Photoinduced Local Heating in Silica Photonic Crystals for Fast and Reversible Switching

Francisco Gallego-Gómez,
Álvaro Blanco and Cefe López

Instituto de Ciencia de Materiales de Madrid,
ICMM (CSIC),
c/ Sor Juana Inés de la Cruz 3,
28049 Madrid, Spain.

francisco.gallego@icmm.csic.es

A number of strategies have been proposed in order to achieve tunable photonic bandgaps in photonic crystals. Many of them imply filling of the voids of the photonic crystal with photo-, thermo- or electroresponsive systems like liquid crystals, isomerizable materials, hydrogels, etc., which generally is complicated and costly, and with slow response.

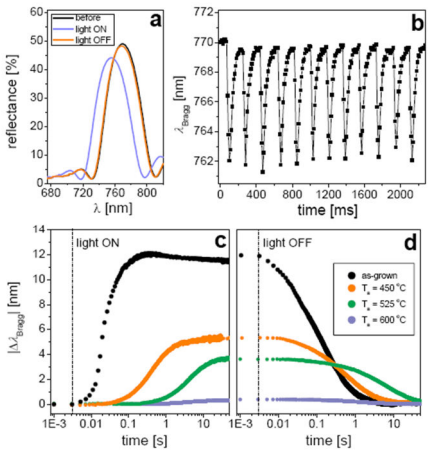

Figure 1: (a) Bragg reflectance peak of a dye-infiltrated as-grown silica opal before, under photoirradiation (for 200 ms) and after relaxation (for 2 s). (b) Modulation of λ_{Bragg} by photoswitching (laser on/off in 30/150 ms periods). Spectra were measured every 10 ms. (c, d) Temporal evolution of $|\Delta\lambda_{Bragg}|$ in infiltrated as-grown (black symbols) and annealed (at 450, 525 and 600 ºC; orange, green and blue lines) opals. The laser was turned on/off 2 ms after beginning the measurement (denoted by the dashed lines). In all cases, photoirradiation was performed on an area of 0.002 mm^2 at intensity of 20 W cm^{-2}.

We demonstrate [1] that just the inherent presence of adsorbed water in an artificial silica opal can be used for rapid and reversible switching of its photonic bandgap. Therefore, we provoked local heating by photoirradiating the opal, dyed with an absorbing chromophore, with a focused 488-nm laser, which induced fast evaporation of the water adsorbed between the opal spheres. As a consequence, the bandgap exhibited fast and highly reproducible shifts to shorter wavelengths. The effect was fully reversed without active cooling as water from the surrounding moisture was quickly readsorbed by the silica, which enabled efficient photoswitching of the photonic bandgap. The overall performance dramatically worsened in hydrophobic (thermally annealed) silica opals (Figure 1).

The observed effect on the bandgap was consistent with previous reports in which water was desorbed by heating the opal on a hot plate [2,3]. As an essential advantage of this approach, the laser-induced opal heating led to fast heating rates that enabled pronounced water desorption in milliseconds (unreachable by standard means), followed by spontaneous and rapid heat dissipation through the non-irradiated structure. The localized photoabsorption of the focused laser enabled such efficiency of both thermal concentration –leading to fast heating– and posterior thermal dissipation –as the opal acts as thermal reservoir regarding the small hot spot. In fact, the performance strongly enhanced by decreasing the photoirradiated opal volume, allowing bandgap shifts of 12 nm and response times of 20 milliseconds. The energy dissipation through the structure compromised the localization of the photoinduced heat, so some bandgap change was observable even at distances of 1.5 millimeter. However, the response times drastically decreased and the local character of the effect was basically preserved (Figure 2).

This very simple and cost-effective approach provides fast switching means in conventional silica photonic crystals, promising an inexpensive solution for a number of applications. This methodology also

opens the possibility to study dynamic sorption phenomena.

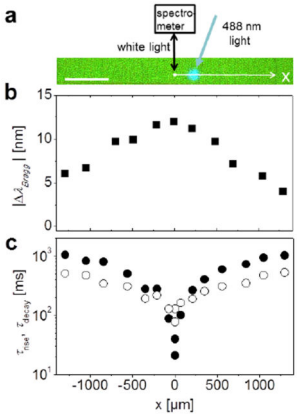

Figure 2: Local nature of the photoinduced PBG changes tested by displacing the irradiation spot from the measurement point a distance *x*. (a) Optical microscope image of the opal under 488 nm laser excitation (lighter spot); scale bar is 500 μm. Scheme of the setup and the defined *x*-axis were added. The white circle denotes the point at which the opal PBG was measured (area of ~ 20 μm^2). (b) *x* dependence of $|\Delta\lambda_{Bragg}|$ and (c) rise and decay half-times. Experiments were performed on an area of 0.002 mm^2 at intensity of 20 W cm^{-2} in an infiltrated as-grown opal.

References

[1] F. Gallego-Gómez, Á. Blanco, C. López, Adv. Mater. (2012), DOI: 10.1002/adma.201202828.

[2] F. Gallego-Gómez, Á. Blanco, V. Canalejas-Tejero, C. López, Small 7 (2011), 1838.

[3] F. Gallego-Gómez, Á. Blanco, C. López, J. Phys. Chem. C 116 (2012), 18222.