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Nonlinear self-action of Bloch surface waves governed by gradient optical forces

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Abstract

An experimental study of the nonlinear self-action of Bloch surface waves (BSWs) is reported. The BSWs are excited by a continuous-wave diode laser at the interface between a one-dimensional photonic crystal and a water suspension of 50-nm polystyrene particles, as revealed by the angular reflectance spectrum. Redistribution of the particles under the action of the gradient optical forces leads to a significant modification of the BSW resonance curve at an incident power as low as 14 mW. The results highlight that nanosuspensions can be used as artificial Kerr media to perform model experiments on the optical switching of surface waves.

Keywords: nonlinear optics, photonic crystals, nanosuspensions, surface electromagnetic waves

I Introduction

Gradient optical forces acting on polarizable particles in non-uniform electromagnetic fields are commonly used for optical trapping and manipulation,[1,2] near-field microscopy,[3,4] and measuring forces.[5,6] Beside these fields, the gradient forces play a determining role in the nonlinear optical responce of dense suspensions of dielectric nanoparticles.[7,8] Due to the fact that the particles tend to be concentrated in volumes where the intensity is higher, these media can serve as artificial Kerr media, where nonlinear effects can be observed using low-power continuous-wave laser sources.

Surface electromagnetic waves in photonic crystals also known as Bloch surface waves (BSWs) are propagating modes localized at the interface of photonic crystal structures.[9,10] Similar to surface plasmon polaritons (SPPs) in metals, they can be excited using a prism scheme under conditions of attenuated total reflection. In contrast to SPPs, they do not suffer from thermal losses and consequently are more promising candidates for nonlinear optical processing and integrated optics.[11,12] Recently, we have shown that BSWs can also be used for the optical manipulation of particles and measured the forces induced by the BSW evanescent field.[13]

In this contribution, we study the nonlinear self-action of BSWs excited at the interface between a one-dimensional photonic crystal and a water suspension of polysterene nanoparticles.

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II Methods

The experimental setup is schematically shown in Fig 1. The nonlinear medium is a water suspension of 50-nm polystyrene nanoparticles ($n = 1.59$) with a concentration of 25 mg/ml. The BSWs are excited in the Kretschmann scheme by using a prism with an angle of 54.6° and a refractive index of 1.66. The photonic crystal is a dielectric multilayer structure consisting of 4 pairs of quarter-wavelength layers of Ta_2O_5 and SiO_2 with a bandgap centered at 1.3 μm. The multilayer structure is deposited on a cover glass with a refractive index of 1.52. The optical contact between the prism and the glass is realized by using immersion oil.

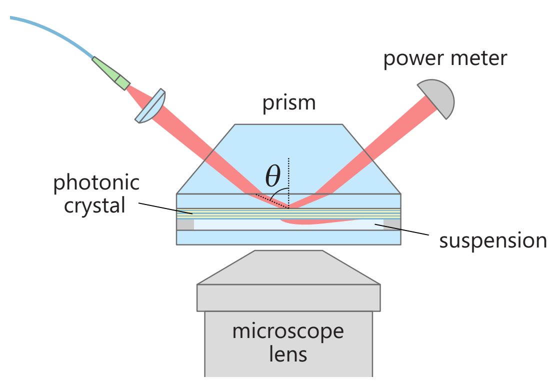

Figure 1. Experimental setup. BSWs are excited in the Kretschmann prism configuration at the interface between a one-dimensional photonic crystal and a water suspension of nanoparticles. Light-induced redistribution of particles leads to a modification of the BSW resonance as detected by measuring the angular reflectance spectrum for different incident powers.

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The light source is a continuous-wave single-mode diode laser emitting a wavelength of 638 nm. The laser output is transmitted through an optical isolator and coupled into a single-mode polarization-maintaining optical fiber. At the fiber output, light is collimated by an aspheric lens with a focal distance of 8 mm. The fiber output and the collimator are mounted on a rotational stage for precise control of the angle of incidence. The angular divergence of the incident beam in glass is approximately 0.4°. The reflected power is measured using a power meter.

To visualize the interface of the photonic crystal during the measurements, we use an objective lens with a numerical aperture of 0.85 and a focal distance of 4 mm. The field of view of the objective is imaged by a CMOS camera. The exposure of the sensor is manually set to be inversely proportional to the incident laser power.

III Results and Discussion

The angular reflectance spectrum at a low incident power (0.6 mW) is shown in Fig 2, as indicated by the black dots. Total internal reflection occurs for angles above 61.4°. The BSW excitation reveals itself as a dip around 63.4°. The width of the dip is determined primarily by the angular divergence of the laser beam. At a higher power (14 mW), the position of the resonance shifts to larger angles of incidence and the shape of the dip is modified. With the angle slightly detuned from the resonance to larger ones, we also observe self-focusing of the BSWs.

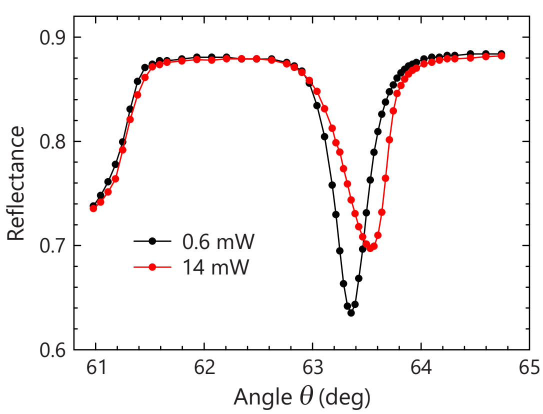

Figure 2. Angular reflectance spectra for incident powers of 0.6 and 14 mW. Total internal reflection is achieved at an angle of approximately 61.4°. The dip around 63.4° corresponds to the BSW excitation.

Note that dielectric particles localized in the BSW evanescent field are not only pulled to the surface due to the gradient optical force, but also pushed in the direction of the wave propagation due to the scattering force.[13] If the particle size is small enough, the gradient forces play a determining role.[1] However, when 100-nm polystyrene particles were used instead of 50-nm ones, we did not observe the self-focusing effect. This can be due to the scattering force causing the particles to leave the region of the BSW propagation.

IV Conclusions

Nonlinear self-action of BSWs on the interface between a one-dimensional photonic crystal and a suspension of dielectric nanoparticles has been observed. The position of the BSW resonance has been shown to depend on the incident power. The results highlight that suspensions of dielectric nanoparticles can be used as artificial Kerr media to perform model experiments on the optical switching of surface electromagnetic waves.

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