GaN-Based Resonant Cavity-Enhanced UV-Photodetectors

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Resonant cavity-enhanced UV-photodetectors (RCE-UV-PDs) based on GaN have been investigated. The RCE-PDs [1] are photo-detectors whose absorption layers are placed in optical cavities composed by distributed Bragg reflector (DBR) mirrors. Due to the resonant cavity effect, the optical field intensity drastically increases at the absorption layer. For a high finesse cavity, for example, the internal optical intensity can be enhanced 10-50 times at the resonant wavelength as large as the incident optical intensity. So the RCE-PD can show the high quantum efficiency for a thin absorption layer, with high wavelength selectivity.

Photo-responses of GaN-based RCE-PDs are theoretically analyzed. And then for the first step of experiment, GaN/AlGaN distributed Bragg reflectors (DBRs) were fabricated by RF-plasma assisted molecular beam epitaxy (RF-MBE). High peak reflectivity values of DBRs (95% and 92%) were achieved at the wavelength of 444nm (blue) and 377nm (UV), respectively. The conventional GaN photoconductor (without DBR) was fabricated to evaluate the relative photo-response spectrum. On the base of the spectrum, the photo-response spectrum of GaN-based RCE-PDs with a 20nm GaN absorption layer is simulated. For the thin absorption layer, the high quantum efficiency of 88% can be expected with the sharp wavelength selectivity.

The analysis model of GaN-based MSM-RCE-PD is shown in Fig.1. The GaN absorption layer with thickness d and absorption coefficient α is placed between two DBR mirrors. R_1 and R_2 are reflectance of top and bottom DBRs, respectively. The resonance wavelength of RCE-PDs is assumed 360nm and α is $1x10^5 cm^{-1}$. The maximum quantum efficiency of RCE-PDs (η_{max}) as a function of absorption layer thickness (d) is shown in Fig.2 with solid curves, for various R_2 values. Here R_1 is chosen as $R_1=R_2 \exp(-2\alpha d)$ for maximizing η. The dashed curve is the quantum efficiency for the conventional detector without DBR (i.e. $R_1=0.16$, $R_2=0$). The η_{max} of RCE-PD ($R_2=99\%$) could be achieved 97.5％ for a thin absorption layer (d=20nm). On the contrary, η for the conventional scheme photo-detector is only 15％ for the same absorption thickness. The calculated wavelength selectivity of GaN-based RCE-PD is shown in Fig.3, for various d values, i.e. 20, 50 and 100nm. Here R_2 is 0.95 and R_1 is 0.65. We note that the wavelength selectivity decrease remarkably with increasing the absorption layer thickness d. A thin absorption layer and a high reflectance of bottom mirror are essential to obtain both of the high quantum efficiency and the excellent wavelength selectivity.

GaN/AlGaN DBRs with 20.5-periods of AlN(43.2nm)/GaN(50.8nm) and 50-periods of $Al_{0.14}Ga_{0.86}N$ (37.2nm)/GaN(35.9nm) quarter-wave stacks were grown on (0001) Al_2O_3 substrate by RF-MBE. In the growth, atomically flat GaN surfaces were realized for Ga-polarity GaN by use of high-temperature (750^{o}C) grown AlN buffer layer. The measured reflectance spectrum of the GaN/AlN-DBR is shown in Fig.4, with the theoretical curve. The experimental peak reflectance was 95% at 444nm in wavelength. For the AlGaN/GaN-DBR, the peak reflectance of 92% was achieved at 377nm.

The relative photo-response spectrum of GaN-photoconductor was experimentally evaluated, as shown in Fig.5, with a dotted line (in this case, η is given in arbitrary unit). The steep cut-off ratio over 10^3 was confirmed between 360nm and 400nm in wavelength. By use of the relative spectral response of GaN, the quantum efficiency spectrum of GaN-based RCE-UV-PD with 20nm GaN absorption layer is calculated (see a solid line in Fig.5). Here the wavelength dependencies of DBRs are taken into account. The sharp wavelength selectivity at 360nm is expected with a high quantum efficiency of 88% even for very thin absorption layer (20nm).

Reference [1] K. Kishino et al., IEEE J. Quantum Electron, 27 (1991) 2025-2034.

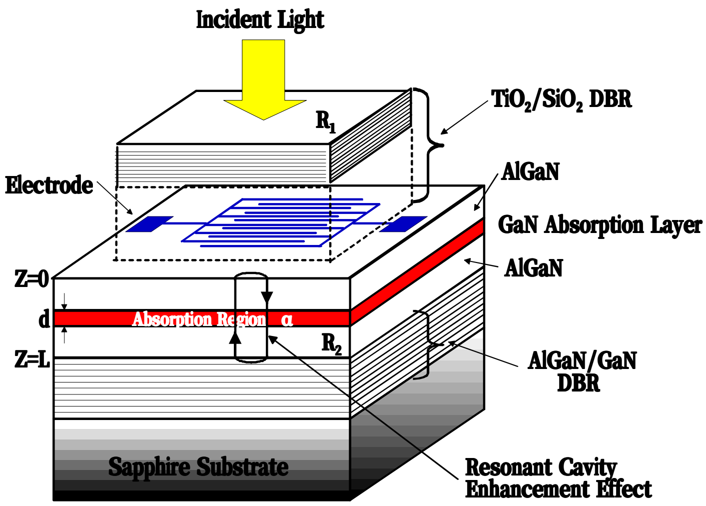

Fig.1 Analysis Model of Resonant Cavity-Enhanced (RCE) MSM Detectors

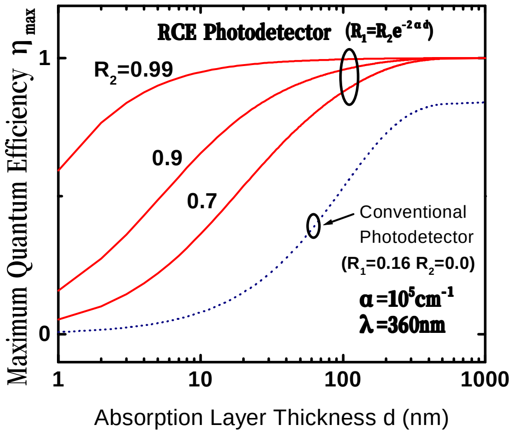

Fig.2 Theoretical maximum quantum efficiency of RCE-PD as a function of active layer thickness d for various R_2

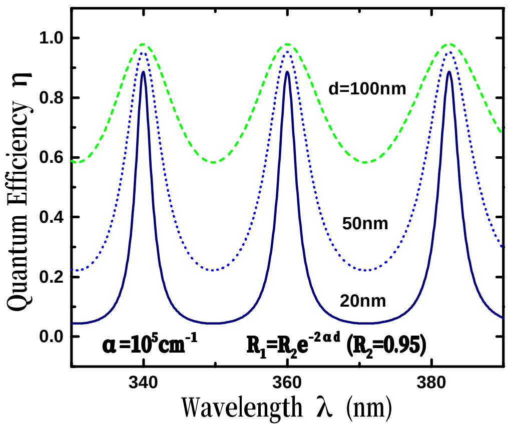

Fig3. Theoretical quantum efficiency of RCE-PD as a function of wavelength λ for various d

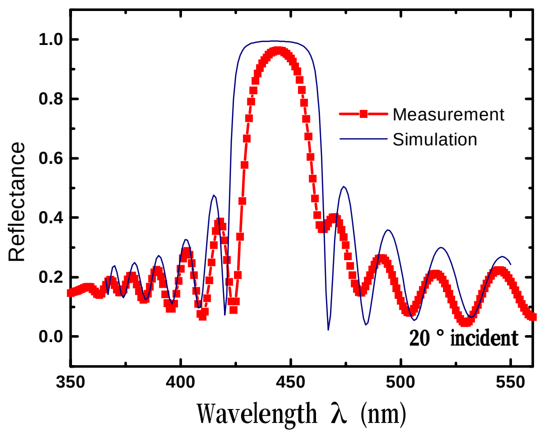

Fig4. Experimental and theoretical reflectance spectra of GaN/AlN DBR mirror

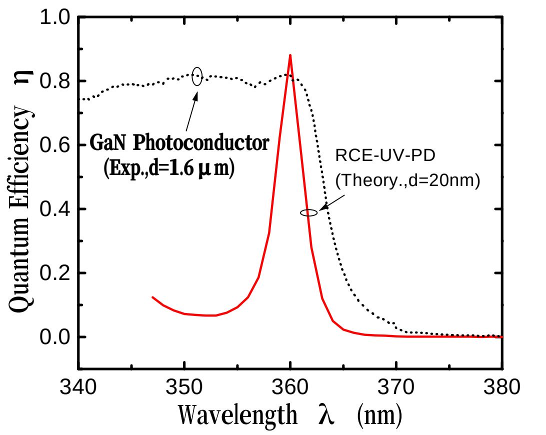

Fig.5 Experimental photo-response of GaN-photo conductor (d=1.6μm) and theoretical quantum efficiency of GaN-based RCE-UV-PD (d=20nm)