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Miniaturized laser Doppler velocimetry (LDV) integrated on silicon on insulator (SOI)

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I. INTRODUCTIONS

Laser Doppler velocimetry is a non-contact velocity measurement technique that employs the Doppler effect (named after Austrian physicist Christian Doppler) of lasers. They can be used to measure the speed of fluids or the vibration of eardrums, and have drawn much attention in variety fields, such as aerospace, automotive, semiconductor manufacturing and medicine. However, commercialized bulk LDV instruments (e.g. from Polytec) are expensive, not very compact, and of high power consumption (maximum 100 VA). Here we propose a miniaturized LDV system integrated on SOI, which has the potential of overcoming the aforementioned disadvantages.

II. WORKING PRINCIPLES OF LDVS

When a laser is sent to and reflected by a moving target, according to the Doppler effect, the reflected radiation has a frequency change of f_D with respect to the source. The frequency shift f_D is proportional to the velocity of the target relative to the source v, and it can be expressed as

$$f_D \approx \frac{2v}{c} f_0, \qquad (1)$$

where c is the speed of light in the medium, and f_0 is the original frequency of the laser. The Doppler shift (when $\lambda_0 = 1550$ nm) is around 6.5 MHz when the target's velocity is 5 m/s (speed that the pressure wave of aorta can reach [1]), and is 1.3 kHz when the velocity is 1 mm/s (speed level of the vibration of ear drums [2]).

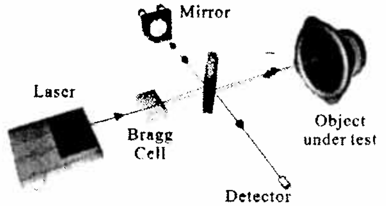

Figure 1. Illustration of a commercialized bulk LDV system with a heterodyne interferometer. The laser is split into two beams: the reference beam (frequency shifted) and the measurement beam (no previous frequency shift). The reflected measurement beam is mixed with the reference beam at the photo-detector, where the detected signal is sent to the decoder for demodulation.

Conversely, if the frequency shift f_D of the reflected radiation is measured, we can obtain the relative velocity of the moving target using the aforementioned relation. It is how LDV system make the velocity measurement. The configuration of the simple bulk LDV system is illustrated in Fig.1.

Homodyne and heterodyne are two basic detection methods of LDV systems. In homodyne the reflected measurement laser is mixed with a reference laser to obtain a measurable beat frequency for the photo detector, while in heterodyne it is mixed with a frequency-shifted one. Heterodyne method is more commonly used because it provides: 1. a better noise tolerance compared to homodyne; 2. and the information of the movement direction that homodyne does not provide. The system illustrated in Fig. 1 uses heterodyne method for the detection.

The frequency shifter for a bulk LDV system is usually a Bragg cell, which can change the frequency of incident laser by using the acousto-optic effect. Unfortunately, they are too large in size for our proposed system, and are difficult for SOI integration.

III. LDVS ON SOI

Developments of micro-photonics have made it possible to integrate LDV systems on tiny SOI substrates. SOI technologies are CMOS compatible, which can reduce the manufacturing price of the devices. Decreasing the dimension of the entire system is also benefit to lower the required power.

SOI waveguide is a good candidate for passive photonic devices (e.g. waveguides, splitters) because of the high confinement of the optical field in the SOI waveguide . Micro structures, such as the Mach-Zehnder interferometers (MZIs) and grating couplers (for sending and receiving radiations) can be fabricated through silicon photonics processes. However, the intrinsic nature of crystalized silicon makes it not suitable for active devices (e.g. laser diode, modulator). In order to generate and detect lasers on SOI, we normally use a polymer called Benzocyclobutene (BCB) to bond the laser diodes and photo-detectors on SOI substrates [3]. Optical phase modulators on silicon, in another way, can be fabricated by injecting electronic carriers in silicon [4]. Optical frequency shifters can be realized by driving the phase modulator with certain sawtooth signals. However, these are not mature techniques and still need to be optimized. The final chip that we want to fabricate is shown in Fig. 2.

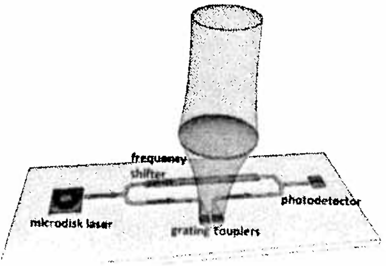

Figure 2. The miniaturized laser Doppler velocimetry on SOI. The laser is generated by a bonded micro-disk laser, and split into a measurement and a reference signal. The measurement signal is sent out and captured through grating couplers and reflected back by the moving target. The reference signal is mixed with the captured measurement signal after being frequency shifted by an optical frequency shifter. The photo-detector, which is also integrated on SOI substrate by BCB bonding, detects the combined signal and sends it to the decoder.

IV. CONCLUSIONS

The silicon photonic technology makes it possible to miniaturize the LDV systems on SOI with a footprint smaller than 1 mm^2. It can also reduce the power consumption (can be lower than 100 mW) and the price of the system. The miniaturized LDV on SOI is a promising technique.

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