PC placed 1 cm away from the LTG-GaAs substrate. The solid line is the reference response without the crystal. The dashed line is the M-crystal response and the markers are the L-crystal response. Region I corresponds to the transit time of the pulse through the LTG-GaAs substrate to the PC interface. Region II corresponds to the first component of reflection from the PC/air interface. Region III is the contribution of the periodicity of the respective PCs.

In order to make a practical antenna, the PC substrate is moved so that it is in intimate contact with the LTG-GaAs substrate. Sample results for the M-crystal are shown in Figure 4. The solid line is the reference pulse and the dotted line is the response with the M-crystal. Note that the amplitude peak in the M-crystal response is increased. This is understood if the M-crystal backing is a better impedence match to the LTG-GaAs substrate. The reference pulse is comprised of multiple reflections between the faces. With the M-crystal-backed structure, the top face is still an air-GaAs interface; however, the other face is a GaAs-PC interface. Because the M-crystal is a better impedence match, the energy propagates more readily into the M-crystal where the periodicity can come into play and redirect the energy towards the receiver. Once again the response of the reference and the M-crystal backed structure remain the same up to approximately 120 psec. This corresponds to the time it takes for the pulse to traverse the LTG-GaAs substrate (Region I). As in the previous case, once the wave interacts with the PC, the amplitude of the response increases due to the reflection of the energy from the stop band of the PC (Region II).

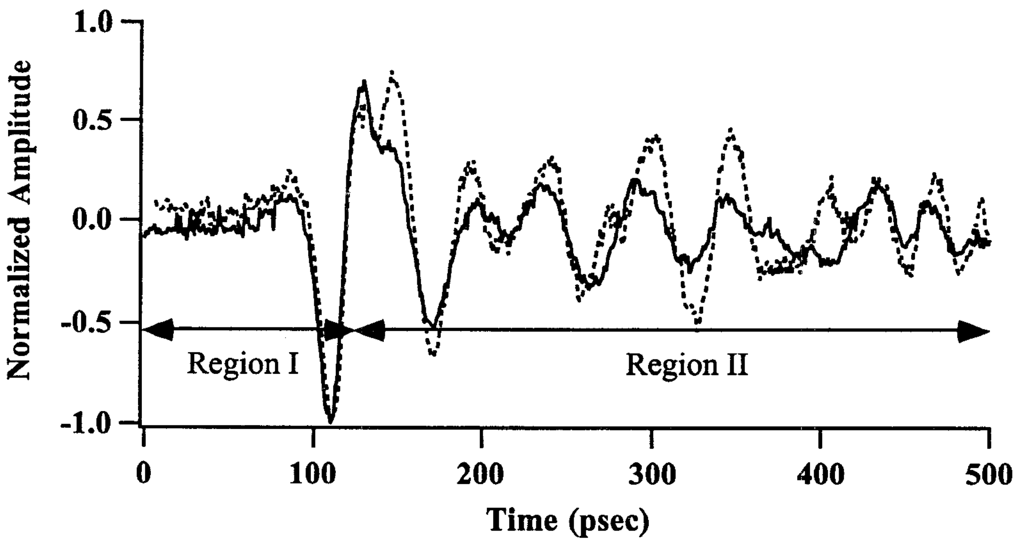

Figure 4. Response of the antenna that is in intimate contact with the M-crystal. The solid line is the reference and the dotted line is the M-crystal backed response. Region I is the pulse traversing through the LTG-GaAs substrate and Region II is the PC contribution.

Conclusions

Photoconductively switched antennas are used to generate a UWB electromagnetic pulse. Photonic crystals are used to redirect energy that would normally be radiated away towards the receiver. By placing the PC 1 cm away from the antennas, the time domain interaction of the waves with the PC is shown. Experiments were also performed with the PC in intimate contact with the substrate of the antenna. These measurements indicate that the PC acts as an effective backing for antennas.

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