Photonic Band Gap Structures

NIL Technology

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Technology Summary

Photonic Band Gap (PBG) materials, also known as photonic crystals, are materials which have a band gap due to a periodicity in the materials dielectric properties. The band gap in photonic crystals represents the forbidden energy range where wave behaving photons can not be transmitted through the material. This behaviour is equivalent to electrons in crystalline semiconductors and in the same manner PBG materials can be used to affect and control the movement of electromagnetic waves.

Photonic crystals are not a new material; in fact they exist in nature and have been studied for more than 100 years. By imitating the periodicity of photonic crystals one can tailor the specific band gap of a structure. This is done in PBG structures by defining a pattern with repeating regions which alternates between materials with high and low dielectric constant.

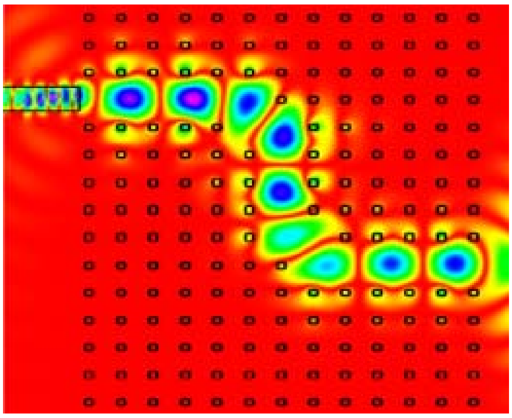

Figure 1: Simulation showing how light will propagate in a photonic crystal. This can be used to guide the light in different directions [http://www.phoenixbv.com].

Diffraction is the underlying physical mechanism describing how periodic changes in the dielectric constant can result in forbidden transmission bands. Since diffraction is the cause of the band formation, the placement of the band gap is defined by the characteristic length scale of the pattern periodicity. By defining the periodicity of the pattern one can therefore limit which specific photon frequencies are allowed to pass and which are not. The size of the band gap is determined by the difference in dielectric constant between the materials used. PBG structures in the optical regime have many applications and can be used in optical devices such as: low-loss waveguides, resonant cavities, optical switches, filters and beam shaping for LEDs.

Fabrication

Naturally occurring photonic crystals with a band gap in the optical range do not exist. One therefore has to fabricate the photonic structure either by self-assembly methods or lithography. In self-assembled based photonic crystals it can be difficult to design specific band gap properties as it is limited by the atoms equilibrium position in the material. Lithography is therefore often used, especially in 2D photonic crystal structures, which can be incorporated in the fabrication process of photonic devices.

The challenge with fabricating PBG structures for use in optical devices is that it calls for band gaps in the optical spectrum, meaning that one has to fabricate patterns of nano meter scale and this is not easily done. Traditional lithographic techniques feature size is limited by the wavelength of the light source used and it can not readily be used to fabricate optical PBG structures as higher resolutions are needed.

Instead methods such as ion beam- and electron beam lithography (EBL) have previously been used to fabricate the needed PGB structures, as these methods have exceptional good resolutions. However, they are expensive to use and have low throughputs. To avoid using these costly methods for every single structure, one can utilize the benefits of nano imprint lithography (NIL). In NIL a reusable stamp is manufactured using for example EBL, thereby limiting the use of expensive low through-put equipment.

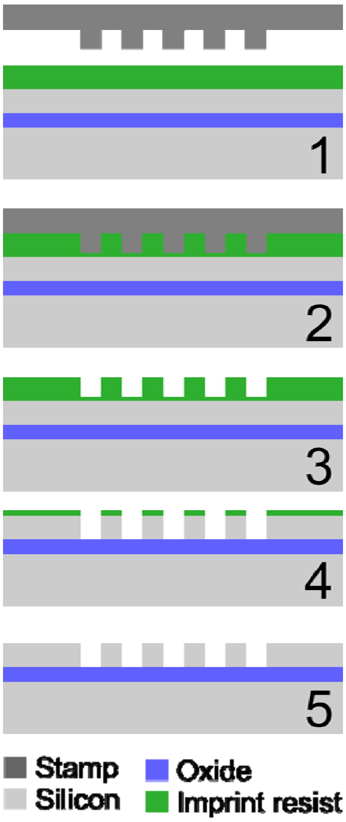

Figure 2: Fabrication of PBG structures in silicon using NIL. 1) A stamp with the desired nano pattern is fabricated and an imprint polymer is spin coated onto the silicon on oxide (SOI) substrate. 2) The stamp is imprinted into the polymer. 3) When the stamp is removed the reverse pattern remains in the polymer with a thin residual layer. 4) After removing the residual layer with an anisotropic oxygen etch, the pattern is etched into the top silicon layer by using the imprint resist as an etch mask. 5) To finalize the PBG structures the imprint polymer is removed.

A fabrication example for a PBG structure can be seen in Fig. 2. First the stamp is created, this have often been coated with an anti-sticking layer allowing for multiple imprints with a single stamp and easy release. For the imprint step a polymer is spin coated onto the substrate. Essentially, the pattern will then be transferred to the imprint polymer by heating the sample whilst forcing the stamp into the polymer. The elevated temperature will decrease the viscosity of the imprint polymer thereby allowing it to flow into the cavities of the stamp. When the sample is cooled the stamp can be released, leaving the desired pattern imprinted in the polymer. After the imprint step, a thin residual layer will remain in the holes where the protrusions have displaced the polymer; this residual layer can be removed by using for instance an oxygen plasma etch. The PBG structures are then defined in the silicon substrate by etching into the exposed silicon where the imprint resist is used as an etch mask. The remaining imprint polymer is then removed thereby leaving the periodic change in dielectric properties on top of an insulating oxide layer, and if designed correctly this will function as an optical PBG structure.

NILT fabrication of PBG structures

NIL Technology has experience in fabricating PBG structures, from the described process. This includes both fabrication of the imprint stamp, the imprint process itself and the post process of the imprinted SOI wafer.

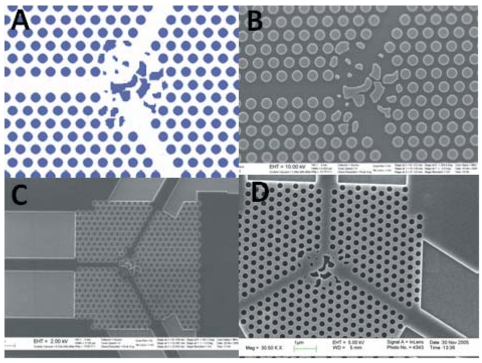

Figure 3: Example of a NIL process used to fabricate PBG structures. A) Shows the design. B) A SEM picture of the fabricated stamp. C) A SEM picture of the imprint done on a SOI wafer, D) Shows the final nano structures etched into the device layer of the SOI wafer.

Fig. 3 shows an example of how a given design is first transformed into a NIL stamp. This stamp is then used to imprint into a substrate and the imprint is transferred into the substrate. This process can then be repeated and the fabrication cost of the substrates will be reduced.