INVESTIGATION OF ELECTRICAL AND OPTICAL PROPERTIES OF InGaAsN/GaAs QW MSM PHOTODETECTORS

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1. Introduction

The InGaAsN/GaAs heterostructures [1] have been successfully used in telecom laser constructions on GaAs substrate. The InGaAsN with a bandgap of 1 eV, lattice matched to both GaAs and Ge for the nitrogen and indium contents of around 3 % and 9 %, is a promising layer material for detecting near infrared optical light. The growth technology of the GaAsN alloy-based diluted nitrides is very difficult because of the large miscibility gap between GaAs and GaN. The incorporation of more than 3 % of nitrogen into GaAs crystalline structure drastically deteriorates the optical quality of InGaAsN epilayers [2]. They contain a lot of the point defects (vacancies, antisites, interstitials) and impurities (oxygen, carbon, hydrogen). The main efforts of the investigators have been made to understand physics of these alloys, to optimize the growth conditions and improve their structural and optical quality due to application in high-performance optoelectronic devices [3,4]. InGaAsN/GaAs heterostructures are typically prepared by LP MOVPE [5].

This work presents electrical and optical properties of MSM photodetectors containing the triple quantum well (MQW) InGaAsN/GaAs structures grown by atmospheric pressure metal organic vapour phase epitaxy (APMOVPE). The main growth parameters such as the growth temperature, the hydrogen flow rate through the bubbler with the organic nitrogen source and the molar ratio of the gallium to indium in the gas phase were changed to achieve the high material quality. The properties of the structures were analysed by using HRXRD, CER and SIMS methods [6].

2. Experimental

The investigated heterostructures were grown by atmospheric pressure metal organic vapour phase epitaxy (APMOVPE) with AIX200 R&D AIXTRON horizontal reactor on (100)-oriented semi-insulating SI GaAs and Si-doped n-type GaAs substrates. Trimethylgallium (TMGa), trimethylaluminium (TMAl), tertiarybutylhydrazine (TBHy) and arsine (AsH_3: 10 % mixture in H_2) were used as the growth precursors [6] High purity hydrogen was employed as a carrier gas. The following growth parameters were changed: the growth temperature T_g=566 - 585 °C, the hydrogen flow rate through the saturator with TBHy – $V_{H2/TBHy}$=1100 - 3000 ml/ min, the ratio of the gallium to indium source concentration in the gas phase III_{Ga}/III_{In}=4.8 and 6.9. Stable parameters during all runs were: the arsine flow rate V_{AsH3}=50 ml/ min (for GaAsN and InGaAsN) and 300 ml/ min (for GaAs), the total flow of the hydrogen carrier gas V_{H2tot}=9.6 l/ min, the organic source temperatures: T_{TMGa}=-10 °C, T_{TMAl}=18 °C, T_{TMIn}=20 °C, T_{TBHy}=30 °C.

The MSM photodetector was prepared on undoped MQW structure consisted of 450 nm thick GaAs buffer and 3x $In_xGa_{1-x}As_{1-y}N_y$ (~ 15 nm)/GaAs (~ 30 nm) with composition x = 14.5%, y = 0.38% (sample NI43), resp. x = 17.1%, y = 0.55% (sample NI46). MQW region was capped by ~ 44 nm thick undoped GaAs. MSM photodetector structure image is shown in Fig. 1. The ratio gap/contact width is 3 μm / 1 μm.

I-V characteristics of the fabricated photodetectors were measured using Agilent 4155C parameter analyzer with wolfram contact probes connected to the expanded contacts. Dark and light I-V characteristics were measured using analyser's built-in voltage and current meter. For illumination of the photodetector a fibre coupled LEDs (400, 610, 855 and 925 nm) were used with calibrated optical power. Spectral characteristics were measured using standard spectral measurements by halogen bulb, chopper, monochromator, lock-in nanovoltmeter and DC source.

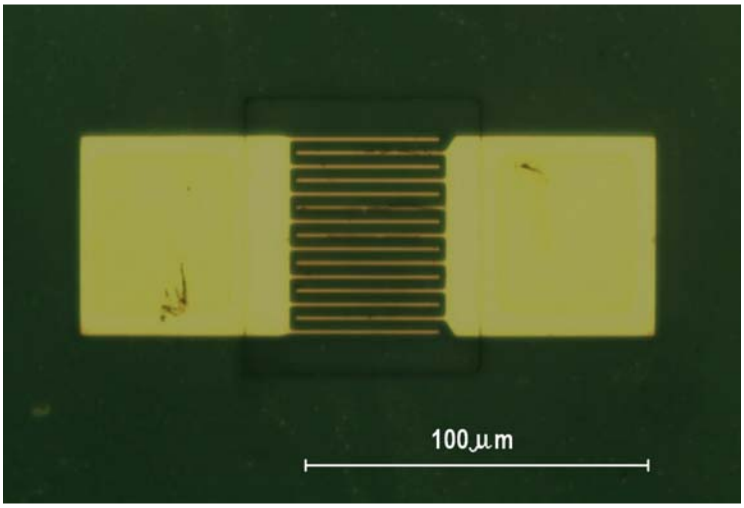

Fig. 1 Optical microscope image of MSM photodetector Schottky contacts

3. Results and discussion

Typical measured I-V characteristic of MSM photodetectors with undoped triple $In_xGa_{1-x}As_{1-y}N_y$/GaAs MQW are shown in Fig. 2a,b. The I-V characteristics are symmetric and correspond to reverse characteristics of each Schottky contact of undoped heterostructure. The photocurrent generated under different illumination wavelength of LEDs corresponds with spectral sensitivity comparable with spectral measurements. Sample NI43 exhibits higher photocurrent than sample NI46 due to better InGaAsN lattice mismatch to GaAs, therefore higher quality of QW structures. Relatively high lateral electric field is presented between interdigited contacts therefore electrical current depends on the cap layer thickness. The carriers trapped in undoped MQW under illumination contribute to the resultant high photocurrent gain in broad range of the bias voltage.

In Fig. 3,4 are depicted the spectral characteristics of investigated MSM photodetectors. Therefore peaks corresponding to optical transitions in $In_xGa_{1-x}As_{1-y}N_y$/GaAs MQW are visible nearby the bandgap of quaternary compound (~ 980 nm) in correspondence with composition of $In_xGa_{1-x}As_{1-y}N_y$ quaternary QW. Due to better InGaAsN lattice mismatch to GaAs for sample NI43 there is less mechanical strain between layers in MQW which exhibits in higher photocurrent than for the sample NI46 and better resolved quantum states in QW. The spectral characteristic of sample NI 46 is shifted due to higher content of In and N in $In_xGa_{1-x}As_{1-y}N_y$ layer of QW.

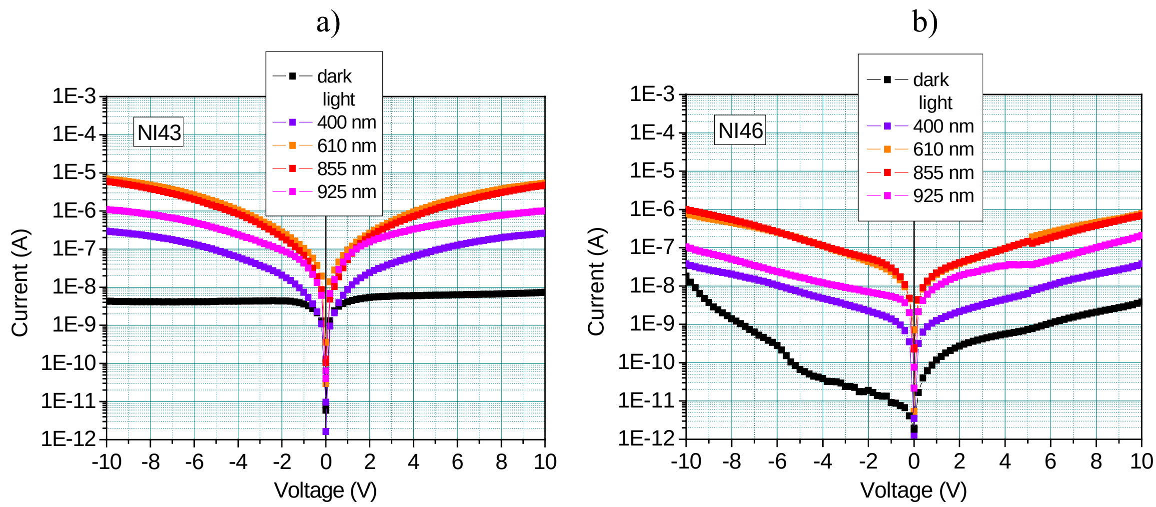

Fig. 2 I-V characteristics of $In_xGa_{1-x}As_{1-y}N_y/GaAs$ MQW MSM photodetector
a) (x = 14.5%, y = 0.38%) b) (x = 17.1%, y = 0.55%)

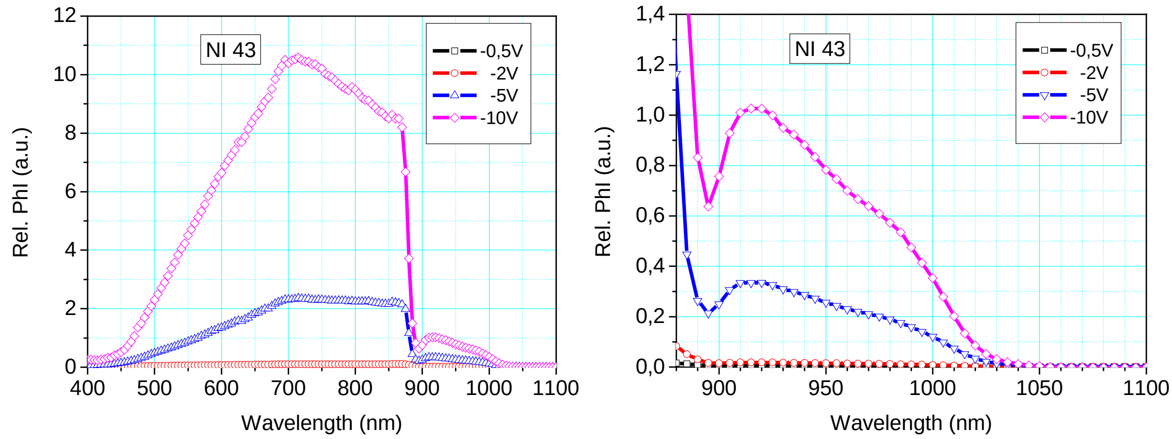

Fig. 3 Spectral characteristics of $In_xGa_{1-x}As_{1-y}N_y/GaAs$ MQW MSM photodetector (x = 14.5%, y = 0.38%)

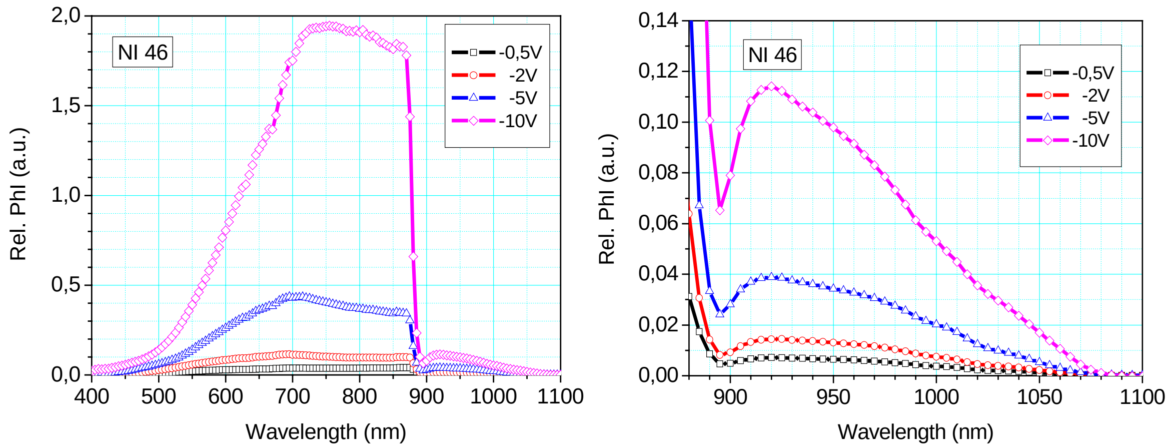

Fig. 4 Spectral characteristics of $In_xGa_{1-x}As_{1-y}N_y/GaAs$ MQW MSM photodetector (x = 17.1%, y = 0.55%)

4. Conclusions

I-V characteristics and spectral characteristics of the MSM photodetectors with undoped triple $In_xGa_{1-x}As_{1-y}N_y$/GaAs MQW were measured and analysed. The I-V characteristics show low dark current, the carriers trapped in undoped MQW under illumination contribute to the resultant high photocurrent gain in broad range of the bias voltage. In photocurrent spectra peaks corresponding to optical transitions in $In_xGa_{1-x}As_{1-y}N_y$/GaAs MQW are visible nearby the bandgap of quaternary compound at ~990 nm for sample NI43 and ~ 1030 nm for sample NI46. Due to better InGaAsN lattice mismatch to GaAs there is less mechanical strain between layers in MQW which exhibits lower composition x = 14.5%, y = 0.38% (sample NI43). The low temperature spectral measurements will be the next step in this work as well as theoretical calculations of energy stages in MQW because of actual unknown material parameters of InGaAsN.

Acknowledgement

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