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Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 183-184
3-5 December, 2014

Watching arbitrary acoustic whispering-gallery modes in the GHz range using ultrashort light pulses

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1. Introduction

Surface acoustic waves (SAWs) are used in various domains such as nondestructive testing and evaluation, filters or waveguides. Furthermore, knowledge of their propagation is essential to better understand two-dimensional phononic crystals and phononic metamaterials with the aim of mastering negative refraction or super lensing.

The SAW propagation can be effectively studied by time-resolved two-dimensional imaging [1-6]. A typical set-up for such measurement involves an optical pump-probe technique, with a periodic light pulse source of subpicosecond duration, in order to work in the GHz range. The SAWs are generated by the absorption of light pulses (pump light) focused on the sample, while they are monitored by delayed light pulses (probe light) also focused on the sample. By scanning the focused position of the probe light, two-dimensional imaging is achieved. A delay line on one of the beams allows one to scan the delay time in order to get time-resolved information. This 'classical' set-up is however limited to generating and detecting acoustic waves at frequencies only at integer multiples of the repetition frequency f_{rep} (typically ~80 MHz) of the laser, that is at frequencies $n f_{rep}$, where n=1, 2, 3,…

Here we propose a method using amplitude modulation to overcome this frequency limitation and offer the possibility of mapping SAWs at any given frequency [7]. This new set-up is applied to a copper disc in order to observe whispering-gallery (WG) modes [8]. Such modes, propagating around the disc rim, have applications in the nondestructive testing of pipes or in signal filtering for telecommunications, for example. Recently, WG modes have been observed with a 'classic' SAW imaging technique [9]. We present here results of different WG modes that were inaccessible with the 'classical' method.

2. Principle of frequency control

In order to obtain information on the sample at any desired frequency, the proposed method takes advantage of the amplitude-modulated pulse train. The frequency spectrum of the amplitude-modulated pulse train contains the main carrier components (integer multiples of the repetition frequency, as in the 'classical' SAW technique) and their sidebands, separated from the carrier frequencies by the modulation frequency on both the upper and lower frequency sides (USB and LSB, respectively). The SAWs generated by such modulated light pulse trains exhibit a similar frequency spectrum.

The generated SAWs can be monitored by the probe light through its intensity or phase change. This is detected by a photodetector and ta lock-in amplifier referenced to the modulation frequency. By simultaneously using information from the in-phase (X) and the quadrature (Y) components of the optical phase difference, and by appropriate Fourier analysis, it is possible to discriminate the USB and LSB of the signal [7]. This offers a means to tune to frequencies of interest by adjusting the modulation frequency.

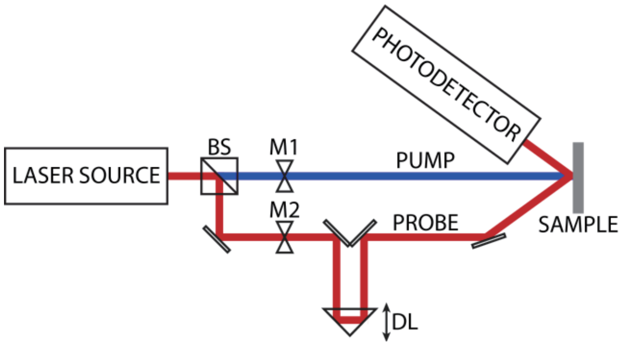

Fig. 1: Schematic representation of the experimental set-up

3. Experiments and results

The sample is a disc of copper of 50 μm diameter and 375 nm thickness, embedded in a layer of silica. Part of the light from a mode-locked Ti-sapphire laser (repetition frequency f_{rep}=75.6 MHz) is frequency doubled and used for the pump (wavelength 415 nm). Another part of the light is used for the probe (wavelength 830 nm). Both beams are focused to a spot of radius ~1 μm on the surface of the sample. The pump beam is focused near the rim and the delayed probe beam scans a 70×70 μm^2 area of the sample surface. With the interferometer set-up, the probe beam detects the

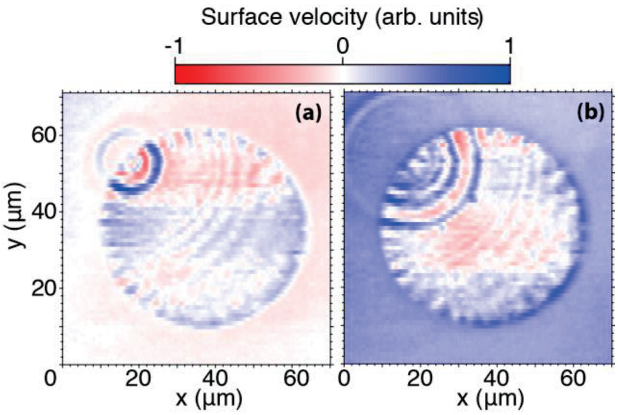

Fig. 2: Surface acoustic wave images of the quadrature (Y) component at delay times (a) 2.9 and (b) 6.3 ns after pump pulse arrival.

out-of-plane surface motion as the variation of the output light intensity, which is detected by a photodetector and a lock-in amplifier. Since our photodetector has a 3 MHz bandwidth, we used a heterodyne set-up to reach higher frequencies. Both pump and probe beams are amplitude modulated at different frequencies f_{pu} and f_{pr}, respectively, with $|f_{pu}-f_{pr}|<3$ MHz. The resulting signal is then analyzed with the lock-in amplifier at the difference frequency $|f_{pu}-f_{pr}|$. The experimental set-up is displayed on Fig. 1.

Figure 2 shows an image of the out-of-plane velocity of the surface at the delay times t=2.9 and 6.3 ns (Fig. 2(a) and 2(b), respectively). The SAW wavefronts are propagating as concentric circles from the excitation point at the upper left rim of the copper disc. The copper/silica boundary is clearly observable by the displacement intensity.

Fig. 3 displays 4 sets of results with a pump beam modulated at 6 MHz, and a probe beam modulated at 7.7 MHz. Results around 530 ($f=7f_{rep}\pm f_{pu}$) and 605 MHz ($f=8f_{rep}\pm f_{pu}$) display clear whispering gallery modes. Distinction between upper and lower sideband offers the possibility to exhibit different patterns: 25 (Fig. 3(a)) and 26 (Fig. 3(b)) periods are respectively visible in the first case. Similarly, 31 (Fig. 3(c)) and 32 (Fig. 3(d)) are respectively visible in the second case.

Other modes can also be revealed by repeating the experiment at different pump modulation frequencies. We can also evaluate the quality factor of a particular mode by using the tunability of our technique to follow the amplitude of one particular mode.

4. Conclusion

We use a laser picosecond ultrasonics set-up to generate whispering gallery modes in a copper disc at arbitrary frequencies. The technique involves intensity modulation of both pump and probe beams, and discrimination between the upper and lower sidebands. Our results demonstrate clearly the selective excitation of some particular modes.

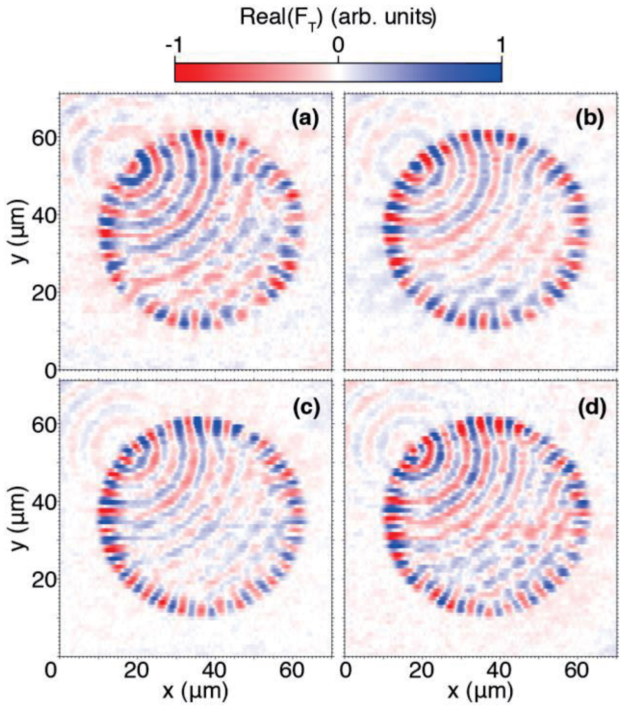

Fig. 3: Real part of the temporal Fourier transform of the signal for the LSBs ((a) and (c)) and USBs ((b) and (d)) at (a) f=524 MHz, (b) 535 MHz, (c) 599 MHz and (d) 611 MHz.

Acknowledgment

S. Mezil is an International Research Fellow of the Japan Society for the Promotion of Science (JSPS).

References

1. J. W. Dally, Exp. Mech. **20**, 409 (1980).
2. R. E. Vines, M. R. Hauser, and J. P. Wolfe, Z. Phys. B **98**, 255 (1995).
3. M. Clark, S. D. Sharples, and M. G. Somekh, J. Acoust. Soc. Am. **107**, 3179 (2000).
4. Y. Sugawara, O. B. Wright, O. Matsuda, M. Takigahira, Y. Tanaka, S. Tamura, and V. E. Gusev, Phys. Rev. Lett. **88**, 185504 (2002).
5. A. A. Maznev, A. M. Lomonosov, P. Hess, and A. A. Kolomenskii, Eur. Phys. J. B **35**, 429 (2003).
6. C. Glorieux, K. Van de Rostyne, J. D. Beers, W. Gao, S. Petillion, N. V. Riet, K. A. Nelson, J. F. Allard, V. E. Gusev, W. Lauriks, and J. Thoen, Rev. Sci. Instrum **74**, 465 (2003).
7. S. Kaneko, M. Tomoda, and O. Matsuda, AIP adv. **4**, 017142 (2014).
8. Lord Rayleigh, Philos. Mag. **20**, 1001 (1910).
9. T. Tachizaki, O. Matsuda, A. A. Maznev, and O. B. Wright, Phys. Rev. B **81**, 165434 (2010).