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Full Length Article

Laser textured GFRP superhydrophobic surface as an underwater acoustic absorption metasurface

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ABSTRACT

Underwater acoustic absorption metasurfaces (UAAMs), featured with artificial periodic unit cells as acoustic micro-absorbers, are crucial for the enhancement of the underwater stealth, energy transition, sonar detection, etc. How to implement the acoustic metasurfaces for practical engineering applications requires the support of efficient manufacturing techniques. Here we present a simple way of laser texturing for fabrication of the patterned superhydrophobic surface on glass fiber reinforced plastic (GFRP). Unlike the traditional acoustic absorbing material whose thickness should match the corresponding wavelength, the laser textured superhydrophobic micro-grooves have thickness less than the absorption sound wavelength by 2–3 orders of magnitude but promisingly demonstrate over 88% of the underwater incident acoustic power absorption from 50 kHz to 250 kHz. The physical mechanism of the UAAM ascribes to the multiple interface scattering effect induced by the air layer between water and superhydrophobic micro-nano structures.

1. Introduction

Efficient control of the generation, propagation, reception, and processing of sound waves is the basic problem and long pursuit of the acoustics. Modern complex sound field processing problems such as aircraft [1], submarine noise isolation [2], underwater sonar detection [3], and music hall's acoustic design [4] are increasingly related to the manipulation of selective acoustic absorption/transmission. Acoustic metasurfaces are artificial composite structures built by repetitive unit cells whose dimensions are much smaller than the acoustic wavelength and have many special acoustic properties which greatly expand the connotation of natural acoustic materials with applications such as one-way transportation [5], cloaking [6], super absorption [7], etc.

Acoustic metasurfaces have been a research hotspot as a candidate smart module in intelligent acoustic design for years. Pioneering works on acoustic metasurfaces have inspired extensive studies. Extraordinary acoustic wave transmission was predicted by Zhang [8], followed by Lu et al. [9] who first reported the extraordinary acoustic wave transmission of grating structure. Recently, several groups measured the transmission properties of sound through plates with slits and holes [10–12] and proposed three types of the acoustic extraordinary transmission: periodic-lattice resonances [13], Fabry-Perot–type resonances [12], and elastic Lamb-mode resonances [14]. J. Mei. et al. [7] achieved very high acoustic absorption at resonant frequencies through the concentration of curvature energy at the perimeters of asymmetrically shaped platelets and G. Ma. et al. [15] investigated the acoustic metasurfaces with hybrid resonances.

In the field of underwater acoustic absorption, one of the most efficient technological solutions is the use of decoupling coatings and anechoic coatings [16], but the problem is the size of the coating is on the same order of wavelength, which restrains the use of the coating. Li. et al. [17] investigated the asymmetric underwater acoustic transmission by a plate with quasi-periodic surface ridges. Owing to the huge ratio of 3600 in the acoustic impedances from water to air, only 0.1% of the acoustic energy is naturally transmitted at such a boundary. Eun Bok. et al. [18] investigated the metasurface for water-to-air sound transmission, allowing about 30% of the incident acoustic power from water to be transmitted into the air.

In this study, a simple way of laser texturing is proposed for the fabrication of the patterned superhydrophobic surface on glass fiber reinforced plastic (GFRP), which demonstrates selectively high absorption of a sound wave as a promising underwater acoustic absorption metasurface (UAAM).

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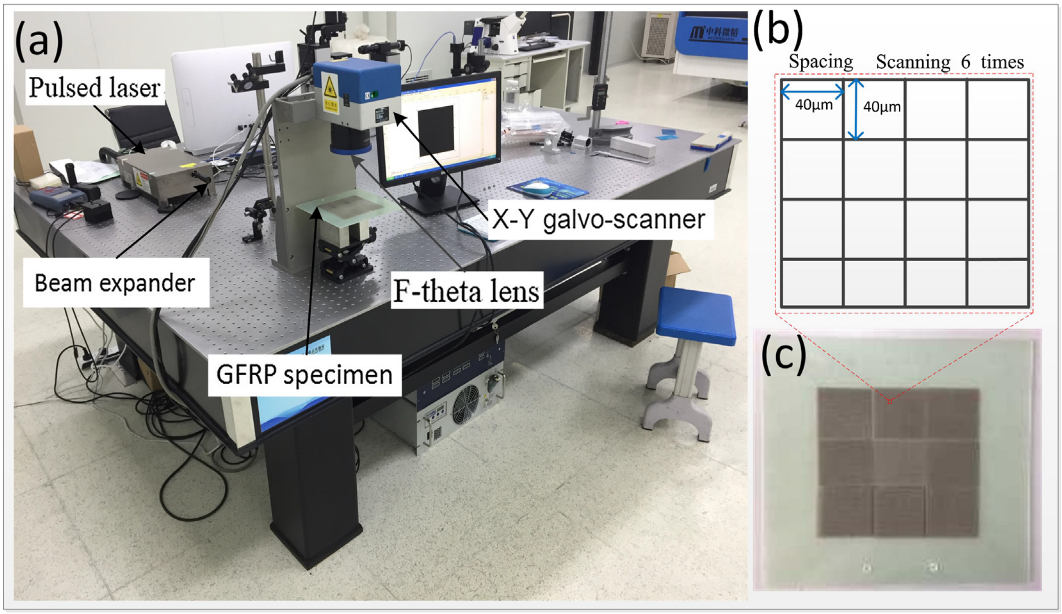

Fig. 1. Setup of the laser micro-machining system and the cross grid patterns on GFRP specimen.

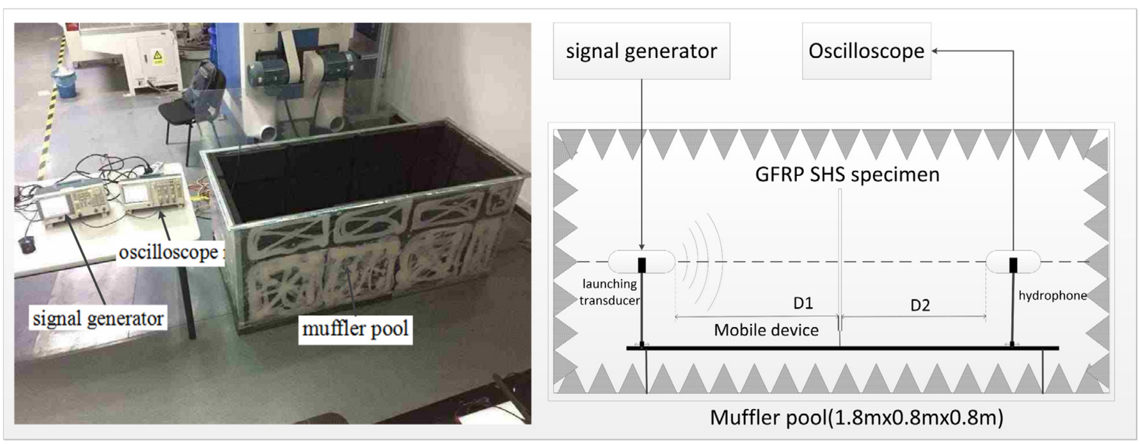

Fig. 2. The experimental setup for ultrasonic transmission coefficient test.

2. Experimental

Glass fiber reinforced plastic (GFRP) is the most common type of - fiber-reinforced plastic using glass fiber which is cheaper and more flexible than carbon fiber. GFRPs are stronger than many metals by weight, and can be molded into complex shapes, which have wide applications in aircraft, boats, pipes, bath tubs and sonar dome, etc. Therefore, GFRP (Shenzhen Shengjili co. Ltd.) plates with the dimensions of 200 × 200 × 1 mm3 are used as the substrates. The GFRP plates are ultrasonically cleaned in anhydrous ethanol solution for 10 min and then blow dried before and after the laser texturing. A laser micro-machining system is used for precision ablating grid groove patterns on GFRP surfaces, as shown in Fig. 1(a). The UV laser (Awave-355, Apto-Wave co. Ltd.) outputs pulsed Gaussian laser beam at an average power of 3 Watts, wavelength of 355 nm, the pulse width of 20 ns, and the focused laser spot diameter of 15 μm. At an operational pulse repetition rate of 90 kHz and X-Y galvo-scanning speed of 200 mm/s, the designed grid patterns are laser textured on the GFRP specimen surfaces by 6 times repetitive scanning, as shown in Fig. 1(b) and (c). Thus, the used laser pulse fluence for the texturing of GFRP surface is 4.72 J/cm2, which is near four time of threshold fluence (1.2 J/cm2, obtained by experimental) to get the designed micro-groove structures. The fabricated crossed micro-grooves pattern has the optimized dimensions by multiple pre-tests to achieve high contact angle and low slip angle as a low-adhesion superhydrophobic (LASH) surface, specifically 25 μm of depth, 20 μm of width and the spacing between the crossed micro-grooves is 40 μm. (Heptadecafluoro-1,1,2,2-tetradecyl) trimethoxysilane (PSD-J20P, Shenzhen Passedat Chemical co. Ltd.) is spin-coated and heat-treated by thermostat at 170 °C for 30 min as the chemical modifier that lower the solid surface energy and make the laser textured surface superhydrophobic.

The micro-morphologies of the prepared superhydrophobic GFRP surfaces are investigated by Laser Scanning Confocal Microscopy (OSL 4100, OLYMPUS) and the Scanning Electron Microscope (SEM) (QUANTA 200F, FEI). Static contact angles (SCAs) [inserted in Fig. 6(c) and (d)] are measured five times at different tested area using a video optic CA instrument (OCA15EC, Dataphysics) equipped with a goniometer. The images of a 3 μL distilled water droplet placed on the specimen's surface are analyzed by a Low-Band Axisymmetric Drop Shape Analysis (LBADSA) software. The temperature and relative humidity in the SCAs tests are 25 °C and 65% RH, respectively.

An ultrasonic transmissivity measurement system is built to measure the underwater acoustic absorption properties, as shown in Fig. 2. The overall system is immersed in a muffler pool for measurement of underwater sonar transmission coefficient, which includes a signal generation (AFG 3021B, Tektronix), transducer (DYW-50/200-NA) as