Photonic Crystal Enhanced Photoacoustic Detection

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Abstract: A photonic crystal sensor has been demonstrated to enhance photoacoustic signal from light absorbing molecules. The developed system was applied to detect an absorbing dye and gold nanoparticles and exhibited signal enhancement over 40 times.

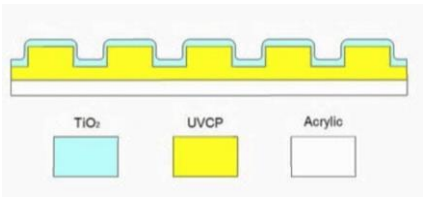
OCIS codes: (110.5125) Photoacoustics, (160.5298) Photonic crystals, (010.1030) Absorption

1. Introduction

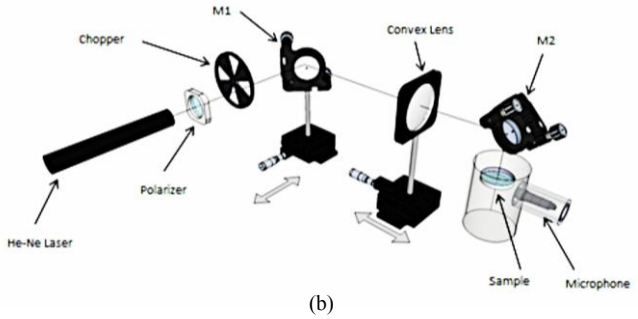
Photoacoustic (PA) spectroscopy has been used to analyze light absorbing substances over substantial ranges of concentrations [1]. It exhibits a higher sensitivity compared to the direct optical absorption spectroscopies. To further improve its signal-to-noise ratio to the point of detecting trace amounts of molecules, people have developed different methods to enhance the PA signals. For example, an optical nanocavity has been developed to increase the light absorption of molecules residing inside the cavity [2]. Alternatively, this paper exploits a 1-D photonic crystal (PC) substrate to enhance light absorption and to generate stronger acoustic signals. The photonic crystal relies on the guided-mode resonance (GMR) [3,4], which is associated with an evanescent field much stronger than that of the incident light, thus resulting in an amplified optical absorption by the analyte. By spectrally overlapping the GMR wavelength with the absorbing band of the analyte, one can enhance the PA signals.

2. PC design and instrumentation

The PA experiment demonstrated here utilizes a photonic crystal structure shown in Fig. 1(a). Comprised of a linear grating structure, the PC was fabricated using a low-cost nanoreplica molding process [5]. Briefly, liquid ultra-violet curable polymer (UVCP) was squeezed between a silicon mold, bearing a negative grating pattern, and a transparent acrylic film. After the UVCP was solidified by UV exposure, the substrate was peeled off from the silicon mold. Upon the acrylic substrate, the cured UVCP carries the desired grating structure. A layer of titanium oxide (TiO_2) was subsequently coated on top of the UVCP to function as a light confinement layer.



(a)



(b)

Fig. 1. (a) The schematic of PC structure (not to scale). The grating structure has a period of Λ = 400 nm, a duty cycle of 60%, and a depth of d = 80 nm. A 100 nm thick TiO_2 layer (n=2.0) was coated onto the UVCP layer. (b) PC enhanced PA detection instrument. The incoming laser beam is directed towards the sample by a set of mirrors and a convex lens, which tunes the incident angle of the laser beam and allows it to be coupled into the GMR mode.

The experimental setup, as shown in Fig. 1(b), consists of a He-Ne laser with a wavelength of 632.8 nm, a polarizer, a chopper that modulates the laser beam at a frequency of 13 Hz, and a set of mirrors together with a convex lens to direct the laser towards the PC sample. The sample is placed inside a sealed testing chamber to minimize ambient noises. The PA signal is measured by a microphone which is connected with an oscilloscope. The mirror M1 and the convex lens are used to tune the angle of incidence to the resonant angle. By translating M1, the angle of incidence can be controlled between -7˚ to 7˚.

3. Results and discussion

To characterize the PC enhancement capability, we measured the PA signals of a light absorbing dye molecule (Epolight 5262) deposited on a PC substrate. Fig. 2 shows the PA signal and the transmission coefficient of the sample with respect to the incident angle. The peak in the PA signal well correlates with the GMR, which is indicated by the dip in the transmission curve. Fig. 3 compares the PA signals generated by the dye molecule at different concentrations when the sample was illuminated on resonance ($\theta_r = 3.5°$) and off resonance ($\theta_r = 7.0°$). At low concentrations the PA signal changes linearly with the concentration with the signal enhancement factor around 10 times. The intensified local field enhances the light absorption of the dye molecule and consequently a stronger PA signal is generated.

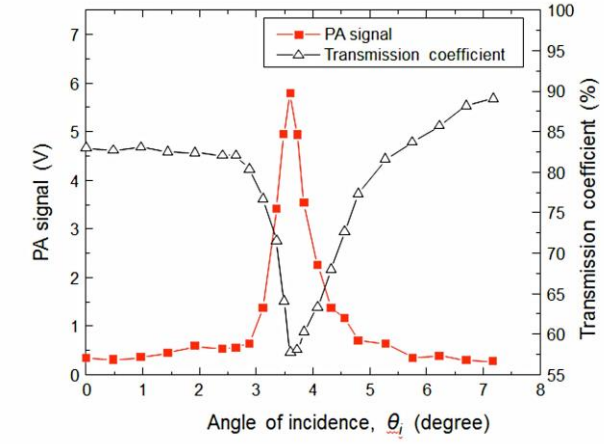


Fig. 2. PA signal and transmission coefficient with respect to the incident angle

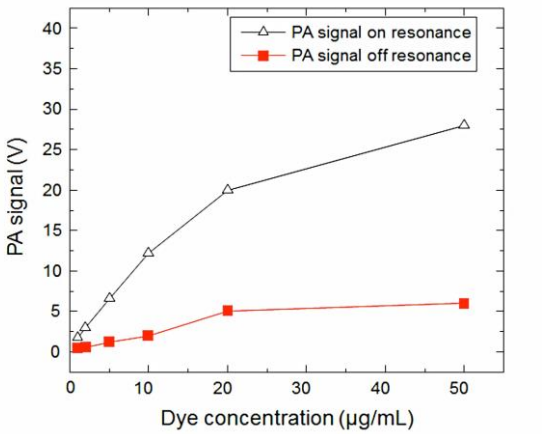


Fig. 3. PA signal of the dye molecule with PC substrate illuminated at on resonance and off resonance conditions

We further applied this technique to detect gold nanoparticles (AuNPs) and the results also show strong signal enhancement by the PC substrate. Fig. 4 shows the PA signal of gold nanoparticles dispersed on a PC substrate as a function of incident angle. As shown in the SEM images, the density of AuNPs is less than 5 particles within a 100 μm^2 area. Due to the PC enhancement, it is possible to measure the PA signal generated by only a few AuNPs. The PA signals of AuNPs at different concentrations on the PC substrate and a planar acrylic substrate are compared in Fig. 5. Measured under resonant conditions, the PA signal is over 40 times stronger than the PA output measured upon an acrylic substrate.

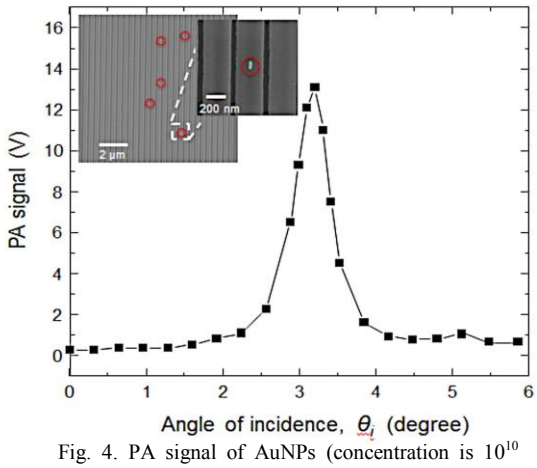


Fig. 4. PA signal of AuNPs (concentration is 10^{10} NPs/mL) as a function of incident angle

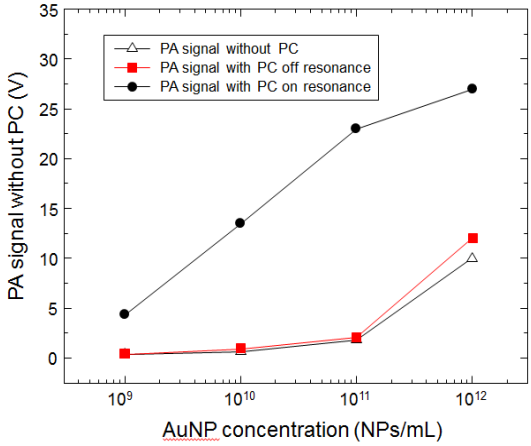


Fig. 5. PA signal of AuNPs on a planar acrylic substrate and on PC substrate illuminated at on resonance and off resonance conditions

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