Probing thermal evanescent waves on dielectric surfaces

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***Abstract*—Our passive near-field microscope probes thermal evanescent waves due to local phenomena on material's surface. With the microscope, we study dielectric samples since they have surface phonon resonances whose resonance wavelengths are very close to our detection wavelength. From the results, GaAs, SiC, and AlN show reasonable signals due to thermal fluctuations, whereas GaN show very unique characteristics. In this report, we show and discuss the results.**

I. INTRODUCTION

OUR passive near-field microscope can probe spontaneous surface waves with 20 nm spatial resolution without any external illumination. [1] As shown in Fig. 1(a), a sharp tungsten tip approaches the sample surface, the tip apex scatters thermal evanescent waves, and an ultra-highly sensitive detector, CSIP (charge sensitive infrared phototransistor; shown in Fig. 1(b)), [2] detects the scattered photons. With the passive near-field microscope at the wavelength of 14.5 μm, we achieve passive near-field signals like Fig. 1(c). Theoretical and experimental analyses have revealed that the passive near-field signals on metals/dielectrics should originate from thermal charge/current fluctuations. [3] We have thoroughly studied thermal evanescent waves only on metals with the microscope so far. [3] Much more interesting samples to be studied should be dielectric materials since they show surface phonon resonances in infrared/terahertz region (wavelength λ: 10~20 μm). In this report, we show thermal near-field signals on several dielectric samples and discuss the guiding principle of passive near-field detection.

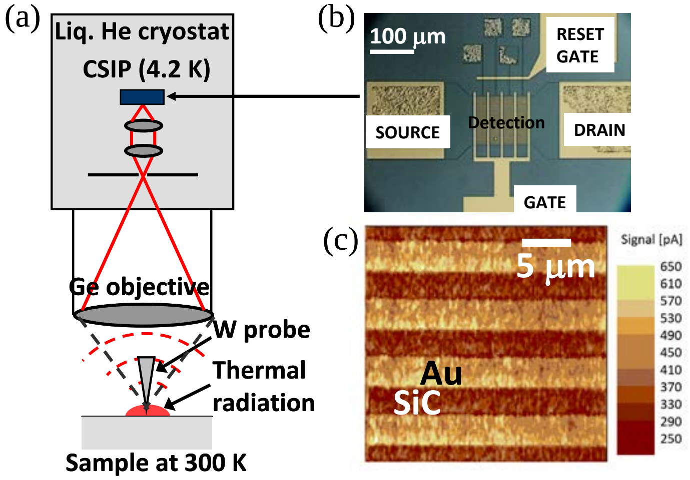

Figure 1 (a) Schematic diagram of our passive s-SNOM. (b) Microscope image of a CSIP detector. (c) Passive near-field image on SiC/Au gratings.

II. EXPERIMENTS AND RESULTS

We prepared GaAs, SiC, AlN, and GaN single crystal samples via electron beam lithography as well as a Au sample as a reference. The wavelengths of the surface phonon polaritons are 34.5 μm, 10.6 μm, 11.8 μm, and 14.2 μm, respectively. In this study, the wavelength of the CSIP detector is 14.5 μm, very close to the GaN resonance.

We first studied prepared samples with a tip apex height of 10 nm. GaAs, SiC, and AlN showed finite passive near-field signals due to thermally excited phonons. However, surprisingly, we could not find any signal on GaN surface though its phonon-resonance wavelength lies very close to the detection wavelength (14.5 μm). For further understanding, we then studied the tip height dependence on passive near-field signals. Figure 2 shows the results over GaAs, SiC, AlN, GaN, and Au. When the tip (probe) height is small (< 20 nm), signal amplitudes lie AlN > Au > SiC > GaAs > GaN. Figure 3 plots numerical calculations of the amplitude of electromagnetic local density of states (LDOS) [4] at tip height h = 10 nm. The amplitudes of thermal evanescent waves on metal/dielectric samples are strongly correlated to electromagnetic LDOS. In Fig. 3, the detection wavelength of the CSIP (14.5 μm) is also shown. Judging from this calculation, the amplitude order at h = 10 nm in Fig. 2 is reasonable except GaN (Finite signals on GaAs can be attributed to piezoelectric acoustic phonon). In Fig. 2, GaN shows very unique height dependence. When the tip height is ~10 nm, the signal amplitude is almost zero. On the other hand, as the tip height increases, the signal amplitude also increases. Then when the height is more than 50 nm, the amplitude gradually decreases. We will discuss the result in the next chapter.

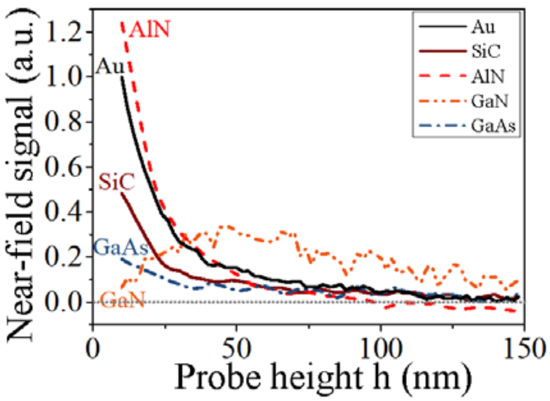

Figure 2 Tip height dependence of passive near-field signals over Au, SiC, AlN, GaN, and GaAs.

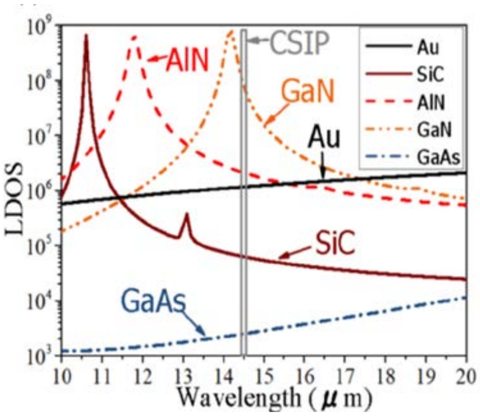

Figure 3 Numerical calculation of the wavelength dependence of LDOS at h = 10 nm.

III. DISCUSSION

The interesting characteristics of GaN in Fig. 2 can be interpreted with the interaction between the tip and the thermal evanescent waves. In our passive near-field microscope, first the dipoles at the tip apex are generated by spontaneous thermal evanescent waves. The dipoles at the tip apex then generate mirror dipoles in a substrate of the studied sample. After that, such optical interactions radiate (scatter) photons and the CSIP detects the scattered photons. The polarizability of the tip apex plays main roles as well as electromagnetic LDOS. Figure 4 shows the calculation of tip polarizabilities for each studied material. Here we approximate a tip apex by a spheroid [5]. In this figure, the polarizabilities of AlN, SiC, and GaAs decrease rapidly with increasing probe height, whereas GaN shows very unique height dependence. In the range of 10 – 60 nm, the polarizability of GaN gradually increases, with increasing probe height. Then, beyond 60 nm, the polarizability gradually decreases. These calculations are relatively similar to experimental results in Fig. 2.

Here we discuss this unique result over GaN. In this study, the detection wavelength is almost the same as the GaN surface phonon resonance. It should be noted that the surface polariton has very long coherence length (~λ), which means the decay length is very long. In our study, we vertically modulate the tip at Δh = 100 nm at 10 Hz to avoid thermal far-field noises (Planck radiation)[1]. This means that we obtain difference signals between h = 10 nm and h = 110 nm. When we probe thermal fluctuations strongly localized near the surface, we obtain large signals and very rapid decay like SiC and AlN. On the other hand, when we probe surface polaritons, we obtain very small signals at h = 10 nm because of the long decay. In Fig. 2 and 4, we find maximum values at h = 60 nm over GaN. We do not know the reason in detail, but we assume that the interference of surface phonon polariton between the tip and the surface can cause such interesting characteristics. In order to further understand the polariton characteristics and the guiding principle of passive evanescent signals, we need more studies with other detection wavelengths (e.g 12 μm, 17 μm).

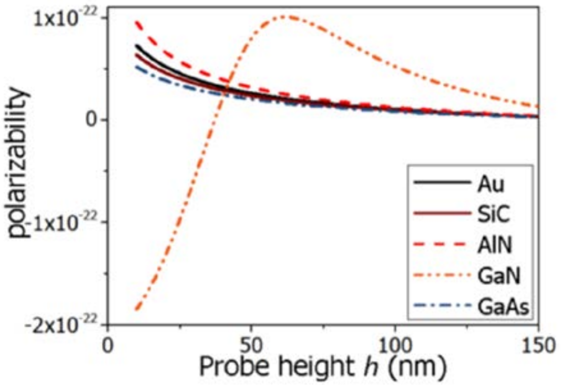

Fig. 4. Numerical calculation of the probe height dependence of the polarizability.

IV. SUMMARY

We studied thermal evanescent waves on dielectric samples (GaAs, SiC, AlN, GaN). GaAs, SiC, and AlN show finite and reasonable signals, whereas GaN represents very unique characteristics. It can be interpreted with the interaction between the tip and the phonon polariton. For more further discussions, we need to obtain passive near-field signals with other wavelengths near future.

ACKNOWLEDGMENTS

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