Numerical modeling of a fiber-optic acoustic emission sensor in composite materials

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Abstract

Numerical modeling of a fiber-optic acoustic emission sensor is performed in this work. The finite element method is used to calculate the deformation field of the core and cladding of a quartz fiber under the influence of an acoustic field created by an acoustic emission source in a multilayer composite material. The influence of the parameters of the cladding of an optical fiber on the value of the deformation response of its core has been studied. The values of the material parameters of the fiber cladding are found to increase the specific sensitivity of the sensor by more than two times.

Introduction

Currently, more and more composite materials are used, for example, based on carbon fibers. Acoustic emission can serve as a good diagnostic sign of early detection of irreversible deformations of structural elements. Attempts are being made to create fiber-optic acoustic emission sensors, since optical fiber can be embedded inside the composite material at the manufacturing stage. The use of a fiber sensor based on a coil with a large cylindrical working body is not suitable for insertion into a composite material, since this will greatly degrade the strength characteristics of the manufactured part. Therefore, there is a need to study a fiber-optic sensor in which there is no coil with a working fluid. To do this, it is necessary to study in detail the point sensitivity of an optical fiber to acoustic impact. For this purpose, in the present work, an estimate was made of the optical response of the fiber based on the calculation of the core deformation under the action of an acoustic wave given by a point source.

Model

The optical sensor model is defined as a set of layers of a composite medium and an optical fiber with a cladding. The 2D analysis model is divided into two regions, each of which is considered a separate physical analysis module of Comsol Multiphysics. In the first region, the acoustic field is calculated, which is set by a point source, indicated in Figure 1. The material characteristics of the layer are set by only two parameters: density and speed of sound. In the second region, the displacement field is calculated, in which the source is given by the acoustic field at the interface between the regions. The material characteristics of the layers are set by the parameters: Young's modulus (E) and Poisson's ratio (nu). The calculation is performed for various parameters E of the shell layer. The calculation was used in the frequency domain, with a set of frequencies 50-250 kHz.

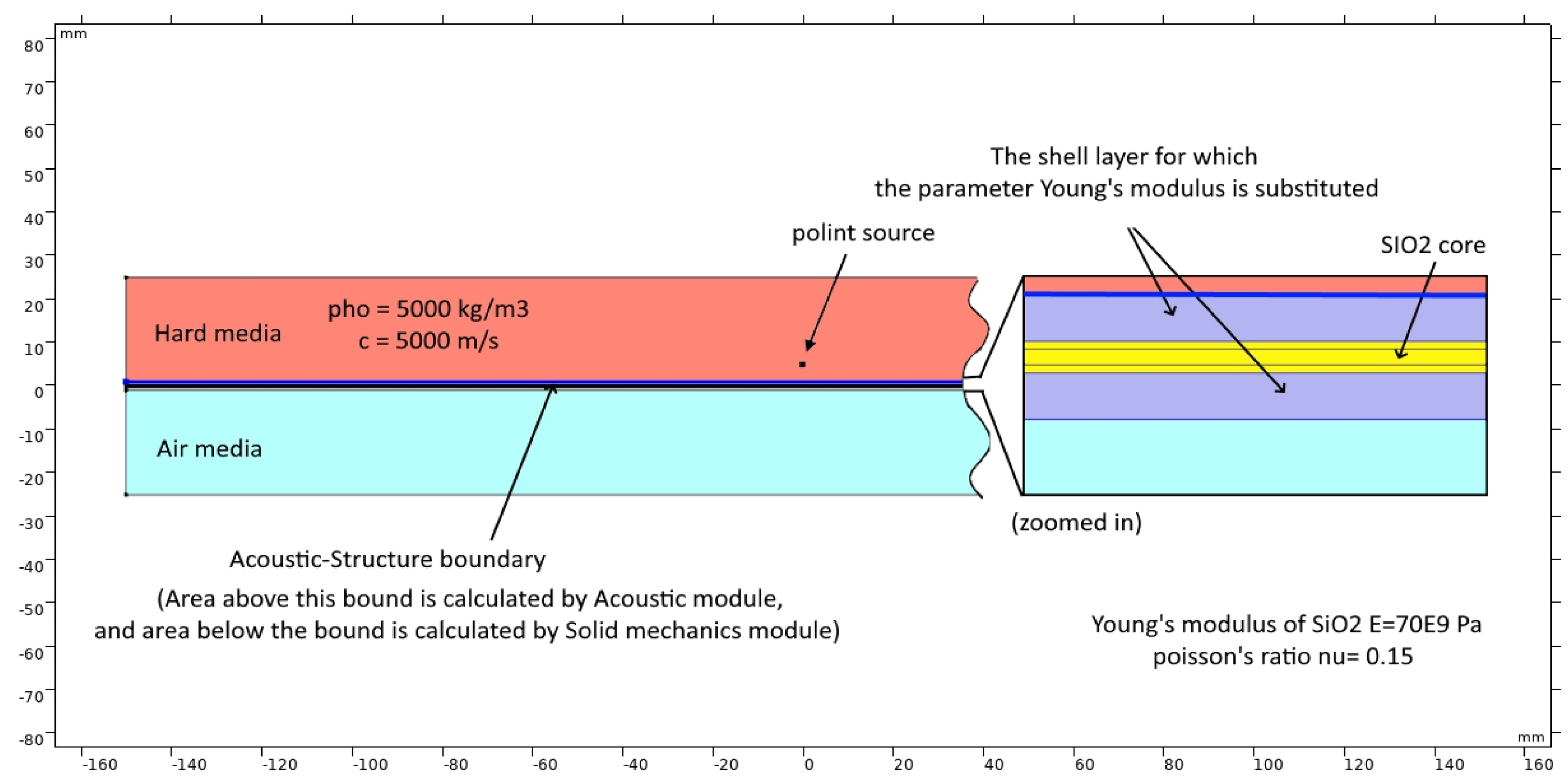

Fig 1. Geometry of the calculation model. The arrangement of the layers is shown. On top is a layer of dense composite material. Further, an optical fiber consisting of a core and a cladding, as well as a surrounding cladding with different values of the parameter E. The lower layer is air media

Results and discussion

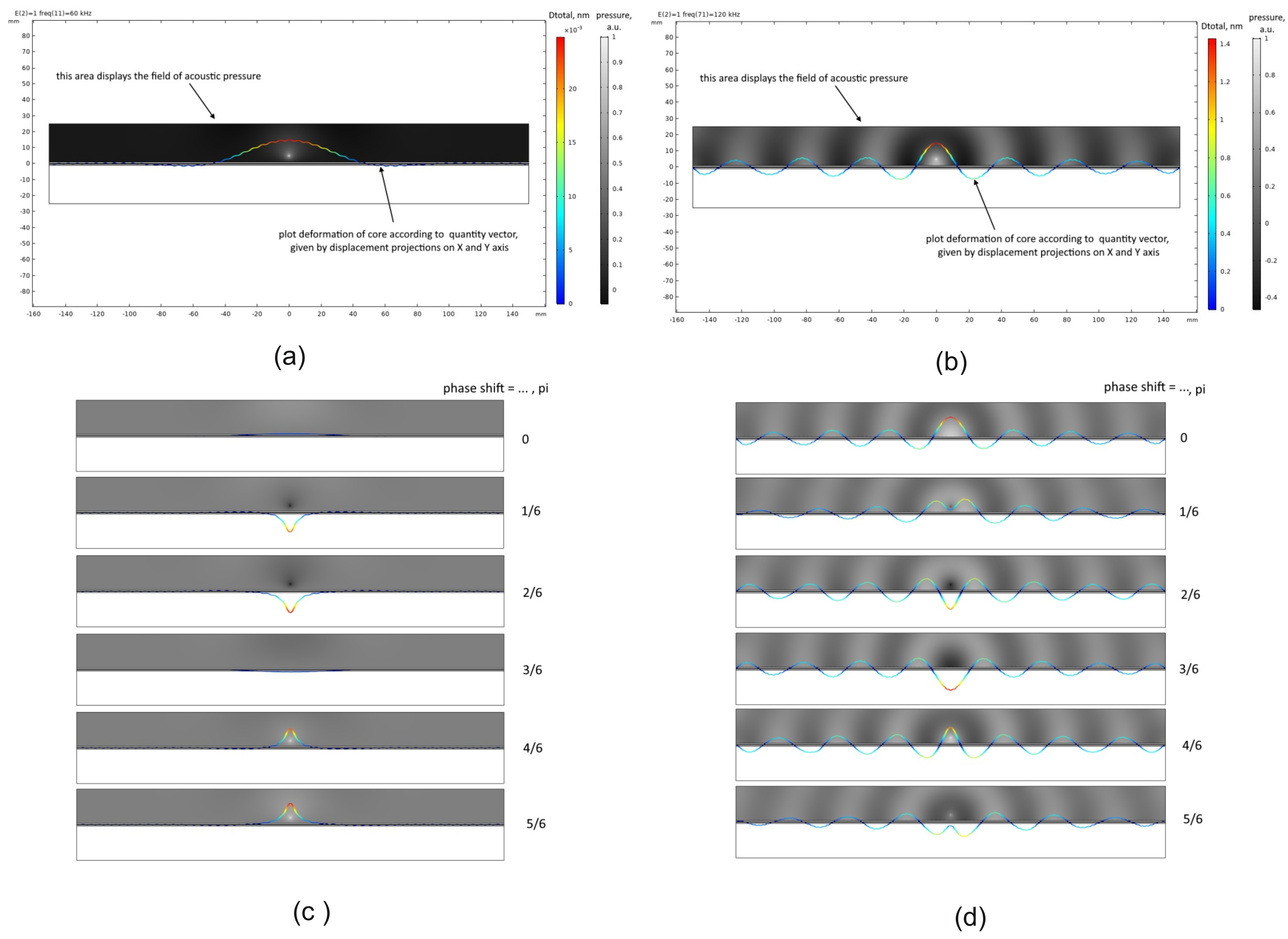

Fig. 2. Calculated field of acoustic pressure and field of displacement for fibre core with deformation. (a) for E=1 GPa and f=60 kHz, (b) for E=1 GPa f=120 kHz. (c,d) corresponding fields at any phase moments

The acoustic pressure and displacement field shown in Figure 2 (a,b) for frequencies of 60 and 120 kHz is calculated. Additionally, the deformation of the core is displayed, which is shown in the figure on a relative scale. It can be seen how the acoustic source deforms the core at different phase moments shown in Figure 2 for the corresponding frequencies in Figure 2 with d. The deformation of the core leads to modulation of the optical path, which varies depending on the phase of the oscillations. It can be seen in Figure 2 (b, d) that for a frequency of 120 kHz, the deformation waves are traveling, which means that the optical path length does not change along the edges from the center, and only the central section of the core contributes to the optical response.

The calculation of the change in the length of the fiber, in relation to the maximum to the minimum, was performed. The result of the calculation is shown in Figure 3. Where the values of the change in the optical path length for various cladding parameters E are shown. As can be seen from Figure 3, adding a 1 mm thick cladding around the fiber core made of a material with an elastic modulus E=1 GPa can increase the optical response for a wide frequency band by more than than twice as compared with the absence of such a shell (at E=70 GPa).

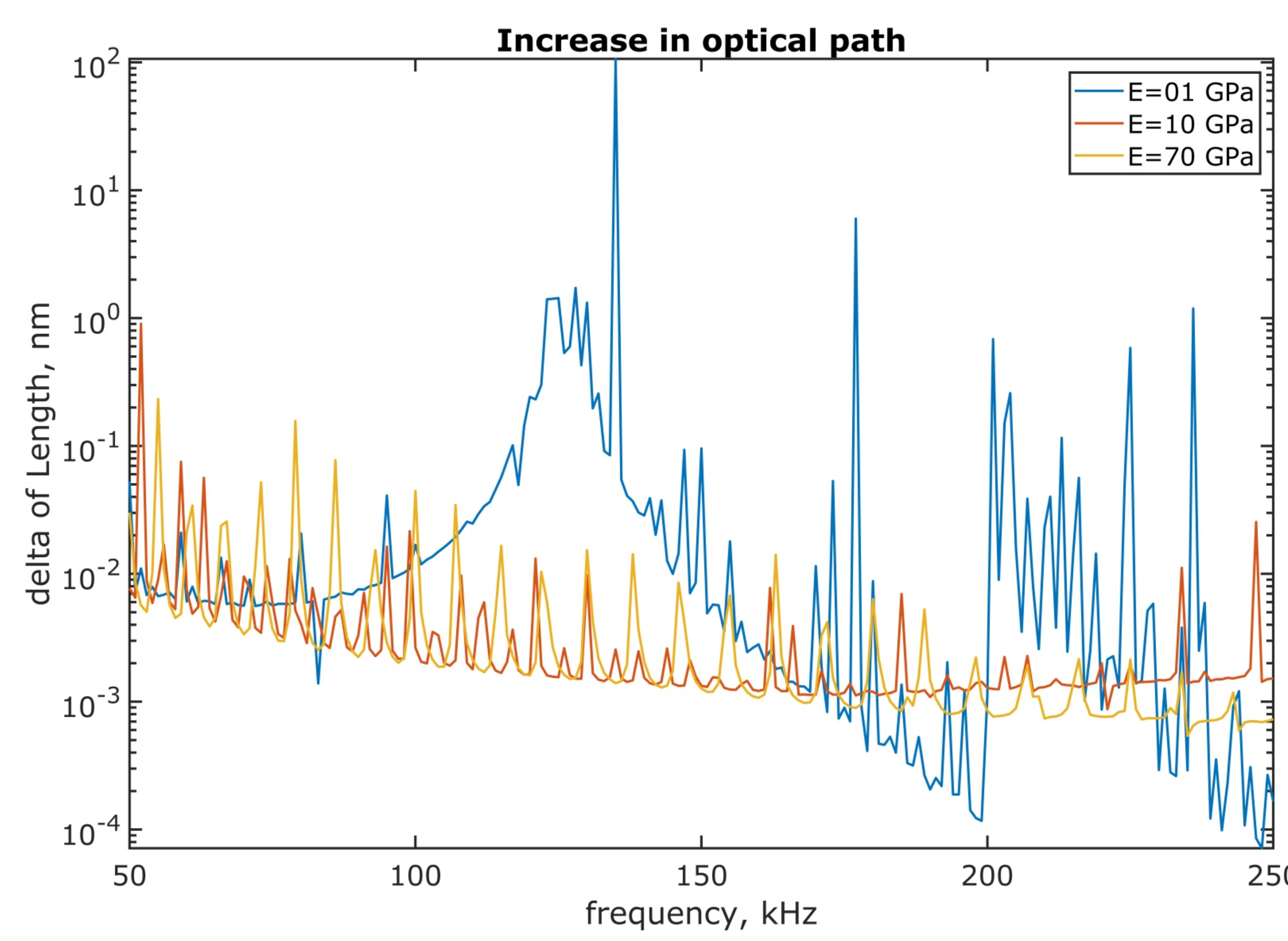

Fig 4. Increasing the length of the optical path for a single fiber on the surface of a composite material for different parameters of the cladding layer. The amplitude of the source is acoustic emission is 1kPa

This study was supported by the Russian Science Foundation, project no. 21-19-00896