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Ultrasonic transmission from fiber optic generators on steel plate

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ABSTRACT

Fiber optic acoustic generators have generated a lot of interest due to its great potential in many applications including nondestructive tests. This paper reports four acoustic generation configurations. All the configurations are based on gold nanoparticles/polydimethylsiloxane (PDMS) composites. Since gold nanoparticles have high absorption efficiency to optical energy and PDMS has a high coefficient of thermal expansion, the composites can transfer optical energy to ultrasonic waves with high conversion efficiency. The strength and bandwidth of ultrasonic waves generated by the composites can be changed by different designs and structures of the composites. This paper explores the relation between the structure of fiber optic acoustic generators and the profile of generated ultrasonic waves. Experimental results also demonstrated that four ultrasonic generation configurations have similar features of ultrasonic transmission on a steel plate, which is important for future choices of ultrasonic receivers.

Keywords: Optical Fiber; Acoustic Generator; Nanocomposites; Photoacoustics

1. INTRODUCTION

Since 1980s, structural health monitoring (SHM) has become an attracting interest in engineering, especially for the nondestructive testing of civil infrastructural community and aerospace structures [1-3]. In past decades, the electronic systems such as piezoelectric (PZT) transducers have grown quickly and have been applied in various applications such as structural health monitoring, damage detection, and nondestructive evaluation. However, the application of PZT transducers is limited by the electromagnetic interference and less flexibility in permanent installation. Even though the piezoelectric wafer active sensor reported recently was regarded as a kind of potential sensor with small size and flexible geometries, there is still a long way to overcome the challenges in the durability of embedded or surface-bonded PZT material, especially for the harsh environment [4, 5].

Since the outside environment will affect the optical transmission in certain fiber optic structures (such as gratings), fiber optic sensors have created a new field and have been drawing more attentions in their applications for SHM [6, 7]. Considering the advantages of small size, the immunity to the electromagnetic interference and the ability to survive high temperature and extreme environments, fiber optic sensors have a growing and competitive market in SHM.

In this paper, four fiber optic ultrasonic generation configurations based on the gold nanocomposites were explored. From the experiments, the ultrasonic signals from the four configurations were analyzed. The capability of these configurations for the acoustic generation on the steel plate was verified. It was also found that there were some features of the gold nanocomposites material itself and how different configurations influenced on the transmission of ultrasound.

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2. PRINCIPLE OF ULTRASOUND GENERATION BASED ON GOLD NANOCOMPOSITES

After Alexander Graham Bell found the properties of light emitting sound in various materials, the photoacoustic generation has been attracting substantial industrial interests [8]. Photoacoustic principle heavily relies on the photoacoustic material, which absorbs the optical energy and converts it to the thermal energy. The thermal energy will cause the material to expand due to the thermal expansion effect. The material will contract when there is no optical energy. Therefore, this expansion/contraction cycle generates ultrasound. Recently, a novel composite with a high energy conversion efficiency was reported by Wu *et al.* [9]. The composites involved with polydimethylsiloxane (PDMS), which has a high coefficient of thermal expansion (CTE). Gold nanoparticles have a high optical energy absorption capability at certain wavelength, which can generate heat and then transfer it to PDMS. The PDMS can provide more thermal expansion and stronger mechanical waves compared to metal and epoxy due to its high CTE. High frequency ultrasound can be generated by the gold nanocomposites , which have a wide application in ultrasonic SHM and medical imaging [10, 11].

3. EXPERIMENTS

The experimental setup and the schematic diagram of four ultrasound generator are shown in Figure 1 and Figure 2.

A nanosecond laser (Surelite SL-I, Continuum) generated the green laser which went through a coupler and was introduced into a multi-mode fiber (400/425 μm). The gold nanocomposites of four configurations was irradiated by the laser and then generated mechanical waves. The acoustic (mechanical) signals transmitted through a steel plate (1 ft. by 2 ft. by 0.5 in.) and a thin film of the ultrasonic couplant (glycerol). They were detected by a piezoelectric transducer (PZT) (Olympus, V116-RM). The mechanical signals were transferred to electrical signals by the PZT and were amplified by a pulser/receiver (Olympus, 5072R). A personal computer (PC) collected simultaneously the trigger signals from the nanosecond laser and the signals detected by the transducer. The amplitude ratio of the pulser/receiver was set at 40 dB and the sampling rate of data acquisition (DAQ) was set at 50 M/s.

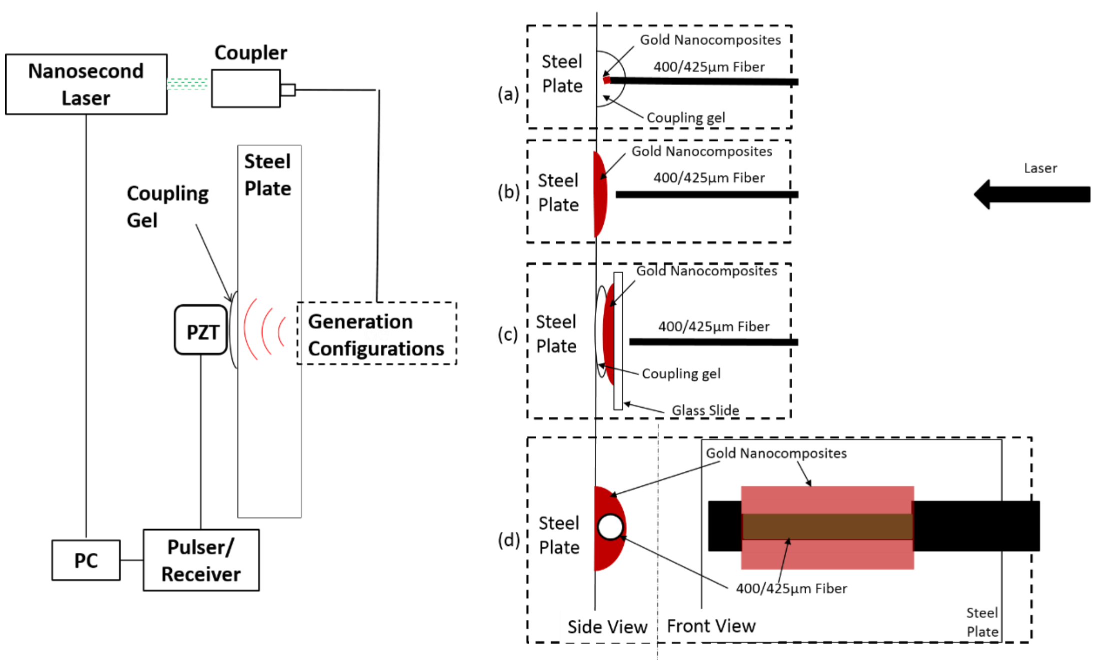

Figure 1 Experimental setup and structures of four ultrasound generation configurations

Here is the fabrication of four ultrasound generation configurations. Configuration (a) was fabricated by dip coating. One end of a 400/425 µm fiber was cleaved and dipped in an uncured gold nanocomposites. A hot plate was used to cure the composites overnight. The prepared fiber-tip generator was clamped perpendicular to the steel plate and embedded in the coupling gel. Configuration (b) was fabricated by directly curing the gold nanocomposites on the steel plate. Configuration (c) was the gold nanocomposites cured on a glass slide. When testing, the laser beam penetrated the glass slide and irradiated on gold nanocomposites. Between the gold nanocomposites and steel plate, there was a thin film of coupling gel used for well transmitting ultrasonic signals. To make Configuration (d), part of a 400/425 µm fiber was cleaved and scorched with a torch flame to remove the polymer coating and cladding. Some laser leaked from the fiber without cladding and irradiated the gold nanocomposites. The curing process of the composites fixed the fiber on the steel plate. The comparison of the four ultrasound generation configuration is shown in Table 1.

Table 1 Comparison of the structures of four ultrasound generation configurations

Configurations	Laser Exciting Approach	Components
(a)	fiber end	fiber; gold nanocomposites; coupling gel; steel plate
(b)	fiber end	fiber; air; gold nanocomposites; steel plate
(c)	fiber end	fiber; glass slide; gold nanocomposites; coupling gel; steel plate
(d)	fiber side	fiber; gold nanocomposites

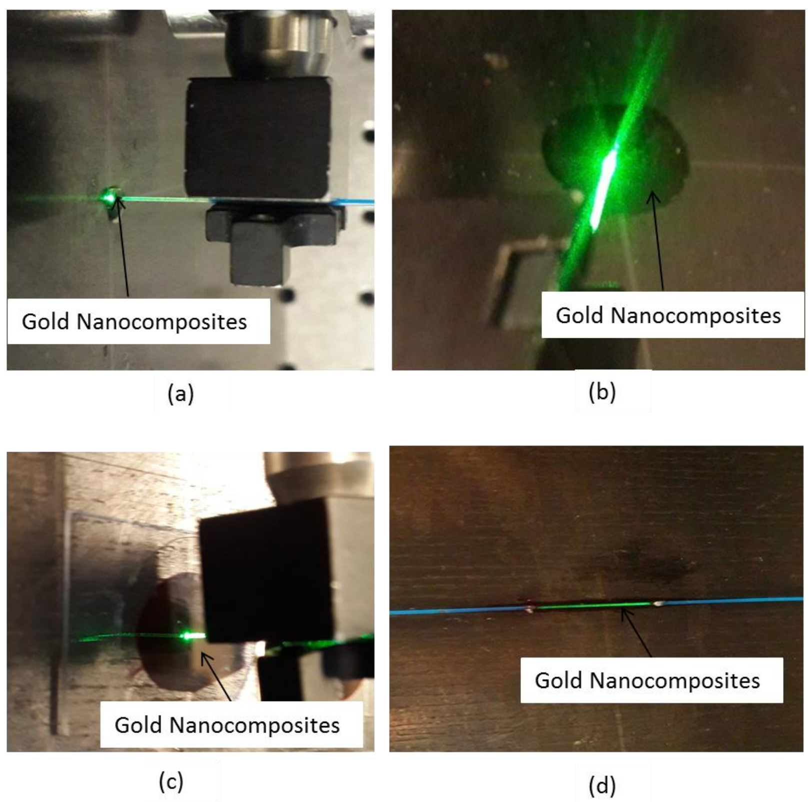

Figure 2 Pictures of four ultrasound generation configurations

4. RESULTS AND DISCUSSION

As shown in Figure 3, the signals from four ultrasound generation configurations were analyzed in both time domain and frequency domain.

From Figure 3, the reflection time of the first peak in the signals of all the configurations was figured out and the average value was 4.22 μs. As the thickness of the steel plate was 0.5 in. (12.7 mm), the speed of the signals was about 6019 m/s. The speed of longitude waves in steel was in the range of 6100 m/s [12], which depends on the type of steel. It can be verified that ultrasonic signals have been generated.

The comparison between signals from four ultrasound generation configurations is shown in Table 2.

Comparing configuration (b) and (d), the type of laser exciting approach influenced the attenuation from the first peak to the second peak and the strength of acoustic signals. The thickness of the gold nanocomposites was the main effect factor on the strength of acoustic signals [9]. And also, the type of laser exciting approach influenced the power of laser irradiating on gold nanocomposites and then the strength of acoustic signals. The influence of glass slide in configuration (c) was mainly presented in frequency domain. Some same frequency components appeared simultaneously in the four configurations, which was the features of the gold nanocomposites in ultrasound generation.

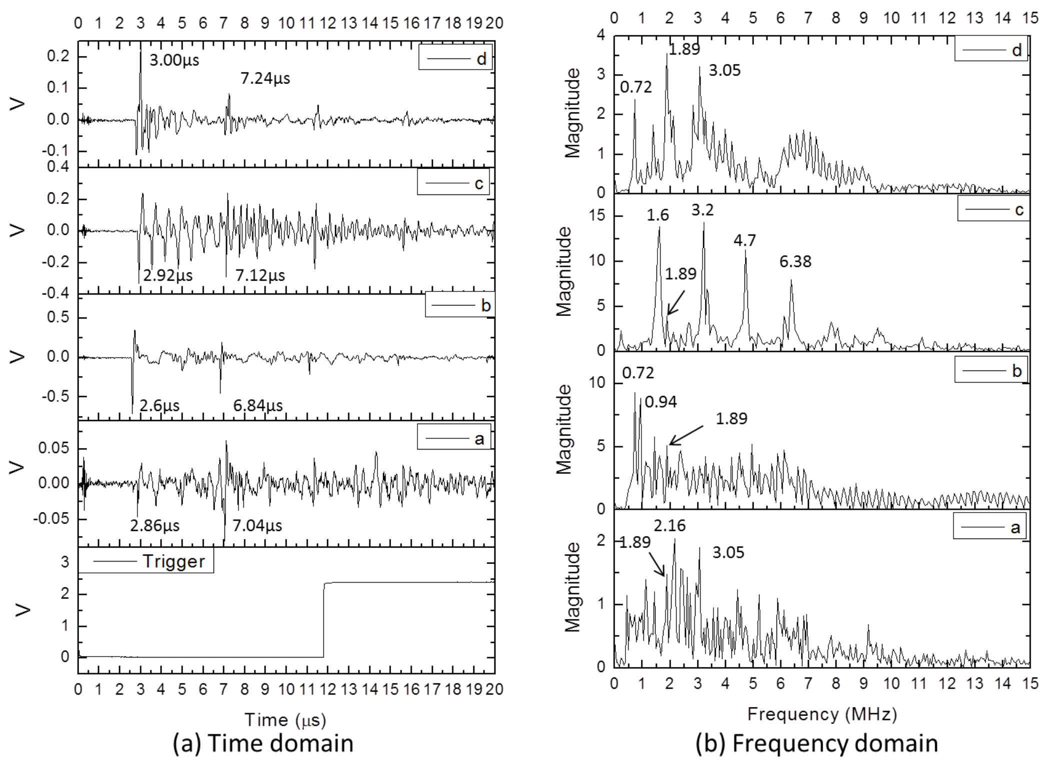

Figure 3 Signals of four configurations in (a) time domain and (b) frequency domain

Table 2 Comparison of experimental results

Configurations	Attenuation from Fist to Second Peak	Peak to Peak Value	Main frequency components (MHz)
(a)	-	0.14V	2.16; 3.05; 1.89
(b)	0.41V	1.05V	0.72;1.89
(c)	0.04V	0.57V	3.2; 1.6; 4.7; 6.38; 1.89
(d)	0.2V	0.33V	1.89; 3.05; 0.72

5. CONCLUSIONS

Four configurations were presented to compare how different structures can affect the ultrasonic transmission on the steel plate. It was verified that all the configurations were capable of acoustic generation. From the experimental results, the influence of the structure on the attenuation and the strength of acoustic signals was found. Other than that, in frequency domain, some same frequency components were present in the signals of all the configurations. In conclusion, the ultrasound generation configurations can have various applications considering the different features in the structure and the acoustic signals.

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