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Short Communication

Controllable optical transparency using an acoustic standing-wave device

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ABSTRACT

In this paper, a suspended-particle device with controllable light transmittance was developed based on acoustic stimuli. Using a glass compartment and carbon particle suspension in an organic solvent, the device responded to acoustic stimulation by alignment of particles. The alignment of light-absorbing carbon particles afforded an increase in light transmittance as high as 84.5% and was controllable based on the control of the frequency and amplitude of the acoustic waves. The device also demonstrated alignment memory rendering it energy-efficient.

1. Introduction

Materials with switchable transparency have found numerous applications, especially in dynamic tintable or smart windows. These materials have found utility in applications in agriculture [1], automobile sunroofs [2], personal privacy [3], photovoltaics [4,5], and energy-efficient buildings [6]. Switchable transparency is achievable following various techniques, all of which utilize external stimuli or triggers. The most common are chromic materials, liquid crystals, and suspended-particle devices. The chromic materials are most commonly photochromic, in which case the external stimulus is light, e.g. photochromic lenses. However, other types of stimuli for chromic materials have been developed, namely, electricity (electrochromic), gases (gasochromic), and heat (thermochromic) [1]. Liquid crystal devices while they share the same stimulus with electrochromic, are fundamentally different since they rely on changes in the orientation of the liquid crystal molecules rather than through ion insertion/extraction. Suspended-particle devices that exist today also rely on electrical stimuli to create an electronic field to align light-absorbing particles suspended in a fluid or gel between two transparent and conductive surfaces. The alignment of the particles yields a rapid increase in transmittance that was reported to reach as high as 79% [7–9].

In this work, a suspended-particle device that has switchable transmittance using acoustic waves was developed. Similar to previously reported suspended-particle devices, our light-absorbing particles are aligned using an external stimulus to allow light transmittance. However, instead of using electrophoretic alignment, the presented device utilizes acoustophoretic alignment. The working principles of acoustophoresis has been well exploited in previous studies for microfluidic applications [10,11]. This alignment approach is rapid, low-energy, and can be applied to virtually any particle type not restricted by electrical, magnetic, or chemical reactivity. The acoustophoretic alignment presented in this work is tested on label-free carbon particles. Random suspensions of the carbon particles are practically opaque, while aligned particles of various frequencies afforded higher light transmittance.

2. Experimental procedure

Particle suspensions (1–10% by weight) were prepared using graphitized carbon particles 0.5–5 μm in diameter obtained from MTI Corporation (Richmond, CA) in anhydrous acetone obtained from Sigma–Aldrich (St. Louis, MO). Stable suspensions were obtained by vortex mixing followed by sonicating the suspension in an ultrasonication bath (100 W) for 30 min. The particles were then syringe injected into a custom-made glass compartment $10 \times 10 \times 1$ mm in inner dimensions with one of its walls as a Teflon cap. A piezoceramic transducer PZ-26 obtained from Ferroperm (Denmark) was affixed to this compartment and was wired to a function generator Rigol DG4062 (Beavertown, OR). The experiments were conducted using the setup schematically presented in Fig. 1. In the figure, the device was placed under a stereo microscope with a working distance of 10–20 cm focused on a 10×15 mm window with the light source placed either under or above the device.

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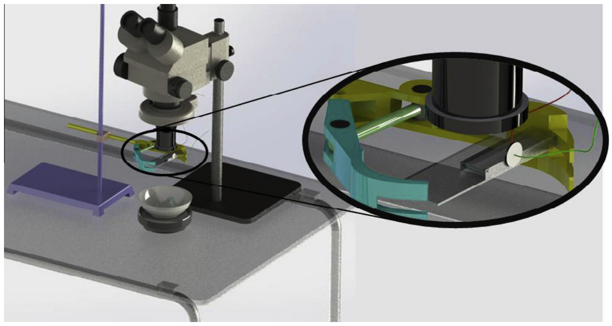

Fig. 1. Schematic presentation of the experimental setup used in the device transmittance study.

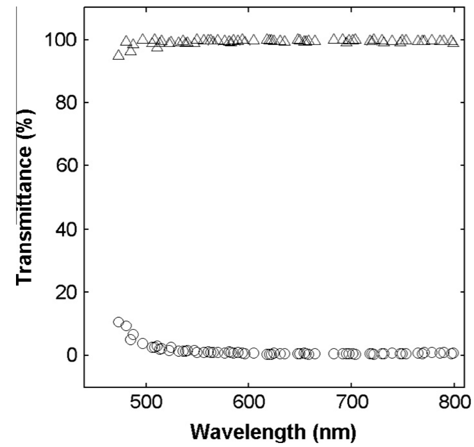

Fig. 4. Spectrophotometric analysis of the device filled with acetone (triangles) and 10% suspended-particles (circles) between 400 and 800 nm.

3. Results and discussion

In a symmetric compartment such as the one described in this work, a transducer produced an acoustic radiation that was reflected from the opposite wall creating a standing-wave. An acoustic force is then imposed on the particles by the standing-wave based on their spatial coordinates, the size of the particles, the density and acoustic compressibility of both the particle and the media [12]. Rigid and dense particles migrate toward the nodal zones while flexible and lighter particles migrate toward the anti-nodal zones shown in Fig. 2. In this study, carbon had instantaneous nodal migrations and aligned into lines across the device with spacing depending on the frequency of the sound wave controllable by the function generator. Since the carbon particles are light-absorbing, when aligned particle-free gaps developed allowing light transmittance through the device as shown in Fig. 3. The device itself with no particles was shown to be highly transparent when filled only with acetone with transmittance of 99.3%. The device with 10% carbon particles randomly suspended with no acoustic stimulation was shown to have 1.5% light transmittance in the visible 400–800 nm range (Fig. 4). This demonstrated that the material selection for this glass device with

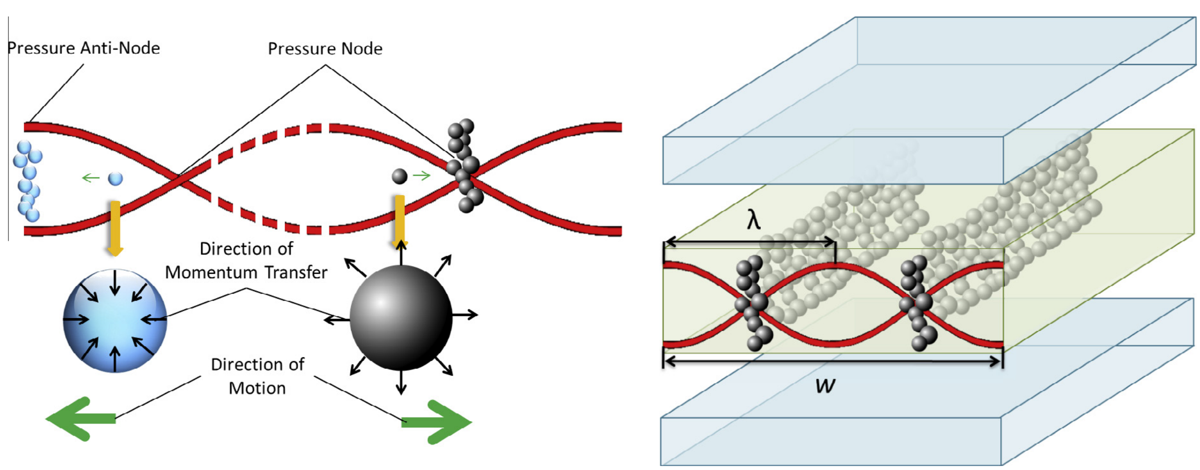

Fig. 2. Schematic of the direction of the acoustic radiation force for rigid (black) and flexible (blue) particle/droplet in an acoustic standing wave. Black arrows denote the direction of the momentum transfer and the green arrows denote the direction of the net force and thus the resulting motion. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

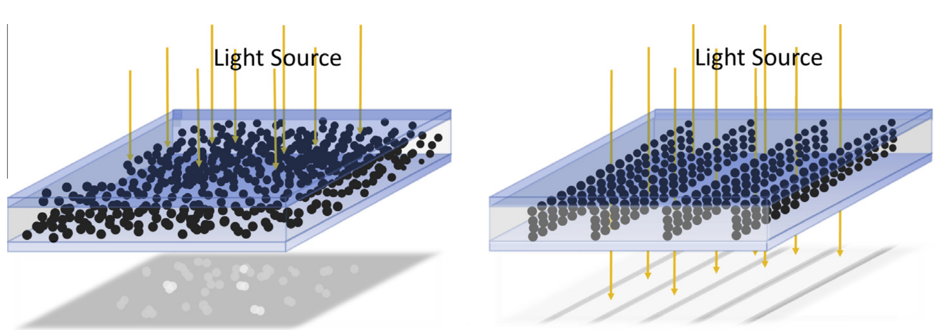

Fig. 3. Comparison of the randomly disperse (left) versus the aligned particles (right) caused by switching on the acoustic radiation.