Non-contact measurement of sub-micron-level ultrasonic vibration by near-field microwave

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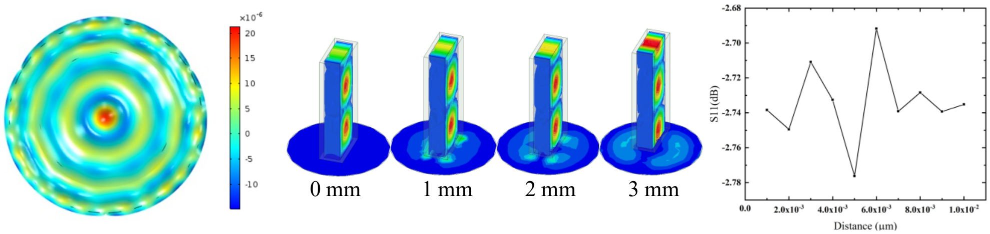
Background – Microwave non-destructive has been widely applied in dielectric properties [1] and internal defects [2] of materials, and moisture content, etc. Sub-micron-level ultrasonic vibration is conventionally detected with piezoelectric transducers which require directly contact. Optical non-contact vibrometry has excellent accuracy but requires sophisticated setup and good surface finish on the measured object. Alternatively, near-field microwave has high sensitivity in perceiving local change of dielectric property and distance, which makes it applicable in testing small ultrasonic vibrations in metal.

Theoretical modelling – Sub-micron ultrasonic vibrations are usually generated by pulse or modulated lasers in photoacoustic techniques [3]. They also occur in piezoelectric transducers operating at a frequency range far away from its resonance states [4]. As depicted in Fig. 1(a), a piezoelectric patch was modeled in an FEM software (COMSOL Multiphysics) and operating at 80 kHz.



(a) **(b)** **(c)**

Fig. 1. The finite element simulation of (a) a piezoelectric patch operating at 550 kHz, (b) electromagnetic simulation between open-ended waveguide and sample with distance changes from 0 mm to 3 mm and (c) the received energy simulation.

The carrier signal $T(t)$ is fed into the waveguide and travels towards the sample, and vibration signal $x(t)$ is modulated to the high frequency carrier signal. The modulated signal $M(t)$ received by waveguide can be expressed as

$$T(t) = \cos(2\pi ft) \qquad \text{Eqn. 1}$$

$$M(t) = \alpha(d)\cos(2\pi ft - \frac{4\pi x(t)}{\lambda}) \qquad \text{Eqn. 2}$$

where d indicates the distance between the piezoelectric patch and the open-ended waveguide. The back propagated microwave is sensitively to the distance, which add $\alpha(d)$ on the amplitude of the modulated signal. The frequency was chosen at 18 GHz with 10^{-3} μm distance stepping changes on 1mm, and the results is shown in Fig. 1(c).

Experimental and discussion – As shown in Fig. 2(a). The open-ended waveguide was placed perpendicular to the piezoelectric patch to obtain the vibration signal directly. The microwave was fed into the measuring system which consists a coupler and a circulator to the open-ended waveguide. Vibration signal was modulated by the microwave and received by open-ended waveguide and sent to the demodulating system, the lock-in amplifier demodulated vibration signal and analyzed by the computer.

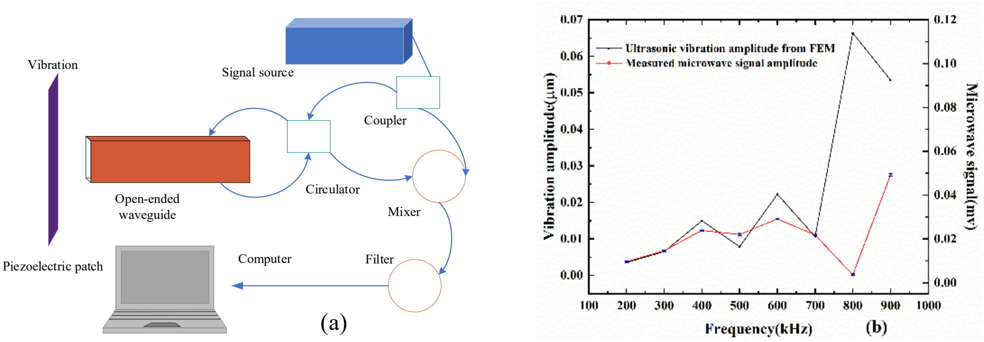


Fig. 2. (a) The measurement of vibration signal by microwave measurement system **(b)** Ultrasonic vibration amplitude from FEM; Measured microwave signal amplitude

Fig. 2(b) shows the experimental frequency-dependent vibration changes and the measured vibration signal in voltages at different frequencies. The result shows the amplitude of demodulated microwave signal has certain qualitative analogy with respect to the sub-micron ultrasonic vibration amplitude. The change trend of voltage signal is basically consistent with the finite element simulation.

Conclusion – A near-field microwave vibrometric configuration was proposed. Ultrasonic sub-micron-level vibration is successfully interpreted by the demodulated microwave voltage signal, which makes it promising for noncontact ultrasonic testing.

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