Single Nanowire Terahertz Detectors

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Abstract: Photoconductive terahertz detectors based on single GaAs/AlGaAs nanowire were designed, fabricated and incorporated into the pulsed time-domain technique, showing a promise for nanowires in terahertz applications such as near-field terahertz sensors or on-chip terahertz micro-spectrometers.

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1. Introduction

Terahertz (THz) spectroscopy and imaging have been widely used for study of structure and dynamics in diverse materials, security screening, biology imaging and non-destructive testing [1, 2]. However, the lack of traditional materials for THz generation and detection has limited the development of this field. Photoconductive (Auston) switches technique [3] based on semiconductor materials by using ion implantation-induced damaged or low temperature grown semiconductor materials, is commonly used for THz detection in current THz system. One-dimensional III-V compound semiconductor nanowires, due to the nano-scale size, direct and tunable band gap, high carrier mobility (close to that in bulk materials), and in contrast short carrier lifetime (typically sub-nanoseconds) [2,4] leading to a fast response time in the THz regime, have been considered as an ideal alternative to bulk semiconductor materials for THz detection, particularly to be used as elements for highly integrated nanoscale THz devices such as a sub-wavelength detector element for near-field imaging or integrated into an “on-chip” THz spectrometer [5]. In this work, we demonstrate the design, fabrication and characterization of single GaAs/AlGaAs nanowire photoconductive THz detectors.

2. Nanowire growth and detector fabrication

The GaAs/AlGaAs core-shell nanowires were grown with metalorganic chemical vapour deposition (MOCVD) technique via the vapour-liquid-solid (VLS) mechanism [4,6]. Fig. 1a demonstrates a schematic cross-section diagram of a typical single GaAs/AlGaAs core-shell nanowire used in our detectors and corresponding TEM image. Fig. 1b is a SEM image of the nanowire. Photoluminescence (PL) measurements were performed to characterize the optical properties of such nanowires (see Fig1c). To fabricate the single-nanowire detectors, the as-grown substrate was cleaved into small pieces and placed in isopropyl alcohol solution for a 30-second ultra-sonication to transfer the nanowires into solution. The solution was dropped onto z-cut quartz substrates and allowed to dry naturally. Then the quartz substrates were spin-coated with photoresist and patterned using direct-laser-write lithography technique [7]. At last, the detector structure was metallized using electron beam evaporation to form 10/300nm Ti/Au contacts on each side of the nanowire.

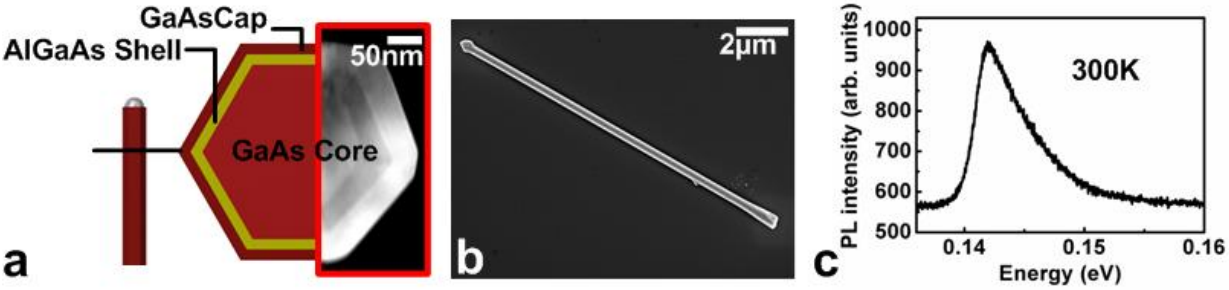

Fig. 1.a) A schematic cross-section of the GaAs/AlGaAs core-shell nanowire used in our detectors and corresponding tunneling electron micrograph image. b) Scanning electron micrograph images of the nanowire. c) A typical PL spectrum of a single core-shell nanowire.

3. THz response characterization and finite-difference time-domain (FDTD) simulations

The single-nanowire detectors were incorporated into a THz time-domain spectroscopy (THz-TDS) system [2] as a sensor to measure the incident THz pulse signal. Fig. 2a shows a schematic diagram of our single-nanowire photoconductive detector in operation. The THz induced photocurrents measured from our single-nanowire detectors were shown in Fig. 2b, and then processed and converted to THz spectral responses (see Fig. 2c). It is can be seen from Fig. 2c that our nanowire detector has a bandwidth in the range of 0.1 to 0.6 THz. Nevertheless, our single nanowire detector has sufficient signal-to-noise ratio for real-world application. We inserted a 290GHz low-pass filter into the THz-TDS system. The spectral response signal was abruptly cut off at the frequency of 290GHz with transmission amplitude around 80%. Comparing with a standard ion-implanted InP receiver, we confirmed that our nanowire detector have good enough sensitivity for practical use and its nanoscale size will bring much more advantages for future applications. FDTD simulations [8] with the same detector geometry used in the experiments were performed in the THz regime to understand the origin of the narrow bandwidth of such detectors. The results from these simulations indicate that the narrowed detection bandwidth arises from the specific detector antenna design, rather than the nanowire itself. Other antenna designs such as bow-tie or strip-line structure, were also simulated, presenting the importance of a properly design of detector geometry for THz detection.

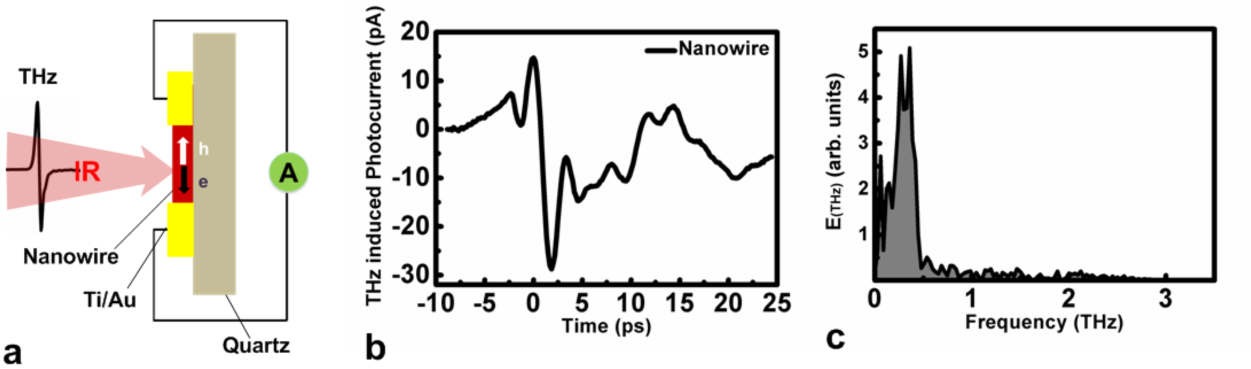

Fig. 2.a) A schematic diagram of a typical photoconductive single-nanowire detector in operation. b) THz induced current measured from a nanowire detector in the THz-TDS system. c) THz amplitude spectrum corresponding to b).

4. Conclusion

Single GaAs/AlGaAs-nanowire photoconductive THz detectors were successfully fabricated and incorporated in to the THz-TDS system. FDTD simulations were performed to provide insight into detector performances for optimal detection.

5. References

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