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Gate-controlled amplifiable ultraviolet AlGa_N/Ga_N high-electron-mobility phototransistor

Seung-Hye Baek¹, Gun-Woo Lee¹, Chu-Young Cho² & Sung-Nam Lee¹✉

Gate-controlled amplifiable ultraviolet phototransistors have been demonstrated using AlGa_N/Ga_N high-electron-mobility transistors (HEMTs) with very thin AlGa_N barriers. In the AlGa_N/Ga_N HEMTs, the dark current between the source and drain increases with increasing thickness of the AlGa_N barrier from 10 to 30 nm owing to the increase in piezoelectric polarization-induced two-dimensional electron gas (2-DEG). However, the photocurrent of the AlGa_N/Ga_N HEMT decreases with increasing thickness of the AlGa_N barrier under ultraviolet exposure conditions. It can be observed that a thicker AlGa_N barrier exhibits a much higher 2-DEG than the photogenerated carriers at the interface between AlGa_N and Ga_N. In addition, regardless of the AlGa_N barrier thickness, the source–drain dark current increases as the gate bias increases from -1.0 to $+1.0$ V. However, the photocurrent of the phototransistor with the 30 nm thick AlGa_N barrier was not affected by the gate bias, whereas that of the phototransistor with 10 nm thick AlGa_N barrier was amplified from reduction of the gate bias. From these results, we suggest that by controlling the gate bias, a thin AlGa_N barrier can amplify/attenuate the photocurrent of the AlGa_N/Ga_N HEMT-based phototransistor.

The class of III-nitride semiconductors are very promising materials for manufacturing high-performance optoelectronic devices such as light-emitting diodes, laser diodes and photodetectors (PDs) because of their wide band gap energies and highly stable chemical/physical properties^{1–5}. In particular, there has been considerable interest in Ga_N-based devices like ultraviolet (UV) PDs^{6–8}, because of their wide applications in military and commercial fields such as flame monitoring, space ozone monitoring, etc^{9,10}. While comparing with other UV detectors based on photoconductors, AlGa_N/Ga_N heterostructure HEMTs can provide high internal gain, favored by highly conductive two-dimensional electron gas (2-DEG) channel at the heterostructure interface due to the built-in electric field induced by strong piezoelectric and spontaneous polarizations^{11–17}. In the AlGa_N/Ga_N high-electron-mobility transistors (HEMTs), the channel conductivity is increased by UV exposure, resulting in a significant change in drain current. Therefore, a few research groups have demonstrated very high responsivities (up to $\sim 10^7$ A/W) in AlGa_N/Ga_N heterostructure-based devices^{18–21}. In the UV detection mechanism of AlGa_N/Ga_N HEMT structure, it is known that the surface charge states and the absorption at the Ga_N channel layer increase 2-DEG channel conductance^{22–24}. In particular, it has been reported that the optical gain is significantly dominated by absorption in the Ga_N channel layer rather than the AlGa_N barrier²⁵. Moreover, to further improve photoresponsivity of AlGa_N/Ga_N heterostructure, nanostructures such as ZnO nanorods or graphene are introduced between the source and drain electrodes^{26,27}.

In the control of the source–drain current (I_{DS}), AlGa_N/Ga_N HEMT structure can be significantly affected by the AlGa_N barrier and gate bias^{24,25}. In particular, the thickness and composition of the AlGa_N barrier are major factors in the formation of 2-DEG, which can improve the channel conductance²⁴. It is known that the gate bias can control the drain current due to carrier accumulation/depletion in the channel region²⁴. However, the effect of gate bias on photocurrent of AlGa_N/Ga_N HEMTs with different AlGa_N barriers has not yet been analysed. Therefore, we investigated the effect of AlGa_N barrier on the electrical and optical properties of AlGa_N/Ga_N HEMT-based phototransistor by applying the gate bias. Furthermore, we demonstrated amplifiable photocurrent of AlGa_N/Ga_N phototransistor with very thin AlGa_N barrier by controlling the gate bias.

¹Department of Nano and Semiconductor Engineering, Korea Polytechnic University, Siheung 15073, Republic of Korea. ²Nanodevices Lab., Korea Advanced Nano Fab Center, Suwon, Gyeonggi-do 16229, Republic of Korea. ✉email: snlee@kpu.ac.kr

Figure 1. Structure and optical properties of AlGaIn/GaN HEMTs with different AlGaIn barrier thicknesses characterized using X-ray (002) $\omega/2\theta$ scans (a) and optical reflectance analysis (b). The inset shows a schematic of the AlGaIn/GaN HEMT with the source, drain, and gate electrodes.

Structure and optical properties of AlGaIn/GaN HEMTs with different AlGaIn barrier thickness

Figure 1a shows the high-resolution X-ray diffraction (HR-XRD) $\omega/2\theta$ scans of the AlGaIn/GaN HEMTs with different AlGaIn barrier thicknesses. It exhibits one peak each at 34.51° and 35.04° which corresponds to the (002) GaN film and AlGaIn barrier layer, respectively. The aluminum compositions of the AlGaIn barrier layers were calculated using Bragg's law ($n\lambda = 2d\sin\theta$, where n is an integer representing the order of the diffraction peaks, λ is the wavelength (0.154 nm) of X-ray CuK α , and θ is the diffraction angle) and Vegard's law^{27–29}. These results reported that the three samples had the same aluminum composition of 30% in the AlGaIn/GaN heterostructures. In addition, the XRD intensity of the $\text{Al}_{0.3}\text{Ga}_{0.7}\text{N}$ barrier increased proportionally with thickness and the interference fringe was developed more clearly as the thickness of the AlGaIn barrier increased. It indicates that the interface quality between AlGaIn and GaN is improved with an increase in the thickness of AlGaIn barrier, which can improve the mobility of 2-DEG. Figure 1b shows the reflectance spectra of AlGaIn/GaN HEMT structure with different AlGaIn barrier thicknesses. The peak before the start of the oscillation can be readily observed and the band gap energies of AlGaIn barrier and GaN channel layer were measured to be 4.03 eV and 3.41 eV, respectively, which is consistent with the values of AlGaIn and GaN obtained from HR-XRD shown in Fig. 1a. In addition, the target thickness of the AlGaIn barriers is observed to be nearly the same as that calculated using Fabry–Perot oscillations ranging from 310 to 360 nm³⁰.

Figure 2. I–V characteristics of AlGaIn/GaN HEMTs with different AlGaIn barrier thicknesses under dark and UV illuminations using 280 nm (a) and 365 nm (b) wavelengths as exposure light sources. (c) Photocurrent (ΔI_{DS}) versus source–drain voltages of HEMTs with different AlGaIn barrier thicknesses using 280 nm and 365 nm UV light. (d) Photocurrent between source and drain as a function of AlGaIn barrier thickness at 3.0 V drain voltage.

Effect of AlGaIn barrier thickness on dark current and photocurrent between source and drain of AlGaIn/GaN HEMTs

Figure 2a,b shows the source–drain dark current (I_{DS}) and photocurrent (ΔI_{DS}) of AlGaIn/GaN HEMTs with different AlGaIn barrier thicknesses in dark and UV exposures at 280 nm and 365 nm, respectively. In the dark, as the thickness of AlGaIn barrier increased, the source–drain current increased from 0.45 to 4.06 A/mm. In general, it is known that a higher Al composition and a thicker AlGaIn barrier increases the 2-DEG channel density formed at the interface between the AlGaIn barrier and the GaN channel layer due to the strong piezoelectric polarization effect resulting in high source–drain current flow^{11–16,31}. The source–drain photocurrents of AlGaIn/GaN HEMT were increased by exposure of 280 nm and 365 nm UV light compared to the dark state. It can be explained by the increase of channel conductance due to the photogenerating carrier of AlGaIn barrier and GaN channel layer²⁵. In addition, it can be seen that the increase of source–drain photocurrent by UV exposure is obtained at the maximum pinch-off voltage just before the onset of the conventional saturation region shown in Fig. 2c. The source–drain photocurrent and dark current are reduced by self-heating effect at the drain bias at a voltage higher than the pinch-off voltage. This is because the induced open circuit photovoltage decreases with increasing temperature, which is well known in solar cell theory³².

Figure 2d shows the photocurrent of AlGaIn/GaN HEMT with different AlGaIn barrier thicknesses using 280 and 365 nm UV light. The photocurrent was calculated using the equation of $\Delta I_{DS} = I_{DS(UV)} - I_{DS(dark)}$, where $I_{DS(UV)}$ and $I_{DS(dark)}$ are the UV illumination current and dark current obtained between the source and drain, respectively. As the AlGaIn barrier thickness increased from 10 to 30 nm, 280 nm-UV induced photocurrent increased from 0.07 A/mm to 0.14 A/mm, whereas 365 nm-UV induced photocurrent decreased from 0.93 A/mm to 0.14 A/mm. Since 280 nm-UV light is mostly absorbed in the AlGaIn barrier region, the photocurrent of AlGaIn/GaN HEMT is proportional to the thickness of AlGaIn barrier layer. However, since 365 nm UV light has lower energy than the band gap of the AlGaIn barrier layer, 365 nm UV light is mainly adsorbed in the GaN channel rather than the AlGaIn barrier. Moreover, it has been reported that the photoexcitation carrier of the GaN film is higher than that of the AlGaIn film²⁴. Therefore, it is expected that as the thickness of the AlGaIn barrier layer decreases, 365 nm-UV absorption of the GaN film increases and the photocurrent increases. In addition, it is found that the photocurrent obtained from 365 nm-UV exposure is much higher than 280 nm-UV light.

Figure 3. Photocurrents between the source and drain of AlGaIn/GaN HEMTs with different AlGaIn barrier thicknesses as functions of exposure light wavelengths.

In particular, 365 nm UV-induced photocurrent (0.93 A/mm) is 13.3 times higher than 280 nm UV-induced photocurrent (0.07 A/mm) in the AlGaIn/GaN HEMT with a 10 nm thick AlGaIn barrier under the applied drain voltage (V_{DS}) of 3.0 V. The 2-DEG density ($1.05 \times 10^{13}/\text{cm}^2$) of AlGaIn/GaN HEMT with a 30 nm thick AlGaIn barrier is much higher than that of a 10 nm thick AlGaIn barrier ($8.59 \times 10^{12}/\text{cm}^2$), leading to the higher dark current ($I_{DS(\text{dark})}$) of HEMT with a 30 nm thick AlGaIn barrier than a 10 nm thick AlGaIn barrier. Moreover, since the transmission of UV light through the AlGaIn barrier is reduced by increasing the thickness of AlGaIn barrier, the photogenerated carriers of HEMTs with 10 nm AlGaIn barrier are higher than those of HEMTs with 30 nm AlGaIn barrier. Therefore, it is believed that the photocurrent of HEMT with a 10 nm thick AlGaIn barrier is higher than that of a 30 nm thick AlGaIn barrier owing to the higher photogenerated carrier than the low dark current formed by the relative low 2-DEG in HEMT with a 10 nm thick AlGaIn barrier.

UV wavelength dependent photoresponsivity of AlGaIn/GaN HEMTs with different thicknesses of AlGaIn barriers

To investigate the absorption regions of the AlGaIn barrier and GaN buffer layers, AlGaIn/GaN phototransistors were irradiated with 240–420 nm UV light using a UV monochromator with a Xenon lamp source covering the band gap energies for the AlGaIn and GaN regions. The power at each wavelength was maintained the same to avoid strong gain dependence on the input optical power. Figure 3 shows the photoresponsivity of AlGaIn/GaN HEMTs with different AlGaIn barrier thicknesses as a function of excitation wavelength. The photoresponsivity (R) and gain (g) of photodetector can be calculated by following equations^{19,21}

$$R = (I_{UV} - I_{\text{dark}})/P_o = I_{ph}/P_o = gqLG_L/P_o, \quad (1)$$

where I_{ph} , P_o , g , L , and G_L are the photocurrent of photodetector, the optical power of exposure light, device gain, sensing space and the generation rate of electron–hole pair, respectively. Although the dark current (I_{dark}) of 10 nm-thick AlGaIn barrier HEMT is much lower than that of 30 nm-thick AlGaIn barrier HEMT, the photocurrent of 10 nm-thick AlGaIn barrier HEMT is much higher than that of 30 nm-thick AlGaIn barrier HEMT as shown in Fig. 2b,c. Thus, the maximum photoresponsivity (1.44×10^6 A/W) of AlGaIn/GaN HEMT is obtained using 10 nm thick AlGaIn barrier. All samples had a sharp transition near the GaN cutoff wavelength of 360 nm, while no significant change was observed at the AlGaIn cutoff wavelength near 300 nm as shown in Fig. 3. In addition, the AlGaIn/GaN HEMTs with 20 nm and 30 nm thick AlGaIn barriers show a very slight decrease of photoresponsivity near the band gap (~ 300 nm) of AlGaIn barrier. In addition, from Eq. (1), it can be seen that the photoconductive gain is proportional to the photoresponsivity^{21,33}. Thus, the photoconductive gain of HEMT with 10 nm thick AlGaIn barrier is higher than that of HEMT with 30 nm thick AlGaIn barrier due to higher UV photocurrent (I_{ph}). It is another clear evidence that the photoconductive gain from absorption is dominant in the GaN region rather than the AlGaIn barrier layer and can be increased using a thinner AlGaIn barrier²⁴. In addition, since the photoresponsivity is proportional to the generation rate of electron–hole pairs shown in Eq. (1)²¹, the photogeneration rate of the high photoresponsivity HEMTs with 10 nm AlGaIn barrier is expected to be higher than that of the low photoresponsivity HEMTs with 30 nm AlGaIn barrier. It means that HEMTs with 10 nm AlGaIn barrier can have a fast response to UV exposure.

Figure 4. I_{DS} - V_{DS} characteristics of AlGaIn/GaN HEMTs with 10 nm (a), 20 nm (b), and 30 nm (c) thick AlGaIn barriers for dark (close square) and UV (open square) illumination conditions. (d) Photocurrent characteristics of HEMTs with different gate biases as functions of AlGaIn barrier thicknesses.

Gate bias dependence of photocurrent in AlGaIn/GaN HEMTs with different AlGaIn barrier thicknesses

We analyzed the effect of gate bias on the I_{DS} - V_{DS} characteristics of AlGaIn/GaN HEMTs with 10 nm, 20 nm, and 30 nm thick AlGaIn barriers in the dark state and UV (365 nm) illumination conditions as shown Fig. 4a–c, respectively. In the dark state, regardless of the thickness of AlGaIn barrier, the drain current increased as the gate bias increased from -1.0 V to +1.0 V. This is typical electrical behavior in AlGaIn/GaN HEMT due to the increase of electron in the 2-DEG channel region by increasing the positive gate bias field³⁴. However, at constant gate bias, the drain current of AlGaIn/GaN HEMT increased with AlGaIn barrier thickness due to the increase of piezoelectric polarization-induced 2-DEG formed at the AlGaIn/GaN interface. As a result, it can be seen thought that higher current flow between the source and drain is achieved by applying a high gate and drain voltage in the dark state. In addition, we measured the source–drain current of three AlGaIn/GaN HEMTs with different gate voltages in 365 nm UV illumination. Regardless of the thickness of AlGaIn barrier and the gate bias, the source–drain currents of HEMTs were increased by 365 nm-UV exposure. Moreover, the pinch-off voltage is decreased by UV illumination. It indicates that the 2-DEG-related source–drain current of AlGaIn/GaN HEMT is significantly affected by the photogenerated carrier due to the exposure of 365 nm-UV light. However, as the thickness of AlGaIn barrier and the gate voltage increased, the increase rate of the photocurrent decreased as shown in Fig. 4d. In the AlGaIn/GaN HEMT with 10 nm thick AlGaIn barrier, the source–drain current is significantly reduced by increasing the negative gate voltage in the dark state, while the source–drain current is hardly affected by the gate bias under the UV illumination. As a result, the highest photocurrent can be achieved using 10 nm thick AlGaIn barrier and gate voltage of -1.0 V. The source–drain current of HEMT with 30 nm thick AlGaIn barrier is not significantly affected by the photogenerated carrier because the 2-DEG is higher than the photogenerated carrier. However, since the HEMT with 10 nm thick AlGaIn barrier had a lower 2-DEG than the photogenerated carrier, the source–drain photocurrent is significantly increased by UV illumination. Based on these results, we believe that HEMTs with low 2-DEG using very thin (~10 nm) AlGaIn barrier and high negative bias can be effective in achieving high photocurrent because they can have higher photogenerated carrier than 2-DEG.

Figure 5. Photocurrent characteristics of HEMTs with (a) 10 nm, 20 nm, and 30 nm thick AlGaIn barriers at the applied gate voltage of 3.0 V as a function of different AlGaIn barrier thicknesses. (b) Time-dependent photocurrents of HEMTs with different AlGaIn barriers; each duration was applied a different gate voltage ($V_G = -1.0$ V for 0–120 s, $V_G = 0$ V for 120–240 s, and $V_G = +1.0$ V for 240–360 s).

Effect of AlGaIn barrier thickness on gate bias-controlled amplifiable photocurrent of AlGaIn/GaN HEMTs

Figure 5a shows the photocurrent of AlGaIn/GaN HEMTs with different AlGaIn barrier thicknesses as a function of gate voltage. It indicates that the photocurrent reduces with an increase in the thickness of the AlGaIn barrier. In addition, the photocurrent of HEMT with a 30 nm thick AlGaIn barrier is hardly affected by the gate bias, whereas the photocurrent of HEMT with a 10 nm thick AlGaIn barrier increased from 0.39 to 1.22 A/mm as the gate bias decreased from +1.0 V to -1.0 V. In other words, it can be seen that a photocurrent of HEMT with a 10 nm thick AlGaIn barrier can be amplified/reduced by applying positive/negative gate voltages, respectively. Thus, we measured the time-dependent photocurrent of AlGaIn/GaN HEMTs with different AlGaIn barrier thicknesses by turning the UV light on/off and controlling the gate bias from -1.0 V to +1.0 V shown in Fig. 5b. Regardless of AlGaIn barrier thickness, the AlGaIn/GaN HEMTs were operated well periodically by turning the UV light on/off and controlling the gate bias, indicating that all HEMTs have good and reliable properties. In addition, HEMT with a 30 nm thick AlGaIn barrier has similar low photocurrents at different gate biases, whereas HEMTs with thin (≤ 20 nm) AlGaIn barriers exhibit an amplification/reduction of gate-bias induced photocurrent. In particular, it can be seen that an HEMT having a 10 nm thick AlGaIn barrier can dramatically control the photocurrent by controlling the gate bias. Moreover, it is observed that the response time of AlGaIn/GaN HEMT becomes faster as the thickness of AlGaIn barrier decreases. Since the 10 nm thick AlGaIn barrier has a relatively lower 2-DEG than the 30 nm thick AlGaIn barrier, the photogenerated carrier can easily exceed 2-DEG in the 10 nm thick AlGaIn barrier, resulting in a fast rising time of photocurrent. In addition, the higher

Figure 6. Schematic band diagrams of AlGaIn/GaN HEMTs with 10 nm (a) and 30 nm (b) thick AlGaIn barriers by applying zero (black line), positive (blue line), and negative (red line) gate biases. The solid and dotted lines depict bands with dark and UV illuminations, respectively.

Al composition and thicker AlGaIn barrier grown on GaN channel layer may have more crystal defects forming impurity-related deep levels such as misfit dislocations and point defects that can play a role in absorbing UV light at the top AlGaIn barrier³⁶. As a result, these crystal defects can delay the formation of the photogenerated carriers in the AlGaIn barrier and the GaN channel layer, resulting in a low response time of the AlGaIn/GaN HEMT with a 30 nm thick AlGaIn barrier layer. Based on these results, we suggest that the photocurrent of AlGaIn/GaN HEMT with a thin AlGaIn barrier can be amplified/reduced by controlling the gate bias.

Schematic band diagram of AlGaIn/GaN HEMTs with different AlGaIn barrier thicknesses by applied gate bias and UV illumination

Figure 6 shows the band diagrams of AlGaIn/GaN HEMTs with 10 nm (a) and 30 nm thick (b) AlGaIn barriers by applying negative/positive gate biases and exposing them to UV light. The interface between the AlGaIn and GaN films has strong band bending due to polarization properties. As a result, the 2-DEG channel increases with the AlGaIn barrier thickness because of the increase of strain-induced polarization effect at the interface of AlGaIn/GaN. At gate zero bias ($V_{\text{applied}} = 0$ V), the Fermi level of the gate metal is same as the Fermi level of AlGaIn/GaN, indicating that the HEMT device is in equilibrium condition³⁵. When UV light is injected, excess holes generated on GaN buffer layer accumulate at the interface of GaN/substrate, causing the bands to bend down and a positive back-gate bias maintained by the photocurrent, which increases 2-DEG²⁵. In particular, since the 2-DEG channel of HEMT with a 30 nm thick AlGaIn barrier is much wider than a 10 nm thick AlGaIn barrier, the ratio of photogenerated carriers by bending down in the 30 nm thick AlGaIn barrier is relatively lower than that in the 10 nm thick AlGaIn barrier shown in Fig. 6a,b. Therefore, it can be seen that the photocurrent of AlGaIn/GaN HEMT decreases with increasing the thickness of AlGaIn barrier, which is consistent with Fig. 4d. In addition, when the gate voltage is applied by negative (red line) and positive (blue line) bias, the Fermi level of gate metal moves up and down, respectively as shown in Fig. 6. In this case, the energy band between the metal and the AlGaIn film goes upward and downward, resulting in the decrease and increase of 2DEG channel, respectively. In particular, due to the downward bending effect by UV irradiation, the increase rate of 2-DEG channel is higher in the 10 nm thick AlGaIn barrier than the 30 nm thick AlGaIn barrier. Therefore, we suggest that the 10 nm thick AlGaIn barrier HEMTs with relatively low 2-DEG can amplify/reduce the photocurrent more easily than the 30 nm thick AlGaIn barrier with high 2-DEG by controlling the negative/positive gate bias, respectively.

Conclusions

We have achieved a gate-controlled amplifiable ultraviolet AlGaIn/GaN HEMT-based phototransistor using a 10 nm thick AlGaIn barrier. As the thickness of the AlGaIn barrier increased from 10 to 30 nm, the dark current between the source and drain increased due to the increase of piezoelectric polarization-induced 2-DEG. However, the photocurrent of the AlGaIn/GaN HEMT decreases with increasing the thickness of the AlGaIn barrier under UV exposure conditions. In addition, as the gate bias increased from -1.0 to $+1.0$ V, the source–drain dark current increased, which is a typical behavior of HEMT. However, the photocurrent of HEMT with a 30 nm thick AlGaIn barrier was barely affected by the gate bias, whereas that of the HEMT with the 10 nm thick AlGaIn barrier was significantly amplified by reducing the gate bias. Based on these results, we suggest that HEMTs with a low 2-DEG channel can more easily amplify/reduce photocurrents than HEMTs with high 2-DEG by controlling gate bias.

Methods

The AlGaIn/GaN heterostructure of this work was grown on 4-inch *c*-plane (0001) sapphire substrates by metalorganic chemical vapor deposition. Trimethylgallium, trimethylaluminum were used as group III precursors and ammonia (NH_3) was used as a nitrogen source. The epitaxial structure consists of a high-resistance (HR) GaN buffer, a GaN channel layer, and an AlGaIn barrier layer, as shown in inset of Fig. 1a. After growing the 30 nm thick GaN nucleation layer at 480°C , the $2.0\ \mu\text{m}$ thick HR-GaN buffer layer was grown at 1000°C . HR-GaN buffer layer can be achieved by carbon incorporation because carbon contributes to the compensation of free carrier. Subsequently, a 150 nm thick GaN channel layer was grown with high crystalline quality, considering the 2-DEG characteristics and wafer uniformity. Finally, 10, 20, and 30 nm thick AlGaIn barrier layers with an Al composition of 30% were grown on the GaN channel layers to investigate the effect of the thickness of AlGaIn barrier. The grown epitaxial wafer was fabricated with a Hall bar structure and HEMTs for electrical evaluation. All device patterns were defined by optical lithography. Mesa isolation was performed with an inductive coupled plasma of BCl_3/Cl_2 gas mixture. The source and drain electrodes were formed with the metal stack of Ti/Al/Ni/Au ($20/100/25/50\ \text{nm}$) by e-beam evaporation and then annealed at 850°C in N_2 ambient. Finally, Ni/Au metals ($30/270\ \text{nm}$) were evaporated for gate metallization. The gates were centered within the drain-source. Overlay metallization on ohmic contacts and the measurement pads were also deposited during gate formation. The devices had a gate width of $100\ \mu\text{m}$ and a gate length of $2.0\ \mu\text{m}$. The source–drain spacing was $8\ \mu\text{m}$ and the sensing area was approximately $600\ \mu\text{m}^2$.

We analyzed the crystal and optical properties of AlGaIn/GaN heterostructured phototransistor with different AlGaIn barrier thicknesses using RIGAKU DMAX 2200 high resolution X-ray diffraction (HR-XRD) and THERMO SCIENTIFIC EVOLUTION 300 UV–visible spectroscopy, respectively. To evaluate the electrical properties, current–voltage (*I*–*V*) measurements of dark current and photocurrent were performed using the HP4155 parameter analyzer. For the UV illumination, a Xenon lamp with an exposure power of $17\ \mu\text{W}/\text{cm}^2$ at the wavelength of 360 nm was used as an excitation light source to observe the photocurrent.

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Author contributions

S.N.L. planned and supervised the project; S.H.B. and G.W.L. evaluated the AlGaIn/GaN-based phototransistor. C.Y.C. grew and fabricated AlGaIn/GaN-based phototransistors. All authors discussed and commented on the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to S.-N.L.

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