L.2: Ultra-narrow band UV detection in GaN with simple device architecture

Wavelength-selective ultraviolet (UV) photodetectors (PDs) with high spectral selectivity and narrow full-width at half-maxima (FWHM) are highly desired for many applications including flame sensors, selected-wavelength imaging, military, fluorescence detection, UV-phototherapy, etc. In general, narrowband detectors can be realized by: (1) integrating broadband PDs with a passive bandpass filter, (2) carefully augmenting the absorption coefficient of the material in a specific wavelength range via surface plasmons, or (3) using photo-sensitive materials with narrowband absorption. However, all of these techniques have their own limitations due to either the complexity of device integration or operational point of view. The first method requires the use of expensive filters and it enhances the complexity of device integration. The second method based on plasmon enhanced absorption also has limitation in its operational spectral range and its sensitivity towards other non-plasmonic wavelength ranges. The third approach has been the predominant strategy for achieving narrow band photo detection in inorganic semiconductors, where semiconductors with dissimilar bandgaps can be integrated to achieve the desired bandpass spectral selectivity. Researchers used back-illuminated GaN/AlGaN/AlN multilayer structure to achieve a bandpass spectral response with bandwidth of ~30 nm. However, a persistent photo-response sometimes limits the device bandwidth due to absorption from top layer. Hence, it is very difficult to achieve a very narrow bandwidth <10 nm using such structures. Thus, there is a great demand for cost-efficient narrow band PDs with architectural simplicity.

Development of an ultra-narrow band UV metal–semiconductor–metal (MSM) detector based on a simple p-GaN /un-intentionally doped (UID) GaN epilayer structure has been carried out. The layer structure consists of 2 μm p-GaN/ 3 μm UID GaN/ 30 nm AlN layer/sapphire. The device is processed using photolithography for fabricating fingers of 1 mm length and 100 μm width in cross geometry. Here, a ZrO_2 oxide layer is used for contact isolation and surface passivation and Ni (15 nm) /Au (100 nm) electrode forms Schottky contacts connecting the device active area with the large area contact pads on oxide layer. A microscopic image of the device is shown in Figure L.2.1(a). FWHM of ω-scan of HRXRD for GaN (002) is found to be 233 arcsec (0.064°), which indicates a good crystalline quality of the grown layer.

Figure L.2.1(b) shows the spectral-response of the device over the wavelength range of 270–500 nm at zero bias. An ultra-narrow response centered at 366 nm with an FWHM of 5 nm and UV-to-visible rejection ratio higher than 2×10^3 is measured by comparing the spectral response at 366 nm with that at 400 nm. Note that the peak centered at ~3.38 eV is about 40 meV below the GaN band-edge at room temperature. Several possible transitions related to the observed sub-bandgap feature are identified and marked in the band diagram (Figure L.2.1(c)). Features-1 and 2 are related to band edge and deep acceptor (E_{DA})-to-conduction band (E_C) transition, whereas features-3 and 4 represent valence band (E_V) to shallow donor (E_{SD}) and occupied surface states to conduction band transition. In order to pinpoint the origin and special location of the electronic transition associated with the narrow band feature, conventional and pump-probe surface photo-voltage spectroscopy (PP-SPS) measurements are performed with 325 nm excitation pump beam (Figure L.2.1(d-e)). Due to a high background carrier density in p-GaN, a negligible SPS in the above bandgap region is observed. Also, no change in the magnitude and phase of SPS signal with 325 nm pump beam confirms that the particular feature is not associated with the surface depletion region indicated by process 4 in Figure L.2.1(c). Thereafter, two more transitions are considered, i.e., (1) E_{DA}-to-E_C transition, and (2) E_V to E_{SD} transition. PP-SPS measurements with 1064 nm pump beam are then performed, which confirms that the E_V to E_{SD} transition lying at p-GaN/ UID GaN interface is actually responsible for the narrow band UV response of the device. Further, the room temperature responsivity of the detector under 366 nm illumination is recorded and found to be 3 A/W at 5 V applied bias. The detectivity of the device is also estimated considering shot noise as the major contributor in the dark current and is found to be 1.3×10^{10} Jones. Thus, a stable and highly spectrum-selective device has been developed, which possesses great potential for narrow band UV detection. For more details, please refer to: *Chatterjee et al., Phys. Stat. Sol. RRL, pssr. 202200322, 2023.*

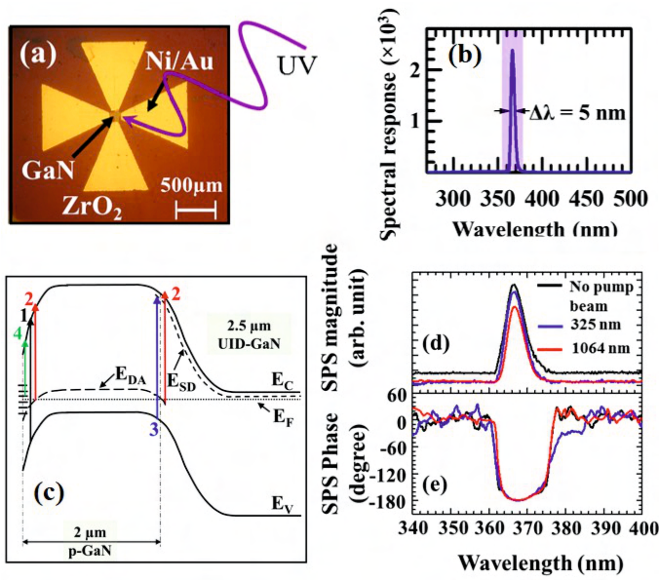

Fig. L.2.1: (a) Optical microscopic image of the device (top view), (b) room temperature spectral response, (c) schematic band diagram of p-GaN/UID GaN structure, comparison of conventional and pp-SPS (d) magnitude and (e) phase spectra.

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