Nano-Schottky Barrier by Bottom-up Technique

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Abstract—Properties of nanostructures realized by bottom-up techniques are often different from their bulk counterparts.¹ Here we present our study of a nano-Schottky barrier formed on the interface between gold catalytic particle and epitaxially grown $\text{Ga}_x\text{In}_{1-x}\text{As}/\text{InAs}$ nanowire. Selective electrical contacts formed to the catalytic particle on one side and to the InAs segment on the other side allowed electrical and photoelectrical characterization of the barriers formed. We demonstrate that the heterostructure region adjacent to catalytic particle may act as an ultra small volume unipolar photodetector with potentially ultra fast response.

I. INTRODUCTION

Studies of semiconductor surfaces and interfaces are of fundamental importance for semiconductor devices. While bulk semiconductor surfaces have been extensively studied over the past decades, surfaces of semiconductor nanostructures have not attracted sufficient attention yet even though the surface influence on properties of nanodevices is much higher.

Self-assembled semiconductor nanowires are quasi one-dimensional semiconductor structures which are epitaxially grown from catalytic seed particles e.g. Au [1]. The nanowires offer the possibility of fabricating heterostructures along the wire and in this way combine materials not compatible in bulk otherwise [1,2]. In spite of the extensive studies done so far on such nanowire and their applications [1] the bottom-up formed interfaces between catalytic particles and nanowires have been rarely studied [3].

Studies of junctions between a metal and a semiconductor are very important for diverse device applications. Here we demonstrate our study of the nano-Schottky barrier formed with bottom-up technique between metal catalytic particle and $\text{Ga}_x\text{In}_{1-x}\text{As}$ nanowire segment. We also demonstrate photo detection functionality of the device realized.

II. MATERIALS AND METHODS

Graded heterostructure semiconductor nanowires for this study were grown with chemical beam epitaxy from Au aerosol catalytic particles [2]. After growth, the nanowires were mechanically transferred onto silicon substrates covered by a thermally grown 100 nm thick silicon dioxide top layer, on which reference markers and macroscopic metal pads were predefined. A high precision alignment for electron beam

lithography allowed precise positioning of the electrical connections and in this way selective contacting catalytic particle, see Fig. 1. A separate EBL step was performed to establish electrical connections to InAs segments of the nanowires through ohmic contacts [4].

The interfaces between Au catalytic particles and semiconductor nanowhiskers were characterized by transmission electron microscopy (TEM) with X-ray energy dispersive spectroscopy (XEDS) and with current-voltage (I-V) characteristics measured at different temperatures and under illumination with different intensity. The illumination was done with $\lambda=488$ nm light wavelength from Ar^+ laser.

III. RESULTS

Fig. 1 demonstrates a scanning electron micrograph of a studied $\text{Ga}_x\text{In}_{1-x}\text{As}/\text{InAs}$ nanowire with selective electrical connections formed. Zoomed region in Fig. 1 shows electrical contact formed to Au catalytic particle. This selective contact allowed electrical characterization of the nano-Schottky barrier and the heterostructure segment next to the catalytic particle.

Fig. 2 shows a transmission electron micrograph (the inset) and corresponding XEDS linescans over the heterostructure nanowhisker studied. The XEDS line scans provide qualitative information on the nanowire material composition.

Fig. 3 presents I-V characteristics measured at different temperatures on the device demonstrated in Fig. 1. The I-V curves clearly demonstrate a rectifying behavior. The current increase with temperature indicates carrier thermal excitation over a barrier.

Fig. 4 demonstrates a short circuit current measured on the device presented in Fig. 1 at different illumination intensities. This demonstrates photo detection functionality of the heterostructure region adjacent to catalytic particle.

IV. DISCUSSION

We demonstrate that selective electrical contact formed to the catalytic particle enable studies of Schottky barriers bottom-up formed on the interface between catalytic particles and graded $\text{Ga}_x\text{In}_{1-x}\text{As}$ nanowire segment. From the I-Vs measurements at different temperatures it is possible to deduce the Schottky barrier height and height of the barrier formed in the graded $\text{Ga}_x\text{In}_{1-x}\text{As}$ nanowire segment. The current-voltage characteristics measured under laser stimulation showed that the device with heterostructure nanowire can be used as a unipolar photodetectors with, to the best of our knowledge, a smallest to date detection volume [5] and potentially ultra fast response due to used materials and the device size.

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Fig. 1. Scanning electron micrograph of a studied nanowire with selective electrical connections. Zoomed region shows electrical contact formed to Au catalytic particle. This selective contact allowed electrical characterization of the nano-Schottky barrier.

Fig. 2. Transmission electron micrograph (the inset) and corresponding XEDS line scans over the heterostructure nanowhisker studied. The XEDS line scans provide qualitative information on the nanowire material composition.

Fig. 3. I-V characteristics measured at 370 K (blue dash-dotted line), 390 K (green dashed line), and 410 K (red solid line). The characteristics show current increase with temperature, which indicates carrier thermal excitation over the barrier.

Fig. 4. Short circuit current measured at different illumination intensities. The illumination was done with $\lambda=488$ nm light wavelength. The plot demonstrates photo detection functionality of the Schottky barrier.