Amorphous p-NiO/n-Ga_2O_3 crystal solar-blind detection

Researchers claim record UV detectivity and open-circuit voltage.

University of Science and Technology of China (USTC) claims record detectivity and open-circuit voltage for its nickel oxide/gallium oxide (NiO/Ga_2O_3) heterojunction solar-blind photodetector (SBPD) [Mengfan Ding et al, IEEE Electron Device Letters, published online 8 December 2022].

Such compact devices are of interest for high-performance, portable, low-power solar-blind ultraviolet (UV) detection systems for secure communication and flame detection, among other applications. Ga_2O_3 has an ultrawide bandgap in the range 4.7–5.3eV (264–234nm photon wavelength). The bandgap is well away from the visible range 1.65–3.26eV (750–380nm).

The researchers used the NiO/Ga_2O_3 heterojunction combination to produce a p–n junction due to the difficulty in achieving p-type conductivity in Ga_2O_3. Amorphous p-NiO has a relatively high hole mobility. The researchers demonstrate that "amorphous p-NiO has potential to construct an excellent staggered band alignment and superior interface with crystalline

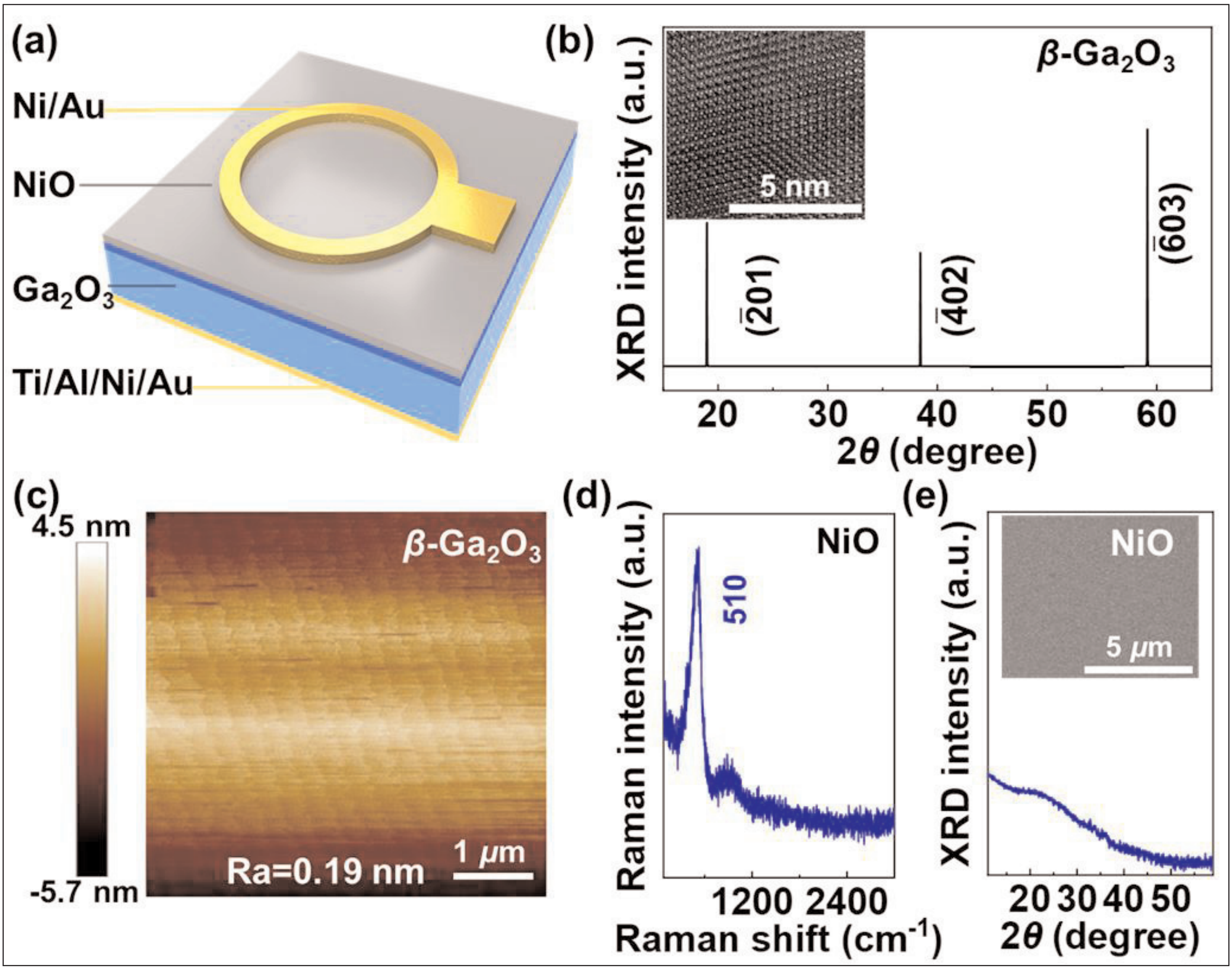

Figure 1. (a) Device schematic diagram. (b) X-ray diffraction (XRD) pattern and transmission electron microscope (TEM) images (inset) and (c) atomic force microscope (AFM) image of β-Ga_2O_3 single crystal. (d) Raman spectrum and (e) XRD pattern and scanning EM (SEM) image (inset) of amorphous NiO film.

Ga_2O_3," avoiding carrier-blocking trap states.

The substrate for the device (Figure 1) was β-Ga_2O_3 with a 1μm halide vapor phase epitaxy (HVPE) epitaxial layer with electron (n) concentration of $2x10^{16}/cm^3$. The backside ohmic electrode of titanium/aluminium/nickel/gold (Ti/Al/Ni/Au) was applied and annealed after some dry etching. Surface damage from these processes was repaired using a Piranha solution consisting of 2:1 sulfuric acid:hydrogen peroxide (H_2SO_4:H_2O_2). This produced "an atomically flat Ga_2O_3 upper surface with clear step structure and low roughness (0.19nm)," according to the team.

The p-type amorphous NiO was the result of room temperature RF sputtering. The Ni/Au top ohmic ring electrode was applied using electron-beam evaporation. The illumination window area was $1.2x10^{-3}/cm^2$.

The rectifying on/off dark current ratio of the diode between +3V and −3V was 10^4. The use of NiO, rather than directly applying Ni to the Ga_2O_3 to form a Schottky junction, enhanced the reverse-bias response to 254nm radiation by four orders of magnitude.

The researchers investigated the performance with varied NiO oxygen content and thickness. The team comments: "The device with 30nm NiO film has the best performance due to the balance of NiO film transmittance and depletion region width of device." It was also found that higher oxygen content gave better performance, "mainly due to the higher hole concentration".

The 0V response to UV is of particular interest since it enables self-powered setups (Figure 2). The dark current noise was at the picoamp scale.

The photo-dark current ratio (PDCR) reached $3x10^6$ under a 254nm illumination intensity of $955μW/cm^2$ with approximately linear performance. At the same intensity, the open-circuit voltage (V_{oc}) reached 1.3V, "exceeding almost all the reported Ga_2O_3 heterojunction photodetectors," according to the team (Figure 3).

The responsivity peaked at an "ultrahigh" 5A/W at $222μW/cm^2$, where the specific detectivity (D*) was $1/6x10^{14}$ Jones. The spectral performance of R peaked at 245nm, with a cut-off around 260nm. The rejection ratio of 460nm visible light was $2x10^4$. The response time to changes in intensity was better than 1ms. ■

Function	Material	Al content	Thickness
Contact	p-GaN	0%	
Contact	p-AlGaN	graded	50nm
Cladding	p-AlGaN	100%-70%	320nm
Waveguide	AlGaN	63%	120nm
Cladding	n-AlGaN	75%	400nm
Substrate	AlN		

Figure 2. (a) NiO/Ga_2O_3 heterojunction photodetector current-voltage performance under 254nm illumination with different intensities. (b) Dependence of PDCR and R at 0V on light intensity. (c) Voc as function of light intensity. (d) Normalized spectral response at 0V.

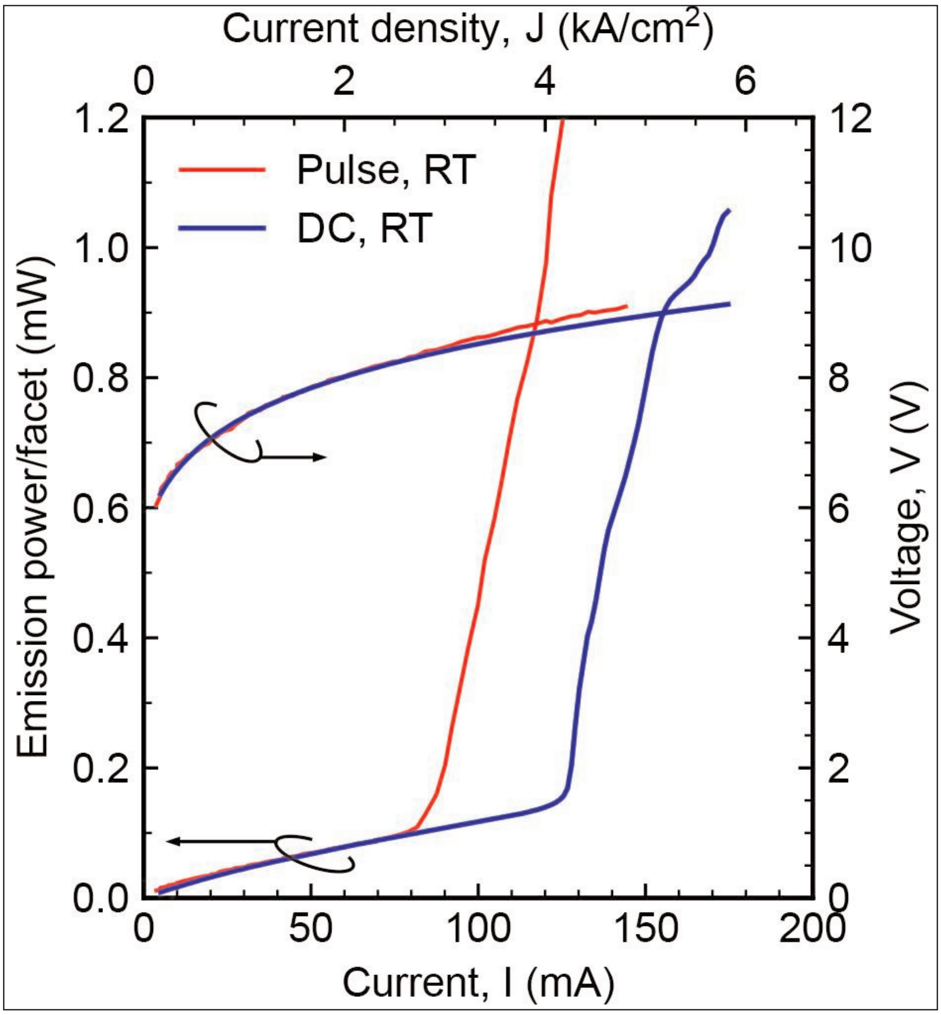

Figure 3. Benchmark plots of (a) PDCR versus R and (b) D* versus 1/(Decay time) from representative self-powered Ga_2O_3 SBPDs. Red star represents USTC work.

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