Electrical Properties Based on 2D GaSe Nanobelts on the Metal-Semiconductor-Metal Photodetector

Bo-Lin, He[1],and Chiu-Yen, Wang[1*]
[1] Department of Materials Science and Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan

(MOST 111-2221-E-011-107-MY2)

Experiment

Precursors of gallium、selenide and tin iodide each for 50、10 and 10 mg are sealed in the quartz tube, a Zirconia (ZrO_2) substrate on which a 5 nm-thick Au film was deposited, was 11 cm away from the precursor, and the distance between the quartz column and the substrate is around 21 cm tin iodide is a catalyst to accelerate the growth response, which substrate is gilding for 15 seconds and annealing at 600 ℃ for 1 minutes that grow at 800 ℃ for 1.5 hours as vapor liquid solid (VLS) conditions in the single zone furnace, and the three elements will mix in onto the substrate, and forming the GaSe nanobelts (NBs) materials. The GaSe NBs fabricating by VLS were conducted the SEM, EDS, XRD, Raman and UV to ensure the crystal structure and optical properties then fabricate the photodetector device with EBL or PHL process then deposit the nickel electrode follow by liftoff obtain the GaSe NBs photodetector device.

Results and Discussion

Fig 1.(a) shows the scanning electron microscopy (SEM) image of GaSe NBs, it can observe that on the top of GaSe NBs have a circular tip, it is an Au on the top of GaSe NBs, it shows its growth mechanism is as VLS conditions as vertical direction growth on the substrate. Fig 1.(b) shows the electron dispersive X-ray microscopy (EDS) of GaSe NBs, the EDS analysis observes that the compositions ratio of Ga/Se NBs is 1.

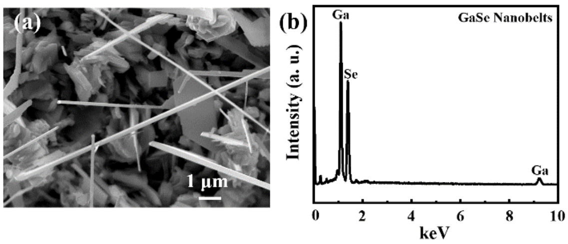

Fig 1. (a) The SEM image of GaSe NBs grew at 800 ℃ for 1.5 hours as VLS conditions in the furnace. (b) The EDS analysis of GaSe NBs grew at 800 ℃ for 1.5 hours, and the composition ratio of Ga/Se NBs is 1.

Fig 2.(a) shows the structure of the grown crystals was analyzed using X-ray diffraction (XRD), the crystal structure was referring to the PDF 81-1971 and the XRD pattern shows that the GaSe TMDs have hexagonal phase with high-level crystallinity. The XRD peaks (006), (101), and (018) are observed at 2θ = 23°, 27°, and 42°, respectively. Then, there is also some ZrO_2 signals that come from the substrate. Fig 2.(b) shows the Raman spectrum with 532 nm incident laser of GaSe nanobelts. Freshly cleaved GaSe shows four prominent peaks at 136 cm^{-1}, 212.9 cm^{-1}, 252.4 cm^{-1}, and 309.6 cm^{-1}. Due to oxidization, amorphous selenium (a-Se) is formed at the surface which exhibits a broad Raman peak near 253 cm^{-1} with a shoulder at 213 cm^{-1}.

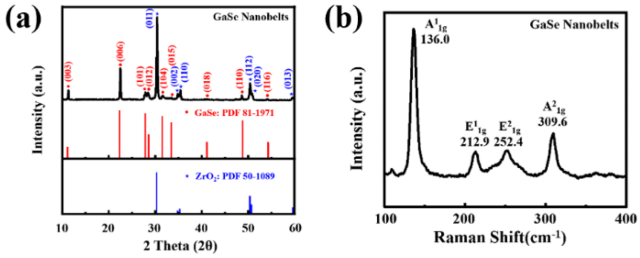

Fig 2.(a) The X-ray diffraction pattern (XRD) shows that GaSe exhibits a hexagonal crystal structure, where gallium and selenium atoms are arranged in alternating layers, forming a layered structure. Fig 2.(b) The Raman spectrum shows the different vibration modes at different four peaks.

Fig 3.(a) shows the ultraviolet-visible spectroscopy (UV) analysis, in the absorption spectrum result, a change slope at about 350 nm can be seen in the image. To further deduce the energy level and the bandgap of the structure, we can transfer the spectrum into the Tauc plot. Fig 3.(b) shows the Tauc plot result, the bandgap is located at ~ 2.33 eV (~ 532 nm), it is close to the theoretical value. Its direct bandgap allows efficient light absorption and carrier transfer, making GaSe attractive for optical applications.

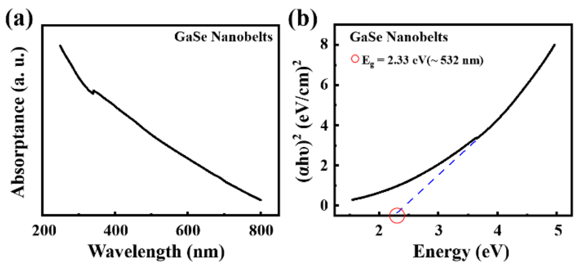

Fig 3. (a-b) GaSe demonstrates a direct bandgap of approximately 2.12 eV, in the ultraviolet-visible (UV) analysis shows the direct bandgap of approximately 2.33 eV.

Fig 4.(a,c) shows the scanning electron microscopy (SEM) image of GaSe NBs device before and after rapid temperature annealing (RTA), it can observe that the nickel from contact diffused into the materials, then, forming the heterojunction metal-semiconductor-metal structure. Fig 4.(b,d) shows the I_d-V_d characteristics of the GaSe NBs before RTA and after RTA at 400 ℃ for 15 s, it can observe that the intensity will increase after conducting the RTA due to the metal nickel diffused.

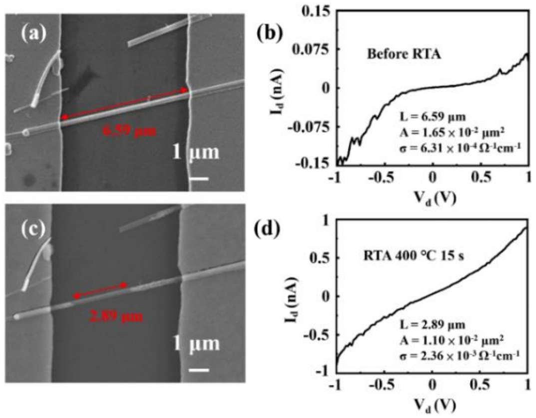

Fig 4.(a,c) The SEM images of GaSe NBs before RTA and after RTA at 400 °C for 15 s. Fig 4.(b,d) The I_d-V_d characteristic of GaSe NBs before RTA and after RTA at 400 °C for 15 s.

Fig 5.(a-b) shows the line scan analysis of GaSe NBs after RTA at 400 °C for 15 s, it can observe the nickel intensity from contact to material will be decrease then come back to the initial intensity.

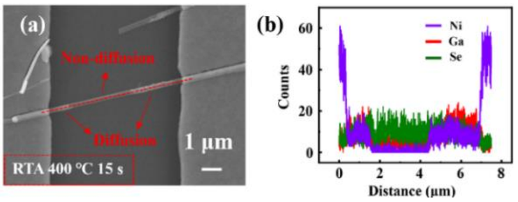

Fig 5.(a) The SEM images of GaSe NBs after RTA at 400 °C for 15 s. Fig 5.(b) The line scan analysis of GaSe NBs.

Fig 6.(a-b) shows the I_d-V_d measurement with five different temperatures prove that the device exhibits the properties of semiconductor which has larger value of conductivity with higher temperature. Fig 6.(c) shows the fitting curve of diagram of Richarson plot, and the calculated Schottky barrier is ~ 0.2 eV.

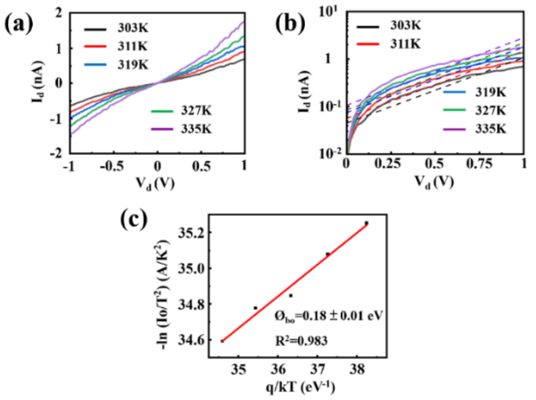

Fig 6.(a) The results of varied temperature electrical test. Fig 6.(b) Temperature dependent I-V characteristic of GaSe device. Fig 6.(c) The diagram of Richarson plot with calculated value of barrier.

Fig 7.(a) shows the I_d-V_d measurement under the 405 nm laser light under dark current and five different power intensity, it can observe that the power intensity increases, the intensity will increase. Fig 7.(b) shows the photoresponse under the four different wavelengths laser light, as the wavelength increases, the intensity will decrease. Fig 7.(c-d) shows the rise and decay time under the 405 nm laser light, it shows the fast-switching at ~ 30 ms.

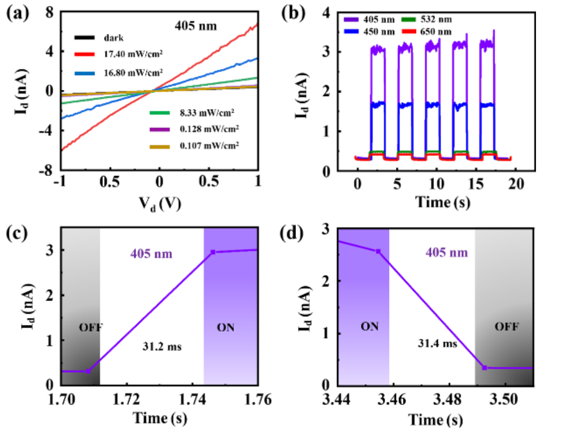

Fig 7.(a) The I_d-V_d measurement under the 405 nm laser light under dark current and five different power intensity. Fig 7.(b) The photoresponse under the four different wavelengths laser light. Fig 7.(c-d) The rise and decay time under the 405 nm laser light.

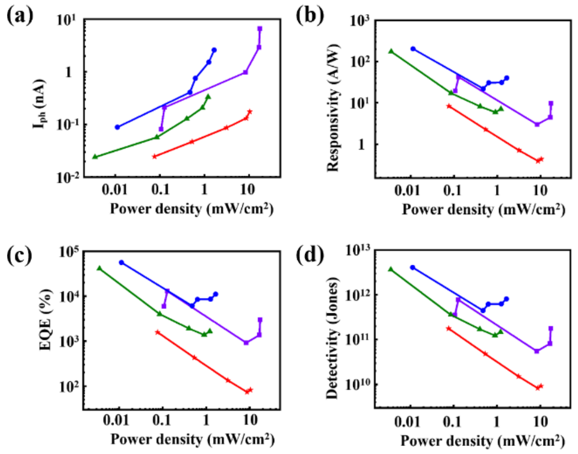

Fig 8.(a-d) The I_{ph}、Responsivity、EQE、Detectivity versus power density as function under the four different wavelengths laser light.

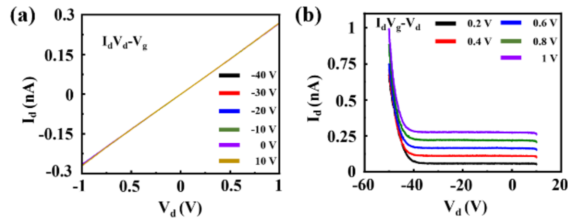

Fig 9.(a) The I_dV_d-V_g characteristic from different V_g 10 V ~ -40 V at constant drain voltage 1 V. Fig 9.(b) The I_dV_g-V_d characteristic from V_d 0.2 V ~ 1 V at constant gate voltage 10 V ~ -40 V.

Conclusion

The data still need to be figured out and to recheck the value of Schottky barrier after RTA. The existence of GaSe/Ni heterostructure after conducted the RTA process and the related optoelectrical properties. To conduct the TEM analysis for studying the phase of Ga-Se-Ni and the realistic interfacial structure in the GaSe / Ga-Se-Ni region.

Acknowledgement

Chiu-Yen Wang acknowledges the financial support by the Ministry of Science and Technology through the grants of MOST 111-2221-E-011-107-MY2.