Cantilever-based photoacoustic detection of electromagnetic radiation

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We report here on a highly sensitive silicon cantilever-based photoacoustic electromagnetic radiation detector of broad spectral bandwidth. The developed detector can be used for measuring the power of radiation in the 100 nW to 10 mW range. Experiments have been carried out using 633 nm and 1523 nm lasers. The results show very good linearity and dynamic range.

INTRODUCTION

For monitoring environmental pollution or detecting toxic, inflammable and explosive gases [1-2], which pose major risk on health, safety and security, photoacoustic (PA) spectroscopy is one of the applied detection methods because of its high sensitivity and selectivity [3-4]. In the gas sensing applications, the non-radiative relaxation processes of electromagnetic-radiation-induced excited molecules generate heat and consequently produce pressure waves, which give rise to the PA signal. One of the common methods for detecting the PA signal employs a capacitive microphone. However, a capacitive microphone has several limitations including the nonlinear response of the membrane in sensing the external pressure. Apart from that, for improving the sensitivity, the gap between the membrane and the backplane of the capacitive condenser cannot be reduced below a certain limit, as the gas cannot anymore flow freely through such narrow region due to viscous effect [5]. An alternative approach has been developed for PA signal detection where optical beam deflection and micro-mechanical silicon (Si)-cantilevers are used. The cantilever-based approach does not have such drawbacks and it has been successfully used in many applications requiring very sensitive PA signal detection [6]. The cantilever-based PA signal detection method employs a compact interferometer for measuring the deflection of the cantilever tip [7]. In this study, we report on a Si-cantilever-based PA detection system for electromagnetic power measurements. Benefits of the new power measurement method include good linearity and broad spectral bandwidth. In contrast, most available power detectors are highly dependent on the operating wavelengths. Si-photodiode detectors, for example, work mainly in 200 nm-1100 nm range whereas, for infrared wavelengths, InGaAs detectors are used. However, the PA principle employs absorption of radiation into a black absorber material and this can be made rather independent of the operating wavelength over a large spectral range.

EXPERIMENT

Figure 1 shows the schematic diagram of the experimental setup. The system comprises three main modules: (1) an electromagnetic radiation source, the power of which falls on the absorbing material (for this experiment, candle soot was used) to generate heat, (2) the acoustic section consisting of a gas cell (in this case, it was filled with air) which contains the sample and a cantilever, (3) the optical readout system, to measure the cantilever deflection using a compact Michelson interferometer. The incident radiation first passes through a chopper and gets absorbed by the black absorber material to produce heat. The generated periodic heating causes volume expansion of the gaseous medium within the closed PA cell and produces pressure waves, which are finally detected by monitoring the position of the cantilever tip by using the optical interferometer.

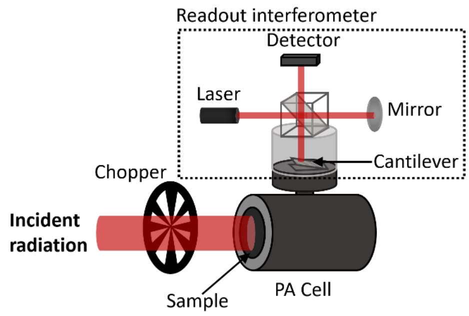

Figure 1. Schematic diagram of the experimental setup.

RESULTS

Experiments were performed using two incident wavelengths: 633 nm and 1523 nm. In both cases, the frequency of the chopper was at 43 Hz and the generated PA signals were measured by varying the input power of the incident radiation. Figure 2 shows the linearity of the PA signal amplitude with the input power. The data shows good linearity with R^2 values of 0.99985 and 0.99982 for 633 nm and 1523 nm wavelengths respectively.

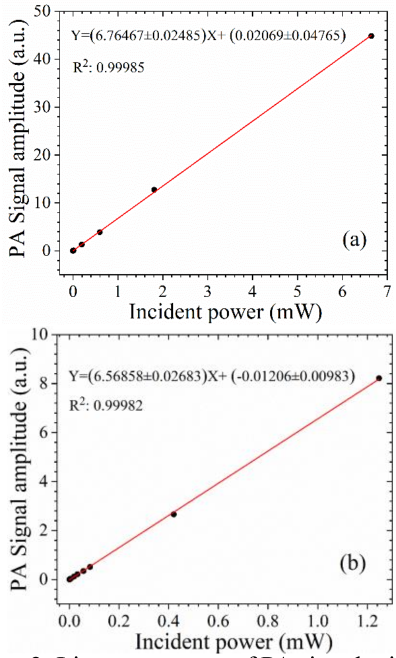

Figure 2. Linear response of PA signal with incident power of input radiation (a) 633 nm and (b) 1523 nm.

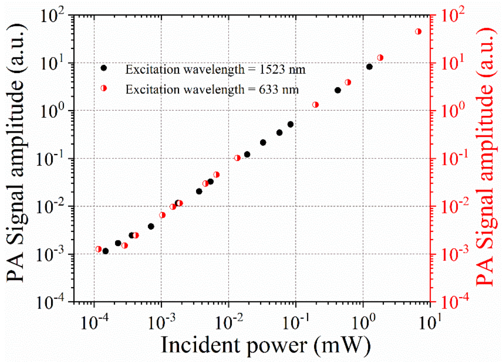

Figure 3. Peak amplitude of PA signal depicts no dependency on the incident wavelength.

The incident power was varied from 116 nW to 6.64 mW for 633 nm and from 147 nW to 1.25 mW for 1523 nm wavelength input radiation. As shown in Figure 2, the dynamic rage is nearly five orders of magnitude. According to theoretical estimation the highest power, which can be measured using the system, is close to 1W. Hence, the dynamic range can still be further extended. As Figure 3 demonstrates, the PA response is practically independent of the incident wavelengths. Thus, this process has potential to get extended to cover spectral ranges from Ultraviolet (UV) to Terahertz (THz) with suitable window materials of the PA cell.

CONCLUSION

We have presented a cantilever-based PA power detection technique, which is capable of measuring incident power from approximately 100 nW to 10 mW. This detection mechanism has the potential to measure up to 1 W making the dynamic range significantly large. In future, the detection scheme will be applied for power measurements of UV, infrared and THz (30 μm – 300 μm) radiation sources. Currently, no single power detector can operate under all the required wavelengths. The new PA power detection technology will be useful not only for scientific research but it can be applied also to medical and chemical industries where power measurement is one of the key necessities.

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