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Guided wave propagation in a 2-D patterned nano-bridge studied by picosecond ultrasonics
ピコ秒超音波法を用いた2次元Auナノブリッジ内のガイド波の計測

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1. Introduction

Recent development in nano-order fabrication techniques allows us to make fine structures, where representative lengths are comparable or smaller than wavelength of visible light. They show interesting optical properties, leading to photonic crystals for selective propagation of electromagnetic waves (photonic bandgap),[1)] conversion of broadband to narrowband thermal emission for an efficient solar cell,[2)] and so on. Such a nano-order-patterned structure also shows interesting acoustic properties, achieving the 'phononic' crystals. To study propagation behaviors of sounds in phononic crystals such as 1-D nanowires,[3,4)] and 2-D patterned nanodots[5)] or nanovoids,[6)] picosecond ultrasound spectroscopy has been used: It can excite and detect ultrahigh-frequency coherent phonons, whose wavelengths are shorter than that of a visible light.

In this study, we study guided-wave propagation in 2-D patterned nano-bridges as shown in **Fig. 1** using picosecond ultrasound spectroscopy. The 30-nm thick Au nano-bridges are fabricated on a Si substrate using electron-beam lithography. The distance between the triangle islands is 5 μm, and the width of the bridge is 500 nm.

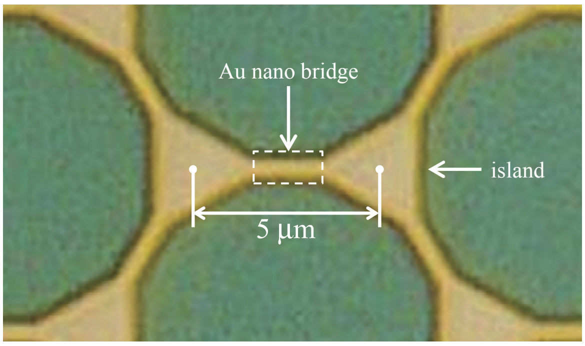

Fig. 1 A SEM image of the 2-D patterned Au nano-brides. Its thickness and width are 30 and 500 nm, respectively. The distance between the triangle islands is 5 μm.

By changing the focusing points of the pump and probe lights using a 150-times objective lens, we observe guided waves propagated in the Au nano-bridge. Usually, guided waves show dispersion, and a strain pulse excited by a femto-second light pulse is broadband. Whereas, by using 20-times objective lens, for example, we could excite coherent phonons in larger area at the same time. This kind of structure is expected to have unique vibrational modes due to its patterned structure.

More importantly, we intend to apply this guided wave propagation for a biosensor to detect proteins in liquids. Although acoustic wave propagation has been already used for biosensors,[7)] there are three advantages in this method; first, higher-frequency and shorter-wavelength acoustic waves can be excited in our method, which are more sensitive to detect biomolecules through mass addition and viscosity change. Second, each bridge can be used as an independent biosensor by immobilizing different receptor proteins, leading to a large-scale multichannel biosensor. Third, this method avoids deterioration of immobilized proteins on the bridges due to the light irradiation because the exciting and detecting points are not the bridge but the triangle islands where proteins are not immobilized. Recently, picosecond ultrasonics has been applied to biosensor[8)] or bioimaging,[9)] where the irradiation must affect proteins; its energy is larger than a few mW but reaches 10 J/m^2.[9)]

2. Experimental method

To excite and detect coherent phonons on the island, we developed an optics as shown in **Fig. 2**. We used titanium/sapphire pulse laser whose wavelength and repetition rate are 800 nm and 80 MHz, respectively. We control the delay time by two corner reflectors and a 200-mm stage controller in the light path of the pump light, leading to the delay time of 2600 ps at most. We modulate the pump light pulses as 100 kHz and use a lock-in-amplifier, enhancing the signal to noise ratio. The wavelength of the probe light pulses is

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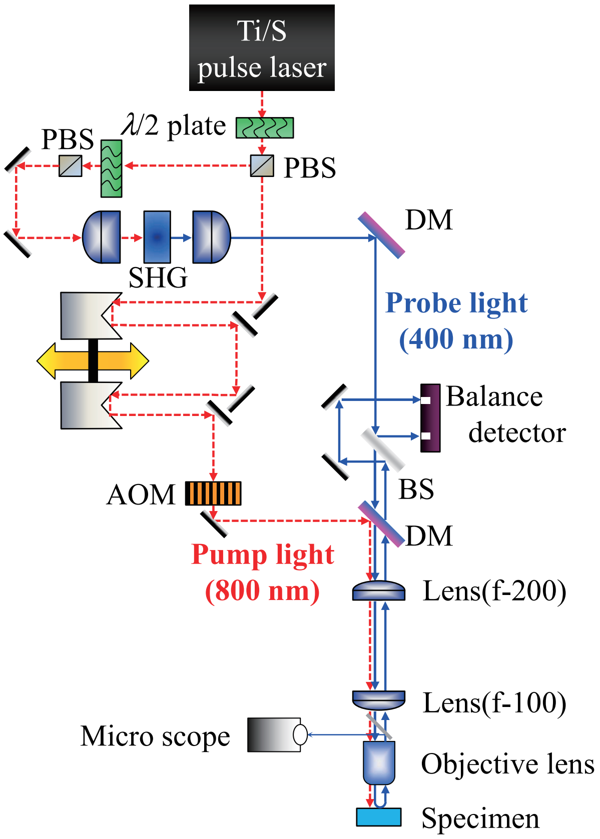

Fig. 2 Schematic of the optics we developed. Dashed and solid lines represent 800-nm and 400-nm wavelength lights, which are used as the pump and probe lights, respectively.

converted into 400 nm by a second harmonic generator (SHG). To change the position of the pump light pulses, we make a relay lens. We use 150-times apochromat objective lens to observe guided waves.

3. Results

Firstly, we focused both of pump and probe light pulses on a same island. The observed signal is shown in **Fig. 3 (a)**. We observed around 40 to 70 GHz vibrations and Brillouin oscillation of Si. We also observed propagated wave in a nano-bridge by

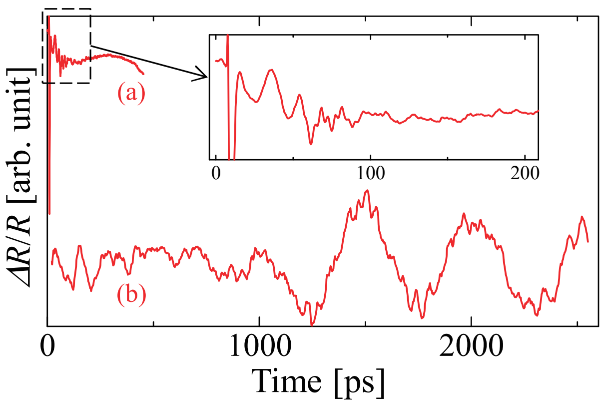

Fig. 3 Observed signals focusing (a) both of pump and probe light pulses on a same island and (b) pump and probe lights on adjacent islands on Si substrate.

focusing pump and probe light pulses on adjacent islands as shown in Fig. 3 (b). The propagation time and its frequency are about 1 ns and 2 GHz, respectively, indicating that sound velocity is order of 1000 m/s. We'll apply this system to a biosensor.

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