Gold nanodisk arrays on the upper surface of GaN nanorods were developed with the aim of achieving hypersonic imaging with a detection frequency above 10GHz. In this talk, we report the interesting phenomenon that the hypersonic signal detected by a single gold nanodisk in this structure is dependent on the array periodicity and rod length. We not only investigate the transport behavior of hypersonic-frequency acoustic phonons at the interface between a bulk material and a periodic nanostructure, but also suggest that the effects of the periodicity and nanorod length need to be taken into consideration for the design of future hypersonic imaging arrays.

1. Introduction

The acoustic imaging technique was demonstrated to be an efficient non-destructive method to obtain the structure below opaque sample surfaces. In traditional ultrasonic imaging, acoustic transducers such as single-element transducers [1] or phased-array systems [2] are widely utilized. In these setups, acoustic waves are generated by piezoelectric materials, such as ZnO or lead zirconate titanate PZT. Theoretically, the system resolution will be limited by the diffraction of the acoustic waves; thus, imaging systems aim to utilize high-frequency acoustic waves to produce high-resolution acoustic images. For example, an acoustic microscope applied a ZnO single-element transducer for the detection of 15.3GHz hypersonic waves in pressurized superfluid helium [3]. However, the disadvantage of systems based on a single-element transducer is that they require an acoustic lens. In contrast, phased-array systems allow dynamic image reconstruction at different depths below the sample surface, and this provides improved detection flexibility and capability. However, the highest operational frequency of phased-array systems is in the sub-GHz region [4]. Therefore, it is highly desirable to extend the detection frequency of phased arrays to above 10GHz for high-resolution imaging.

Recently, gold nanodisks on a GaN nanorod array showed great potential to be utilized as a hypersonic array [5]. The lowest detection frequency is that of the fundamental confined acoustic vibrations (CAVs) of gold nanodisks and is around 10GHz. In this structure, the hypersound detection sensitivity can be enhanced by optically exciting localized surface plasmons (LSPs) at the Au/GaN interface, which turns each gold nanodisk into an independent opto-acoustic detector by eliminating the plasmonic coupling between gold nanodisks [6].

In this work, we report our study on the effect of periodicity in GaN nanorod arrays for >10GHz hypersonic imaging [7]. Our study indicated that a periodicity smaller than the surface hypersonic wavelength would cause the signal detection to be affected by the coupling of the extensional mode of neighboring nanorods, as the detection frequency approaches the extensional mode frequency. This effect could be avoided by increasing the length of the nanorod to shift the extensional mode...
frequency. Furthermore, when the periodicity is either of the same order of or longer than the wavelength of the surface hypersonic waves, the detected signal would be subject to be influenced by the resonance of the surface hypersonic waves between the GaN nanorod array and the substrate. Our work not only investigates the transport behavior of hypersonic-frequency acoustic waves at the interface between the bulk material and a nanostructure, but also suggests a strategy to optimize the effect of the periodicity of the imaging array for future hypersonic imaging applications.

2. Methods and results

In this work, the detection of propagating hypersonic waves by gold nanodisks on GaN nanorod arrays with different periodicities and rod lengths (as shown in Figure 1) was investigated both theoretically and experimentally. The diameter of the gold nanodisk was fixed at 150nm. The investigated frequencies were 11 and 22GHz, which are the frequencies of the fundamental and high-order vibrational modes of the gold nanodisk. The acoustic signal detected by the gold nanodisks in our fabricated samples was studied experimentally by launching hypersonic pulses from the GaN substrate by using 360nm femtosecond pump pulses through deformation potential coupling [7] and the gold nanodisk vibration was detected by 720nm femtosecond probe pulses. The light source of such a transmission-type pump-probe system is a 720nm mode-locked Ti:sapphire laser (Coherent Mira 900) with a 100fs pulse width and a 76MHz repetition rate. Pump pulses were generated by doubling the frequency of the output pulses to 360nm by a BBO crystal. With an absorption depth of 75nm in GaN, the pulse width of the generated longitudinal acoustic pulse was approximately 150nm. The 720nm probe beam was responsible for the excitation of LSPs and acousto-optical detection.

![Figure 1: SEM images of the rod arrays with different GaN rod length and array periodicity.](image)

Our results (summarized in Figure 2) show that the hypersound signal detected by a single gold nanodisk depends on the array periodicity. For a periodicity smaller than the surface hypersonic
wavelength, signal detection would be affected by the coupling of the extensional vibration-like mode of neighboring nanorods as the detection frequency approaches the vibrational mode frequency. This coupling effect could be avoided by increasing the nanorod length to shift the frequency of the extensional mode away from the detection frequency. In contrast, when the periodicity is of the same order of or longer than the wavelength of surface hypersonic waves, the detected signal is affected by the period-dependent resonance of the surface hypersonic waves scattered by the nanorod/substrate interface.

![Graph](image.png)

Figure 2: Comparison of the simulated transmission coefficient (blue open circles for 11GHz hypersound, and red open squares for 22GHz hypersound) and the disk-number-normalized transient transmission change measured in the experiment (blue solid circles for 11GHz hypersound, blue solid squares for 22GHz hypersound) for arrays with different periodicities.

### 3. Conclusion

In conclusion, our study suggested that the periodicity and nanorod length need to be considered when designing future hypersonic imaging arrays using gold nanodisks on semiconductor nanorod systems. Meanwhile, the frequency at which hypersonic waves are detected is the designated fundamental vibrational frequency of the nanodisk detector for acoustic impedance matching between the nanorods and the substrate. The periodicity of the array is required to be smaller than the wavelength of the scattered surface hypersonic waves to avoid possible resonant enhancement, which induces cross talk between pixels. The nanorod length should be concerned so that the difference between the frequency of the coupled extensional vibration-like mode and the desired detection frequency is sufficient. This work not only investigates the transport behavior of hypersonic-frequency acoustic phonons at the interface between a bulk material and a nanostructure, but also suggests that the effects of the periodicity and nanorod length need to be taken into consideration for the design of future hypersonic imaging arrays.

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