2Pb1-1

Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 177-178
8-10 November, 2011

Study of the generation and detection of GHz acoustic waves in a SiO_2 film on a GaAs (411) substrate using picosecond laser acoustics

ピコ秒レーザー超音波法による SiO_2 薄膜/GaAs(411)基板における GHz 音響波の生成と検出

Masahiro Tonomura†, Osamu Matsuda, Motonobu Tomoda and Oliver B. Wright (Fac. Eng., Hokkaido Univ.)
外村将大†，松田理，友田基信, Oliver B. Wright (北大　工)

1. Introduction

High frequency acoustic waves up to or beyond 1 THz may be generated in a medium by the absorption of subpicosecond pump optical pulses. The propagation of the acoustic waves modulates the permittivity of the medium and the optical reflectivity. The reflectivity modulation can be detected by delayed probe light pulses to achieve a time domain measurement. This technique, known as picosecond laser acoustics (PLA), [1] can be used to obtain information on the internal structure of the bulk or thin film samples.

In order to investigate the properties of transparent thin films one needs to deposit an opaque transducer on them. [2] This is a commonly used technique in PLA. For example, a Zn substrate was used to investigate GHz acoustic propagation in a SiO_2 film. [3]

In this paper, we investigate the use of a bulk semiconductor as a transducer in PLA by means of a sample consisting of a transparent film on bulk GaAs. The GaAs substrate acts as a high frequency acoustic wave generator, [4] producing an acoustic pulse that enters the transparent film. Shorter optical penetration depths, corresponding to pump photon energies above the band gap, are generally favorable for higher frequency acoustic generation. The wavelength of the probe light is also important for acoustic wave detection in semiconductors because it affects the depth, on the order of optical absorption depth, over which acoustic wave propagation can be sensed, and therefore the frequency bandwidth of the detection. Here we use above-band-gap photon energies both for the pump and probe light in GaAs to achieve both high frequency generation and detection in a bulk semiconductor coated with a SiO_2 film, extending previous measurements on a similar system to thicker SiO_2 films ~1 μm in thickness. [5] We also present a modified version of the heterodyne setup introduced by Vollman et al. [6] for the measurements to avoid crosstalk between the pump and probe beams.

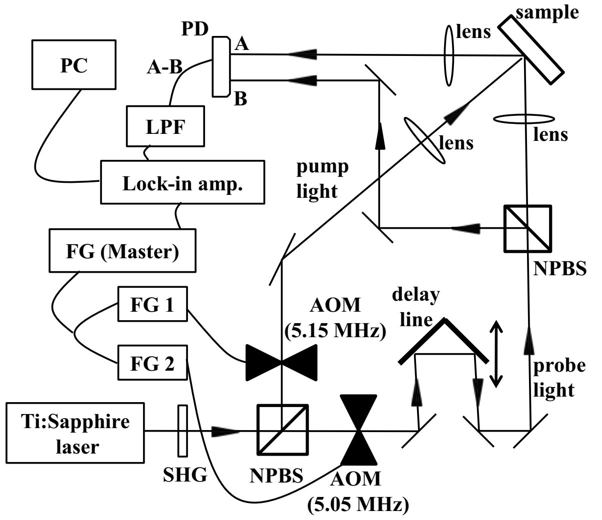

Fig. 1. Schematic diagram of the experimental setup. SHG: second harmonic generation crystal, AOM: acousto-optic modulator, NPBS: non-polarizing beam splitter, PD: photodetector, FG: function generator, and LPF: low-pass filter. PD A receives the reflected probe light, whereas PD B receives the reference light.

2. Experiments

The sample consists of a SiO_2 film of nominal thickness ~1.4 μm deposited on a GaAs (411) substrate using radio frequency sputtering.

Figure 1 shows a schematic diagram of the optical setup. It is based on the optical pump-probe technique with a mode-locked Ti:sapphire laser of central wavelength 830 nm, pulse duration ~200 fs, and repetition rate 80 MHz. The 830 nm light is frequency doubled through a second harmonic generation (SHG) crystal (β-BaB_2O_4) to obtain blue light with a wavelength of 415 nm. This blue beam is divided into two beams, a pump beam and a probe beam. The pump beam is chopped at 5.15 MHz by an acousto-optic modulator (AOM) driven by a function generator (FG1). The chopped beam is then focused onto the SiO_2/GaAs interface. The pump pulses generate acoustic waves through the thermoelastic and deformation potential mechanisms in the GaAs substrate, and the generated acoustic waves are transmitted to the SiO_2 layer. The probe beam passes through a variable delay line, and is chopped at 5.05 MHz by another AOM driven by a second function generator (FG2). The chopped probe beam is focused onto the sample at 45° incidence with s polarization. The detection relies on heterodyning to produce an output signal modulated at the sum frequency 5.15 + 5.05=10.20 MHz and difference frequency 5.15 – 5.05=0.10 MHz. The s-polarized component of the reflected probe beam and a part of the chopped probe beam are fed to a two-channel photodetector, and an output proportional to their difference is obtained in order to reduce the effect of 5.05 MHz component. The 0.10 MHz difference frequency component is detected using a low-pass filter (LPF) and is fed to a lock-in amplifier synchronized to the 0.10 MHz reference frequency. FG1 and FG2 are synchronized to a master function generator [FG (master)]. The output of the lock-in amplifier is recorded as a function of the delay time between the pump and probe light arrival at the sample.

The heterodyne technique is essential to remove the effects of scattered pump light because the same wavelength is used for both the pump and probe light, though the use of cross-polarized light for the pump and probe is also possible in certain experimental configurations. [5]

3. Results and discussion

A typical result for the reflectivity change variation $\delta R/R$ for the SiO_2/GaAs sample is shown in Fig. 2. A characteristic oscillation is observed up to 540 ps. This Brillouin oscillation is known to arise from the interference between the light reflected at the interface and the light scattered at the propagating acoustic pulses in the transparent film. The oscillation frequency is given by $f = 2nv\cos\theta/\lambda$, where n is the refractive index, v is the longitudinal sound velocity, λ is the wavelength of the probe light and θ is the incidence angle of the probe light in the medium (SiO_2). In this case, f = 34.0 GHz, and n = 1.47 gives v= 5.48 m s^{-1}, which agrees reasonably with the literature value for bulk fused silica (5.97 km s^{-1}). At 260 ps, 540 ps, and 810 ps, steps in $\delta R/R$ are caused by the surface and/or interface displacements owing to the acoustic pulse arrival at the surface or interface. Multiple reflection of the probe light in the SiO_2 layer allows this effect to be observed optically. The

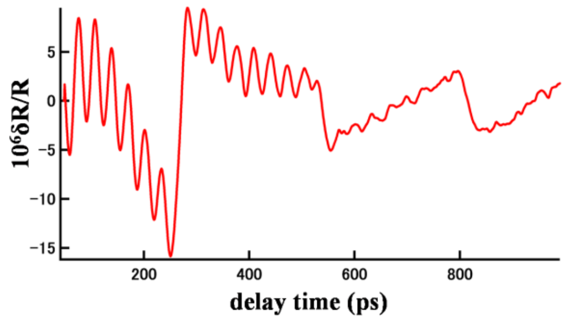

Fig. 2. Reflectivity change as a function of pump probe delay time.

photoelastic contribution from the GaAs substrate to $\delta R/R$ is not clearly discernable is this data.

4. Conclusions

In conclusion we have investigated high frequency acoustic wave generation and propagation in a SiO_2 film on a GaAs substrate using an ultrafast optical pump-probe technique based on a heterodyne method and using identical wavelengths for the pump and probe light. The acoustic pulse propagation can be followed in the SiO_2 film thanks to Brillouin oscillations and arrivals of the acoustic pulse at the surface and interface.

Quantitative analysis of the echo shapes depends on the theory of optical detection with oblique optical probe incidence, [3] and modeling based in this theory will be carried out in future.

References

1. C. Thomsen *et al.*, Phys. Rev. B **34**, 4129 (1986).
2. O. B. Wright, J. Appl. Phys. **71**, 1617(1992).
3. O. Matsuda *et al.*, Phys. Rev. B **77**, 224110 (2008).
4. O. B. Wright *et al.*, Phys. Rev. B **64**, 081202 (2001).
5. M. E. Msall *et al.*, J. Phys. Conf. Series **92**, 012026 (2007).
6. J. Vollman *et al.*, Ultrasonics **40**, 757 (2002).