Highly Birefringent Terahertz Plastic Photonic Crystal Fibers

Y. Han, M. Cho, J. Kim, H. Park, E. Jung, K. Moon, and H. Han
Department of Electrical and Computer Engineering, Pohang University of Science and Technology,
Pohang 790-784, Korea

***Abstract*— Guided-wave propagation of sub-ps terahertz (THz) pulses in a highly birefringent plastic photonic crystal fiber (PPCF) was studied by using a THz time domain spectroscopy technique. The fabricated THz PPCFs exhibit an extremely large birefringence of ~ 2.1×10^{-2}, which is almost one order of magnitude larger than that of previously reported PCFs.**

I. INTRODUCTION

PHOTONIC crystal fibers (PCFs) have engendered growing interest over the past few years since they offer the opportunity to fabricate optical waveguides with enhanced linear and nonlinear optical properties[1]. A typical PCF consists of a guiding core and a periodic cladding region[2]. PCFs with the high index cores guide the light by the total internal reflection while those with the low refractive index defects guide the light by the photonic bandgap (PBG) effect. The conventional polarization-maintaining (PM) fibers have a modal birefringence by applying mechanical stress to the core region. It has been reported that due to the intrinsically large index contrast, the PCFs can have much higher birefringence than the conventional PM fibers[3-4]. Recently, PM PCFs have been fabricated and have yielded a birefringence as high as ~ 3.9×10^{-3} at ~ 1.55 μm[3].

The recent progress in terahertz (THz) technology has attracted much attention in THz waveguides such as metallic waveguides, plastic ribbons, dielectric fibers, photonic crystal fibers, and metallic wires. Among these waveguides, we are interested especially in THz photonic crystal fibers since they have mode properties useful for short pulse, broadband THz systems, such as broadband single-mode operation, anomalous dispersion, and large mode area, as already demonstrated for PCFs at optical frequencies.

In this work, we demonstrate the fabrication of the highly birefringent plastic photonic crystal fiber (PPCF). We show that the fabricated THz PPCFs have extremely strong birefringence, almost one order of magnitude larger than that of the previously reported PCFs.

II. RESULTS AND DISCUSSION

The PPCF was fabricated by using high density polyethylene (HDPE) tubes[4-6]. The lattice constant of the PPCF was 500 μm, and the tube thickness was 50 μm, which corresponds to an air filling factor of 0.673. At the center of the triangular lattice structure, two solid HDPE filaments were inserted to create a highly asymmetric refractive index defect. The optical micrograph of a fabricated PPCF is shown in Fig. 1.

Since the PPCF has the large air hole with high index contrast, it is crucial to use a rigorous model for the field calculation[7]. Since the input THz pulse in the experiment is a fundamental Gaussian beam and the two lowest order guided modes in the PPCF are symmetrical along the x or y axes, the input THz pulse is coupled predominantly to the first or second guided modes, depending on the polarization of the input THz pulse. Therefore the fabricated PM PPCF exhibits broadband single mode propagation. At high frequencies, the THz field is highly confined in the defects, and the field distributions for the two polarizations become almost identical.

The temporal shapes of the THz pulses for two different polarizations after transmitting through a 2 cm-long PPCF are shown in Fig. 2. The inset in Fig. 2(a) shows the input THz pulse which was measured by removing the PPCF and by moving two silicon lenses to back-to-back position. The dot and solid lines indicate the measured and calculated results, respectively. The temporal width of the input pulse was measured to be ~ 0.8 ps (FWHM). As can be seen in the figure, the incident THz pulses are chirped to ~ 6 ps (FWHM) after transmitting through the PPCF for both polarizations. However, the two polarization modes have different propagation constants, showing a relative time delay of ~ 460 fs in the peak position. The material dispersion of the HDPE contributed very little to the total dispersion of the PPCF. The theoretical curve was obtained assuming the single fundamental guided mode per polarization where a frequency-independent refractive index is 1.5. The theoretical results are in good agreement with the experiments.

From the measured and the calculated spectra, the power attenuation constant was estimated to be ~ 0.5 and 4 dB/cm at 0.3 and 1 THz, respectively. In general the low attenuation in the PPCF is limited by the material absorption of HDPE. Depending on the amount of impurities incorporated during the manufacturing process, the HDPE has been shown to have an absorption coefficient as small as ~ 1.5 dB/cm at 1 THz. The absorption-limited attenuation in the PPCF can be further reduced by using better HDPE and improved fabrication technique[8].

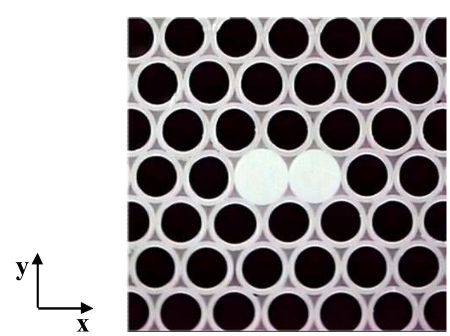

Fig. 1. Optical micrograph of a birefringent plastic photonic crystal fiber.

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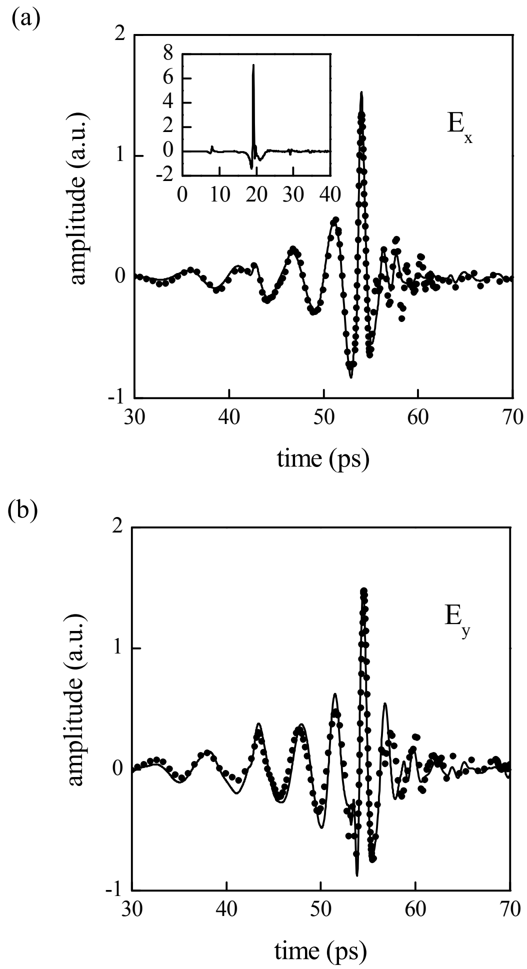

Fig. 2. Measured (dots) and calculated (solid line) THz pulses after propagating through a 2 cm-long PM PPCF. (a) x-polarization (b) y-polarization.

The effective index of the PPCF was obtained from the amplitude and phase spectra of the measured THz pulses. At the high frequency limit, the effective indices approach the refractive index of the HDPE core (n = 1.5) while at the low frequency limit they approach that of the cladding ($n_c = 1.163$) as expected. The measured effective indices of the two polarization modes are 1.296 and 1.275 at 0.3 THz, corresponding to a peak birefringence of 0.021, which is almost one order of magnitude larger than that of the previously reported PCFs at optical frequencies. The polarization mode dispersion has a maximum of ~ 70 ps/m at 0.3 THz, and it vanishes in both high and low frequency limits. The zero group velocity dispersion occurs at ~ 0.5 THz for both polarizations.

In summary, we have experimentally demonstrated highly birefringent PPCFs at THz frequencies. It is expected that these highly birefringent THz PPCFs may find their applications in polarization-sensitive devices such as polarization controllers, filters, and isolators at THz frequencies.

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