Emergent Property Sets & Applications of β-Ga_2O_3 Hetero-epilayers grown by Pulsed Laser Deposition

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Abstract

Recently there has been a surge in interest for the wide bandgap (Eg ~ 4.9 eV) semiconductor gallium oxide (Ga_2O_3). Amongst a whole range of potential applications power electronics, solar-blind photodetectors and UVC transparent electrodes offer exciting perspectives. In this talk we give an overview of these applications illustrated with examples from the β-Ga_2O_3 development work carried out at the French oxide epiwafer foundry, Nanovation.

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1. Introduction

Recently, there has been a surge in interest for the wide bandgap (Eg ~ 4.9 eV) semiconductor gallium oxide (Ga_2O_3). A key driver for this boom is that single crystal wide area bulk β-Ga_2O_3 substrates have become commercially available [1] and a variety of methods have been shown to give high quality epitaxial growth [2,3]. Although Ga_2O_3 has a number of polymorph forms, the more stable monoclinic phase (β-Ga_2O_3) has attracted the most attention. Amongst a whole range of potential applications power electronics, solar-blind photodetectors and UVC transparent electrodes offer exciting perspectives [3-5].

In this talk we give an overview of these applications illustrated with examples from the β-Ga_2O_3 development work carried out at the French oxide epiwafer start-up, Nanovation [4-7].

2. Experimental

In this work, wide area plasma-assisted pulsed laser deposition (PA-PLD) was used to grow nominally undoped Ga_2O_3 layers. In view of the high cost level of single crystal Ga_2O_3 substrates, Ga_2O_3 layers were deposited on *a*-, *c*- and *r*-plane sapphire substrates.

3. Results and Discussion

X-ray diffraction analysis showed all the layers to be in the β-Ga_2O_3 phase. Films grown on *a*- and *c*-plane sapphire showed a preferential orientation of the (-201) axis along the growth direction while those grown on *r*-plane sapphire had an epitaxial offset from the growth direction for the (-201) axis [6]. Optical transmission spectroscopy revealed a transparency of > 80% in the solar wavelength range for all the layers. The absorption edges indicated that there was a very significant increase in apparent bandgap (up to ~5.5 eV), however, as layer thickness was decreased from a micron down to 100 nm [4]. Four point collinear resistivity and Van der Pauw based Hall measurements revealed that β-Ga_2O_3 layers on r-plane sapphire could be up to 6 orders of magnitude more conductive than layers grown on *c*-plane sapphire under similar conditions [6]. Compositional depth profiling for common shallow donor impurities (Cl, Ge, Si and Sn) did not, however, indicate any discernable increase in their concentrations compared to background levels in the sapphire substrate. High temperature Hall measurements gave an indication of a deep acceptor dominating the conductivity in relatively insulating (stoichiometric) layers on c-sapphire [7].

With regards to power electronics, the deep UV transparency advantage of sapphire was leveraged to allow laser lift-off and transfer of the layers onto heat sinks and thus evacuate the crippling heat build up that occurs on thermally insulating native substrates.

With regards to solar blind photodetectors the thickness dependence of the apparent bandgap was successfully leveraged in order the spectral response peak down to a 230 nm peak response without the need for alloying [4].

With regards to transparent electrodes the remarkably conductive layers on r-sapphire were adopted as transparent electrode superstrates for ferroelectric solar cells, which showed world record performance [5].

4. Conclusion

The heteroepitaxial growth of β-Ga_2O_3 layers by wide area PA-PLD on cheap non-native sapphire substrates was explored.

New and intriguing property sets were found including a thickness dependence of bandgap, a sapphire substrate orientation dependence of conductivity and an indication of a deep acceptor dominating the conductivity in relatively insulating (stoichiometric) layers grown on c-sapphire.

These were leveraged to (a) allow laser lift-off and transfer to a thermally and electrically conductive substrate (b) engineer the spectral responsivity of photodetectors without alloying and (c) serve as solar transparent conducting superstrates for solar cell applications,

References

[1] http://www.tamura-ss.co.jp/en/products/gao/index.html
[2] http://nanovation.com/en/products/
[3] M. Razeghi, D. J. Rogers et al. Proc. SPIE 15330 (2018) O R-1
[4] D. J. Rogers et al. Proc. SPIE 15330 (2018) O R-1
[5] A. Perez-Tomas, D. J. Rogers et al. Proc. SPIE 15330 (2018) 1 Q-1
[6] F. H. Teherani, D. J. Rogers et al. Proc. SPIE 10105 (2017) 1 P-1
[7] E. Chikoidze et al. Materials Today Physics 3 (2017) 118

Fig.1: 2 inch Diameter β-Ga$_2$O$_3$/c-sapphire epiwafer produced by Pulsed Laser Deposition at Nanovation [4].

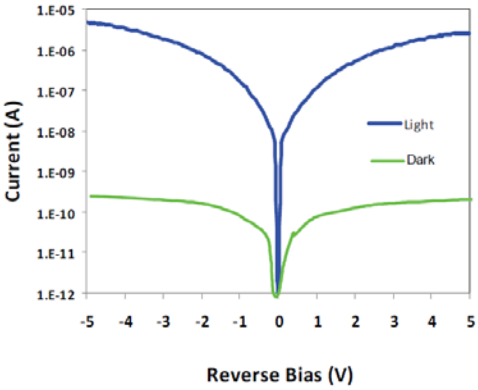

Fig.2: I/V Characteristic (with/without Xe lamp illumination) for a 230 nm Metal-Semiconductor-Metal photodetector fabricated with a Nanovation β-Ga$_2$O$_3$/c-sapphire epiwafer (courtesy: Center for Quantum Devices, Northwestern University) [4].