Electrical characterization of solar-blind deep-ultraviolet (Al_{0.28}Ga_{0.72})₂O₃ Schottky photodetectors grown on silicon by pulsed laser deposition

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Abstract: This study reports on (Al_{0.28}Ga_{0.72})₂O₃-based ultraviolet-C Schottky metal–semiconductor–metal and metal–insulator–metal photodetectors with peak responsivities of 1.17 and 0.40 A/W, respectively, for an incident-light wavelength of 230 nm at 2.50 V reverse-bias. © 2019 The Author(s)

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1. Introduction

In recent years, the heterogeneous integration of a variety of inorganic materials for fabricating electronic and optoelectronic devices on silicon has shown clear promise in reshaping the future of the electronics industry [1]. Such an integration approach is widely expected to pave the way for the implementation of Schottky photodiode device architectures, thereby allowing for the implementation of vertical device structures and lower response times. Researchers so far have focused on relatively narrow-bandgap GaN-based devices fabricated on silicon and sapphire [2, 3] as well as ultrawide-bandgap group III–oxides-based devices fabricated on sapphire. Xu et al. have demonstrated solar-blind deep-ultraviolet β -Ga₂O₃ metal–semiconductor–metal (MSM) photodetectors grown on *c*-plane sapphire by mist chemical-vapor deposition [4]. Their photodetectors exhibited remarkable peak spectral responsivities (SRs) of above 150 A/W for an incident-light wavelength (λ_{in}) of 254 nm under a reverse-bias (V_{bias}) of 20 V. In this report, we demonstrate (Al_{0.28}Ga_{0.72})₂O₃-based solar-blind deep-ultraviolet Schottky MSM and metal–insulator–metal (MIM) photodetectors grown and fabricated on *p*-type silicon (100) by pulsed laser deposition (PLD) and conventional nanofabrication processes. The (Al_{0.28}Ga_{0.72})₂O₃ film was grown at a substrate temperature of 800°C and an oxygen partial pressure of 4.5 mTorr; the film's thickness was estimated to be 150 nm by using atomic backscattering spectrometry to approximate the deposition rate per pulse. Our photodetectors exhibited peak SRs of above 1.10 A/W for an MSM photodiode configuration and 0.40 A/W for a MIM photodiode configuration, for an $\lambda_{in} = 230$ nm at $V_{bias} = 2.50$ V. The devices exhibited low dark-current densities (J_d) of around 4.64×10^{-10} A/cm² and 4.10×10^{-10} A/cm² (for MSM and MIM, respectively) at $V_{bias} = 2.50$ V, while they showed photo-to-dark-current ratios of above 10^3 . Fig. 1 shows a schematic illustration of the photodetector fabrication process.

Fig. 1. Fabrication process: 1) silicon wafer preparation; 2) PLD deposition of (Al_{0.28}Ga_{0.72})₂O₃; 3) and 4) depiction of the electron beam/lift-off and magnetron sputtering deposition of gold (10 nm)/titanium (10 nm) top and bottom metal contacts, respectively.

2. Results and Discussion

Fig. 2(a) shows Rutherford backscattering spectrometry (RBS) measurements of a 35-nm-thick (AlGa)₂O₃ grown on silicon (100) using PLD under the conditions described earlier, thus confirming the atomic composition of the (AlGa)₂O₃ film, while Fig. 2(b) depicts typical current density vs. voltage (J – V) curves for both photodetector device configurations. Fig. 2(c) plots the calculated external quantum efficiency (η_{ex}) values, whereas Fig. 2(d) shows photocurrent density vs. V_{bias} (J_{ph} – V_{bias}) curves. The MSM photodetector configuration was found to exhibit photo-to-dark-current ratios of above 10^3 , while the MIM photodetector configuration showed photo-to-dark-current ratios of above 10^1 . Fig. 2(e) and Fig. 2(f) depict SR vs. V_{bias} plots for the MSM and MIM photodetector configurations, respectively, for the λ_{in} range of 230–280 nm. The MSM photodetector exhibited a peak SR of

around 1.17 A/W for $\lambda_{in} = 230$ nm at $V_{bias} = 2.50$ V, while the MIM photodetector displayed a peak SR of approximately 0.40 A/W at the same λ_{in} and V_{bias} values. The effective device areas were found to be $112 \times 112 \mu\text{m}^2$, and they exhibited low dark currents of around 26 pA at 0 V and $3.70 \mu\text{A}$ at $V_{bias} = 2.50$ V (MSM) and 9 pA at 0 V and $3.26 \mu\text{A}$ at $V_{bias} = 2.50$ V (MIM). The peak MSM photodetector SRs decreased from 1.17 A/W for an $\lambda_{in} = 230$ nm to 0.46 for $\lambda_{in} = 280$ nm as absorption decreased. The material bandgap energy was estimated from a linear interpolation and was found to be approximately 5.35 eV. The MSM and MIM photodetectors demonstrated specific detectivity (D^*) values of 9.60×10^{11} Jones and 3.53×10^{11} Jones, respectively. As depicted in Fig. 2(c), the MSM and MIM photodetectors showed peak η_{ex} values of 631% and 218%, respectively, at $\lambda_{in} = 230$ nm. Therefore, our deep-ultraviolet photodetectors, grown on silicon, showed remarkable performance under the relatively low bias of -2.5 V for a 230 nm incident wavelength when compared to the 254 nm $\beta\text{-Ga}_2\text{O}_3$ -based photodetection devices reported by Xu et al., which were grown on sapphire and operated at a comparatively high bias of -20 V.

Fig. 2. (a) RBS measurements; (b) measured J - V curves of the photodiodes; (c) calculated η_{ex} values; (d) measured J_{ph} - V_{bias} curves for the MSM (top) and MIM (bottom) photodetector configurations; (e) and (f) SR vs. V_{bias} plots for the (e) MSM and (f) MIM photodetector configurations.

3. Conclusion

This paper has demonstrated (AlGa)₂O₃-based ultraviolet-C Schottky photodetectors grown on silicon (100). The solar-blind photodetectors exhibited peak SRs of 1.17 A/W for the MSM configuration and 0.40 A/W for the MIM configuration for an $\lambda_{in} = 230$ nm at a reverse-bias voltage of 2.50 V. Photo-to-dark-current ratios of above 10^3 were achieved for the MSM photodetector configuration. This is the first reported Ga₂O₃-based photodetector to have been grown on silicon, which will pave the way for the fabrication of cheap and vertically structured deep-ultraviolet solar-blind photodetection devices. Because the PLD growth of high-quality monoclinic crystals on cubic silicon is a challenging process, this issue may have compromised the (AlGa)₂O₃ crystal quality, potentially leading to degradations in device performance. Future work includes making improvements to the (AlGa)₂O₃ crystal quality by growing the material on silicon (111) and by further optimizing the film thickness and device design to obtain better photodetector performance.

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