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Evaluating optical properties of real photonic crystal fibers with compressed sensing based on non-subsampled contourlet transform

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Abstract: A real photonic crystal fibers (PCFs) evaluation approach based on compressed sensing with non-subsampled contourlet transform (NSCT) and the total variation model is proposed for modeling optical properties of the real PCFs. The classical images of a commercial large mode area PCF and polarization-maintaining PCF are used to verify the effectiveness of the proposed method. Experimental results demonstrate that the cross section images of real PCFs are rebuilt effectively by using only 36% image data for evaluating the optical properties with the same accuracy as by 100% data. To the best of our knowledge, this is the instance of applying the compressed sensing with the NSCT and total variation to reconstruct the cross section images of PCFs for quickly evaluating the optical properties of real PCFs without the requirement of long fiber samples and expensive measurement apparatuses.

Keywords: non-subsampled contourlet transform (NSCT); photonic crystal fiber; compressed sensing; optical properties

1. Introduction[1]

Photonic crystal fibers (PCFs) have the advantages of novel optical properties and flexible structures [1]. Various PCFs with unique optical properties are developed for fiber device, optical communication, fiber sensor, and so on [2-4]. The accurate evaluation of optical properties is very important for the application of PCFs [5-7].

Generally, the optical properties of PCFs can be evaluated by the direct method and indirect method. The direct method requires long samples and expensive measurement apparatuses. Therefore several indirect methods are reported to evaluate optical properties of real PCFs and to assist in the fabrication of PCFs in the initial stage. Fokoua proposed an indirect method to evaluate optical properties of PCFs by extracting the coordinates of cross sections of PCFs [8, 9]. Wang [10] built a low-coherence interferometry to measure the group velocity dispersion of three kinds of hollow-core photonic bandgap fibers (HC-PBGFs) indirectly. Napoerala et al. extracted the fiber structure from the electron microscope image and then used the finite difference method to evaluate the optical properties of their fabricated PCFs [11]. This indirect method, which rebuilt the geometry of PCFs and utilized the theoretical analysis model to obtain the fiber properties, has the advantages of low cost, wide applicability, and capability for rapidly evaluating fiber properties.

Our group has proposed an indirect method to evaluate optical properties of real PCFs. The method combines the digital image processing technique and full-vector finite element method (FEM) [12-14]. The results obtained are in accordance with the direct measurement results.

During the fabrication of PCFs, we need to sample multiple cross sections of PCFs and evaluate the optical properties of the PCFs sample to determine whether it is in accordance with the design. The evaluating results can be used to adjust the fabrication parameters and determine the uniformity of the PCFs sample [12]. This process will generate many cross section images of PCFs. It is very important to reconstruct the cross section images and then evaluate the optical properties rapidly with small amount of image data.

Compressed sensing (CS) is a new sampling theory only requiring a small amount of data via a tractable convex optimization approach [15-16]. If we want to use CS to reconstruct the cross section images of PCFs by a small amount of cross section data with sound reconstruction quality, we need to find a much sparser representation of the image and meanwhile preserve the detailed shape of the image. The conventional Fourier and wavelet transform of the image cannot give the sparsest representation and can only give three directions of the decomposition of the image. However, for a certain image, the non-subsampled contourlet transform (NSCT) offers a much sparser representation than the Fourier and wavelet transform do [17]. Furthermore, NSCT is an effective representation for the images with contour shapes and keeps the image features with multi-scales and multi-directions. NSCT has the property of shift-invariant that preserves the detailed information of images in different directions, and thus overcomes the shift-variant of the contourlet transform, which introduces the artifacts during the decomposition and reconstruction process. Therefore, NSCT is a relatively preferable representation for the cross section images of PCFs which include some regular circle shapes.

In this paper, we propose an evaluation method of optical properties of PCFs with NSCT-based compressed sensing for reconstructing the cross sections of PCFs with relatively less data and meanwhile preserving the edge detail information of cross section images of PCFs. There is still some noise in the cross section images of PCFs although rebuilt by NSCT-based CS.

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