Fiber optic acoustic sensor based on Fiber Bragg grating Fabry-Perot(FBG-FP) cavity

Pengfei Zhang[1,2], Ziyang Xiang[2], Fangjun Wang[2],Yaqi Tang[3],Chao Wang[3,*],Chi Chiu Chan[3], ZiXiong Qin[1]

[1]Physical Science and Technology, Guangxi Normal University, Guilin, Guangxi 541004, China;

[2]Sino German Institute of intelligent manufacturing, Shenzhen University of Technology, Shenzhen, Guangdong 518118, China;

[3]Center of Commercialization for Advanced Sensors, Julong College, Shenzhen Technology University, Shenzhen 518118, China

Introduction

As an important carrier of information and energy, sound wave plays an important role in production and life. Optical fiber acoustic sensor has attracted much attention in many fields such as detection of mechanical structure , national defense security and medical diagnosis because of its excellent detection accuracy, high signal-to-noise ratio, wide-band frequency response and miniaturization.

This paper shows an acoustic sensor of Fiber Bragg grating and Fabry Perot (FBG-FP) cavity structure, as shown in Fig. 1.(a) and (b). Take two FBGs whose central wavelengths are all near 1550 nm for end cutting treatment before use a Fusion Splicer (Fujikura 80s+) for welding, ensure that the spacing between the two FBGs is 10mm, and vertically fix the optical fiber and flat top plastic cap by electronic coating machine (KSV dip coater). The treated optical fiber is inserted into the latex film，which has 1mm hole in the center and fixed on the 304 stainless steel sleeve with the threaded. And the other end passes the bottom cap of the stainless steel through the 1 mm hole. Then, cured it with the ultraviolet (UV) glue. It should be noted that the bottom cap of the stainless steel needs another additional opening with a diameter of 1 mm as the air outlet to ensure the consistency for the initial internal and external air pressure. It can change the tightness of the latex film by rotating them.

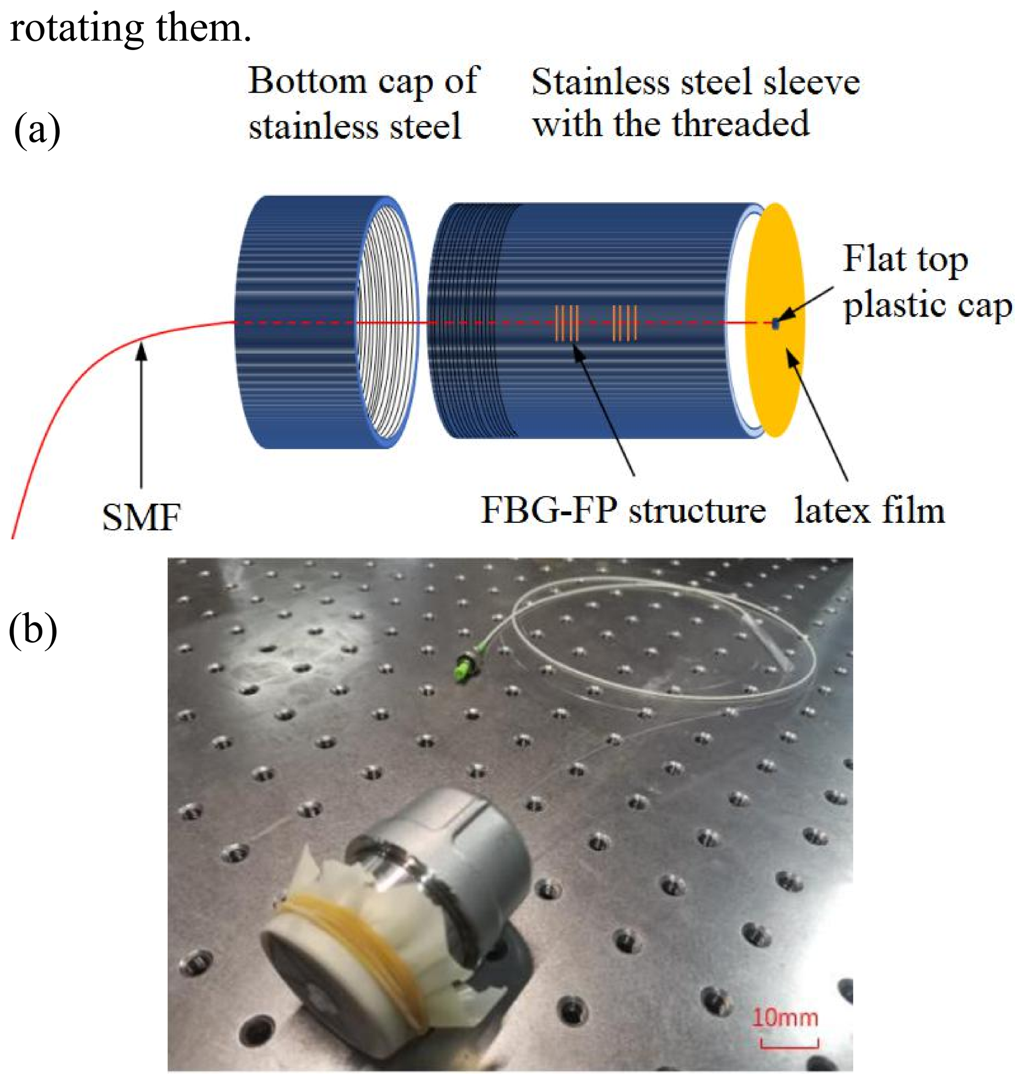

Fig. 1. (a) Structural diagram of optical fiber acoustic sensor;

(b) Physical drawing of optical fiber acoustic sensor.

Optical fiber acoustic sensor

The optical fiber acoustic sensing system proposed in this paper includes light source, optical fiber sensing and signal demodulation. In addition, a commercial acoustic microphone (B&K 4966) is used for technical calibration. After receiving the acoustic signal, the final signal to the oscilloscope after being processed by the amplifier. The system is shown in Fig. 2.

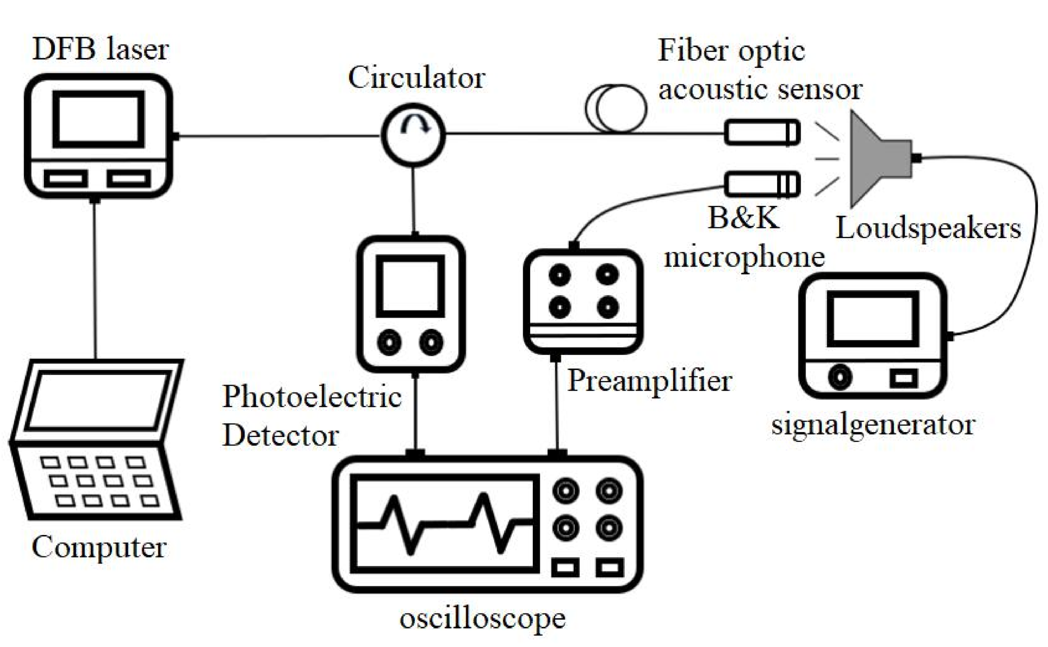

Fig. 2. Schematic diagram of optical fiber acoustic sensing system

A distributed feedback laser (DFB) with center wavelength of 1550.12 nm with the linewidth of 3.00 MHz is used as the light source, and the laser diode controller (THORLABS CLD1015) controls the output wavelength in real time to ensure that its matches the linear working area of the FBG-FP structure. The optical signal sent by DFB reaches the optical fiber acoustic sensor through the circulator. After being modulated by the external acoustic signal, it is reflected back to the circulator and enters the photoelectric detector (New Focus Model 2117) to be converted into voltage signal, and finally transmitted to the oscilloscope (KEYSIGHT MSO-X 4034A) for real-time display. The whole experiment is completed under the condition of constant temperature and quiet environment. The signal generator (keysight 33500b Series) can adjust the frequency and sound pressure of the sound signal to drive the loudspeaker to generate the sound source signal. In the experiment, the reference commercial acoustic microphone and optical fiber acoustic sensor are placed in the center of the loudspeaker in parallel to ensure that the received acoustic signal intensity is consistent.

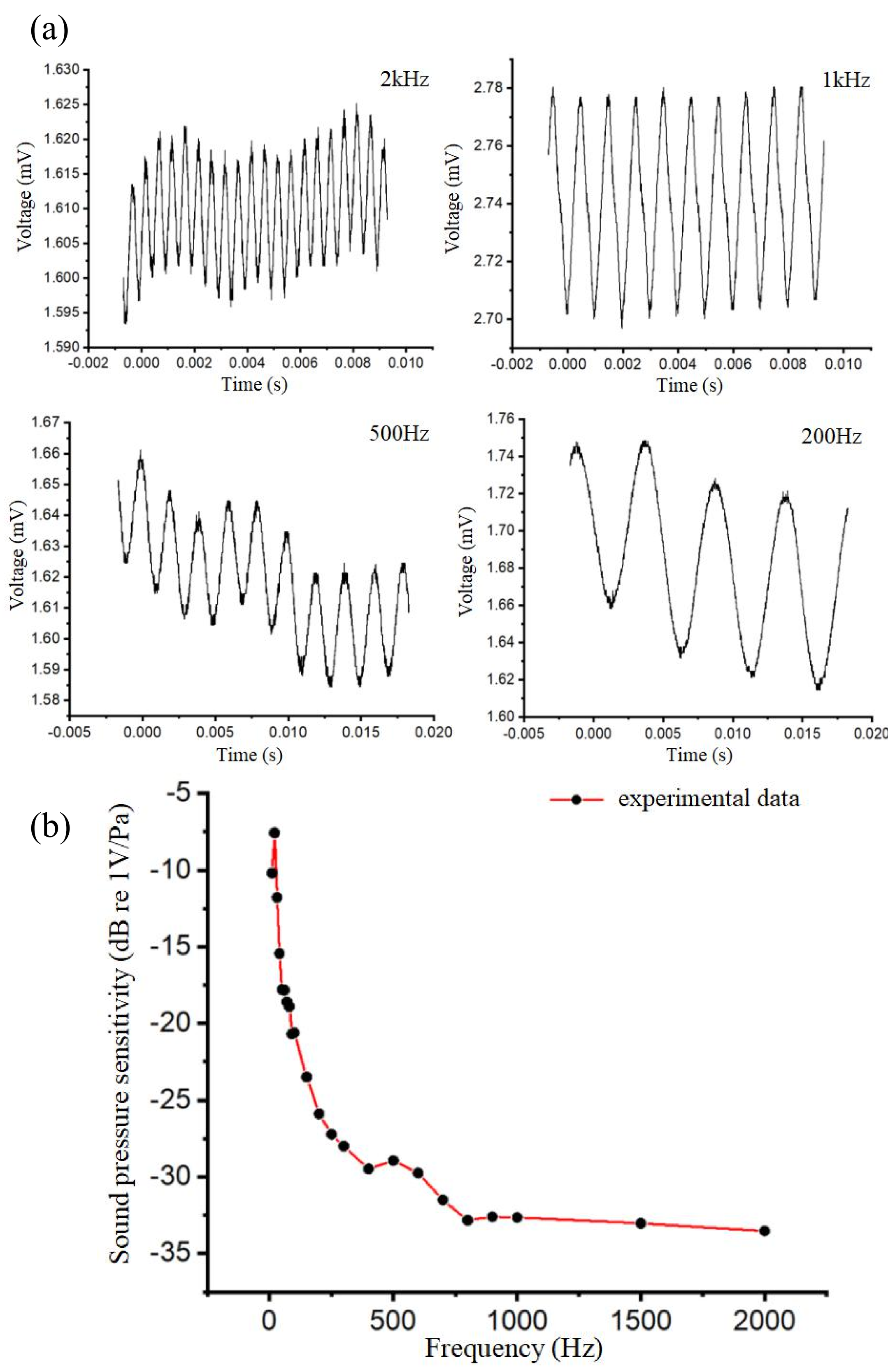

Fig. 3. (a)Time-domain waveforms of FBG-FP acoustic sensor under different frequency acoustic waves;
(b)Response frequency diagram of FBG-FP acoustic sensor;

The radius of film R is 20 mm, thickness d is 0.2 mm; the working area length L of grating is 6 mm; the spacing l between two FBGs is 10 mm; the central wavelength of laser λ is 1550 nm; the sinusoidal output signal amplitude of signal generator is 10 Vpp, acoustic signal frequency is 2 kHz-10 Hz. Fig. 3(a) shows the time-domain signals of acoustic sensor at different frequencies respectively. Fourier transform of the time-domain signal at each frequency to obtain the spectrum, get the sound pressure at the corresponding frequency, compare it with the commercial acoustic microphone, and calculate the sensitivity characteristics of FBG-FP at each sound frequency, as shown in Fig. 3(b).

It was obvious that the sensor has better demodulation ability for acoustic signals with different frequencies. According to the response sensitivity characteristics at different sound frequencies, the response diagram of sound pressure-frequency is shown in Fig. 3(b). The frequency response curve of acoustic sensor decreases gradually with the increase of frequency (700 Hz-2 kHz), and the sensitivity in this area is about 28.2 mV/Pa.

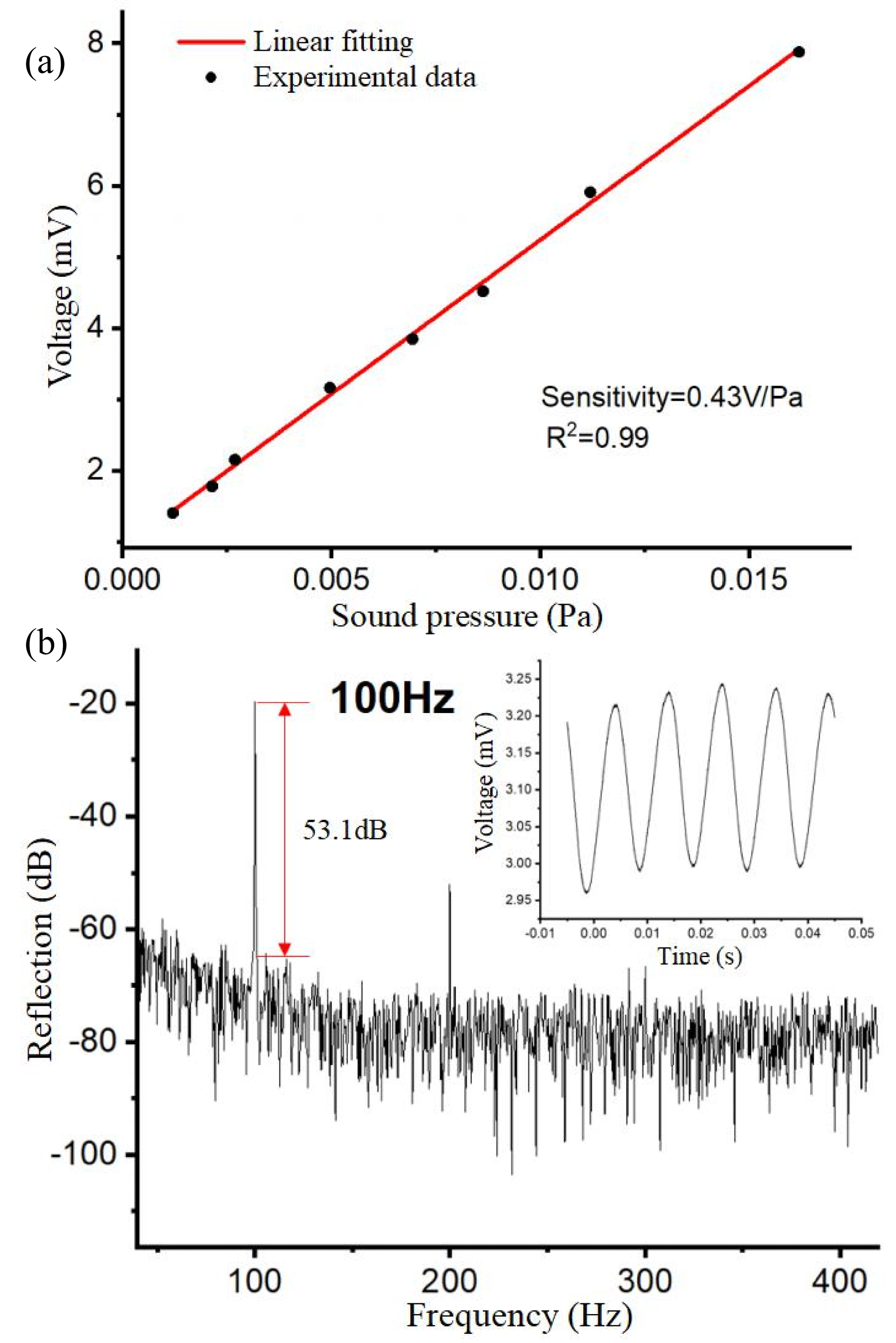

Fig. 4. (a) Relationship between output voltage and sound pressure of FBG-FP acoustic sensor (20Hz);

(b)Time-domain signal and corresponding FFT spectrum of FBG-FP acoustic sensor (100Hz)

The sensitivity response of this sensor reaches the peak near 20 Hz, which is consistent with the simulation results of resonant frequency. Keep the output frequency of the signal generator at 20 Hz and adjust amplitude, record the output voltage of the oscilloscope and data of the commercial acoustic microphone for calibration. The final results are shown in Fig. 4(a). It can be seen that it shows better linear response characteristics at 20 Hz, and the sensitivity is 0.43V/Pa, it can carry out high-sensitivity sensing within this acoustic frequency.

Apply a sinusoidal signal with frequency of 100 Hz with sound pressure intensity 0.987Pa, record the output voltage-time by the acoustic sensor through fast Fourier transform (FFT) as shown in Fig. 4(b). As can be seen the signal-noise ratio (SNR) in the 100 Hz is 53.1 dB. According to the minimum detectable sound pressure: $MDP=Signal/SNR*\Delta f$. Where $\Delta f=0.75$ *Hz* is the frequency measurement resolution of the system, and the minimum detectable sound pressure at 100Hz is 2.52 mPa/Hz$^{1/2}$ (42 dB).

Conclusion

In this study, a high sensitivity fiber-acoustic sensor is reported. In the low frequency (20 Hz) field, the sensitivity reaches 0.43 V/Pa. In the intermediate frequency range of 700 Hz-2 kHz, it has relatively flat frequency response characteristics, and the sensitivity is 28.2 mV/Pa. The signal-to-noise can reach 53.1 dB (100 Hz), and has better acoustic detection stability, the amplitude output jitter is less than 1dB. The minimum detection sound pressure is 2.52 mPa/Hz$^{1/2}$.

Acknowledgements

This work was supported in part by the Department of Education of Guangdong Province under Grants 2019KZDXM021 and 2018KZDXM077; in part by the Science and Technology Innovation Commission of Shenzhen under Grant JCYJ20200109144003948.