GHZ PHONONIC BAND-GAP CRYSTALS: FABRICATION, CHARACTERIZATION AND MODELING

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INTRODUCTION.

Phononic band-gap crystals (PBGCs) are acoustic analogues of photonic band-gap crystals. PBGC is a composite structure possessing periodic variations of sound velocities and mass densities with high acoustic impedance contrast among its constituents, which results in band gaps stopping acoustic waves within certain frequency range due to their total reflection within this synthetic material. By pushing down structural periodicity of PBGCs into hundreds of nanometers or less one can effectively design hypersonic PBGCs to control the propagation acoustic waves with frequencies higher than 1 GHz with an ultimate goal to control heat transport at sub-micron- and nanometer scales (Fig. 1). PBGCs can also find their applications in radio-frequency mobile communication devices and global positioning systems. Femtosecond laser-induced two-photon polymerization (FLITPP) has proved to be a viable fabrication technique to produce periodic synthetic crystals with submicron periodicity [1]. The field of GHz phononics is just emerging, and at this point it is important to explore the actual physics that governs the behavior of these materials, as well as to hypothesize about applications [2].

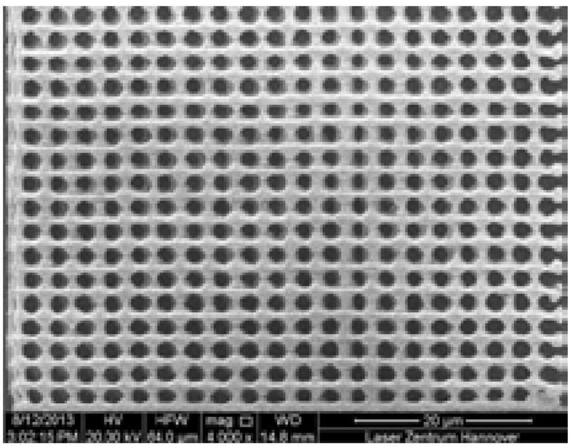

Figure 1. A fabricated hypersonic crystal. (Courtesy of the Research Center for Nondestructive Testing GmbH, Linz, Austria). Hole diameter 500 nm, Lattice constant a = 750 nm, writing volume 500x500x6 mm.

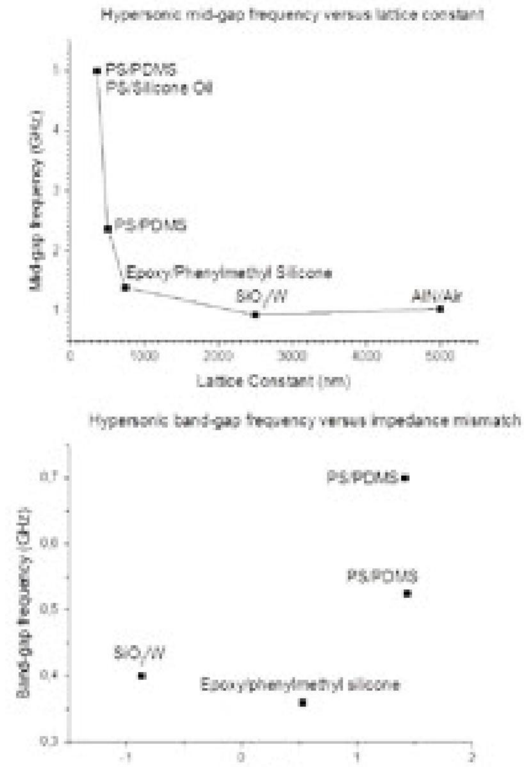

Figure 2. (on the right). Relationship between hypersonic mid-gap frequency and lattice constant (top) and impedance mismatch (bottom).

MATERIALS AND METHODS.

The entire project includes three stages: (1) fabrication of polymer-based phononic crystals by FLITPP method, (2) characterization of the fabricated phononic crystals by Brillouin light scattering (BLS) spectroscopy by means of non-destructive measurement of GHz phonon dispersion relations and (3) comparison with phonon dispersion results obtained by MATLAB and Comsol Multiphysics computer simulations. The following PBGCs are currently computationally tested: 2D, 3D, elastically isotropic polymers and polymers with periodic air holes.

RESULTS AND DISCUSSION.

High quality hypersonic phononic crystals were fabricated using FLITPP at nanofabrication facility of Nanoscribe GmbH in Karlsruhe and Laser Zentrum Hannover e.V. in Hannover, both in Germany (Figure on the right). Currently we are in the process of setting up our own FLITPP system at NU to fabricate PBGCs in house. Phonon dispersion relations of those crystals are being characterized by BLS using Sandercock scanning tandem Fabry-Perot interferometer at our newly built NU Laser Optics Laboratory. We have also solved for eigenvalues and eigenvectors of 2D elastic wave equation and designed periodic materials that have useful phononic properties by using finite-element modeling using Matlab and COMSOL Multiphysics.

CONCLUSION.

FLITPP, BLS and finite element-based computations provide a complete toolset for fabrication of polymeric hypersonic PBGCs and characterization in them of phonons in GHz frequency range.

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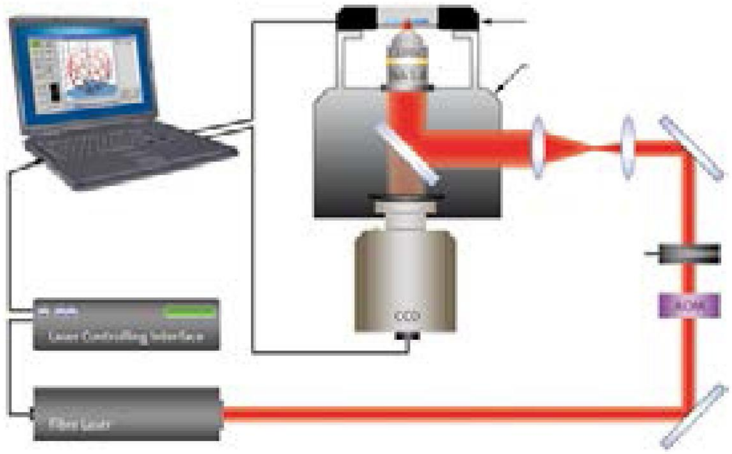

Figure 3. *Schematic of femto-second laser based fabrication of phononic crystals.*

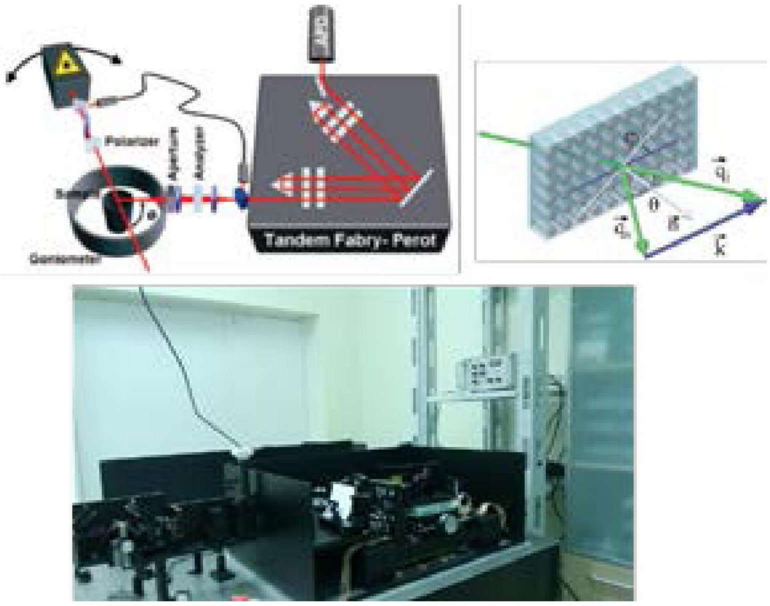

Figure 4. *Schematic and layout of the micro-Brillouin light-scattering system for measuring phonon dispersions and band gaps in phononic band-gap crystals.*

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