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STUDY OF ANTIREFLECTION COATINGS FOR HIGH-SPEED 1.3 -1.55 µm InGaAs/InP PIN PHOTODETECTOR

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Abstract. Single layer antireflection coatings have been studied for optimization InGaAs/InP photodetector with normal incident light over the 1300-1550-nm wavelength range. Silicon nitride coatings with various thicknesses were fabricated using plasma enhanced chemical vapor deposition and inductively coupled plasma chemical vapor deposition. The antireflection coating with thickness of 200 nm demonstrated reflection below 10 % at 1550 nm wavelength.

Keywords: single layer antireflection coating; silicon nitride coating; InGaAs/InP photodetector.

1. Introduction

Infrared photodetectors (PD) have a big number of applications in telecommunications, sensing and gas monitoring. One of the most rapidly developing area is microwave photonics where high-speed PDs with 1.3–1.55 um spectral range corresponds to II and III transmission windows are demanded [1]. In photonic links, PDs convert modulated light signal into ultrahigh-frequency electrical current [2]. One of the important performance criteria for these devices is the quantum efficiency, thus it is important to minimize the power of reflected light from a PD surface. Decrease of the quantity of light reflected from a PD surface leads to increase in the sensitivity of a PD and expands the dynamic range of wavelengths where a PD operates. An antireflection (AR) coating may be used to decrease the quantity of reflected light from a PD surface [3-4].

In this paper we reported on studies of single layer AR coatings fabricated by plasma-enhanced chemical vapor deposition (PECVD) and inductively coupled plasma chemical vapor deposition (ICP CVD) for InGaAs/InP PD for normal incident light. The parameters of the deposited AR coatings and measurements results are described below.

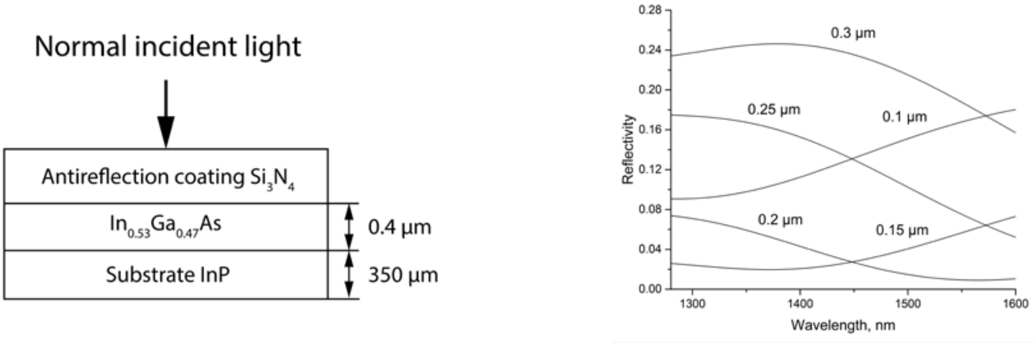
2. Experiment

Heterostructure for high-speed PIN type PD for λ=1300-1550 nm was grown by molecular beam epitaxy on semi-insulating InP substrate. The absorption layer is represented by $In_{0.53}Ga_{0.47}As$ layer of 0.8 um thickness that provides small tunneling time of generated charge carriers resulting in high-speed operation. At the same time, the high absorption coefficient of $In_{0.53}Ga_{0.47}As$ provides sufficient photosensivity. Several gradient layers are designed between contact layer, window layer $In_{0.52}Al_{0.48}As$ and absorption layer to decrease the serial resistance of the heterostructure.

The PD chips were fabricated by dry etching double mesa processing. Ti/Au layer was deposited successively on top p-type contact InGaAs layer and patterned by a lift-off process to form an enclosed circular mesa-structure instituted as a p+ ohmic contact with an inner diameter of 20 μm. Standard photolithography was used for dry etching first and second mesas by BCl_3/Ar. Then AuGe/Ni/Au layer is deposited successively on n-type contact capping layer InGaAs and patterned by a lift-off process. Both ohmic contacts then were rapid thermal annealed at 360 °C. The next step was deposition and patterning PECVD Si_3N_4. Ti–Au interconnect metal was evaporated forming the coplanar waveguide transmission lines by a lift-off process. The AR coating deposition was the last technological operation. Afterward, the wafer was lapped and polished down 120 μm and then dicing on the single PD chips.

To study and optimize the AR coatings for the frontside illuminated PDs a special test structure was grown. The structure consisted of rather thick $In_{0.53}Ga_{0.47}As$ layer emulated the p-contract layer of the PDs. Fig. 1(a) illustrates the cross section of the test structure that was used to study the reflectivity of the high-speed InGaAs/InP PD.

For calculation of a reflectivity of the test structure, we use the transfer-matrix method where each layer of a multilayer structure is described by a characteristic matrix which includes an index of refraction, a layer thickness, a wave number and a wave impedance of a layer. The multilayer structure is described by serial multiplication of the matrixes of all containing layers [5]. Thicknesses of the AR coating were chosen with taking into account the index of refraction of silicon nitride in the range of 1400-1600 nm and the high p-doped contact $In_{0.53}Ga_{0.47}As$ layer [6]. Results of the calculations are shown on the Fig. 1(b).



(a) (b)

Fig. 1. Cross section of the test structure simulating the PD with AR coating (a) and calculated reflectivity of the test structures with different thicknesses of the AR coating.

The AR coating on the surface of test structure (dielectric coating Si_3N_4 with refractive index of 2.0) was deposited by two different methods i.e. PECVD with high temperature deposition and IPC CVD with a low temperature. Detailed characteristics of the deposited AR coatings can be found in the Table 1.

Table 1. Characteristics of the deposited AR coatings.

No.	Processing technique	Temperature, ºC	Thickness, um
1	PECVD	250 ºC	0.1 um
2	PECVD	250 ºC	0.15 um
3	PECVD	280 ºC	0.15 um
4	PECVD	280 ºC	0.3 um
5	ICP	70 ºC	0.1 um
6	ICP	70 ºC	0.2 um
7	ICP	70 ºC	0.3 um
8	Test sample	–	–

For comparison with the PD without AR coating, we use the test sample (No. 8 in the Table 1), which was chemically cleaned with dimethylformamide.

3. Experimental results and discussion

The RPMSigma system by Nanometrics was used for measurements of a PD reflectivity. Reflection spectra for samples No.1-No.4 with PECVD silica nitride are represented on the Fig. 2. Samples No.2 and No.3 had demonstrated minimum reflectivity among the PECVD samples i.e. about 10 % and 13 % of incident light power at the wavelength 1550 nm reflected from the PD. Samples No.1 and No.4 with thicknesses 0.1 nm and 0.3 nm correspondingly had demonstrated reflectivity about 23 %, what demonstrates high interference between the AR coating and top p- $In_{0.53}Ga_{0.47}As$ layer.

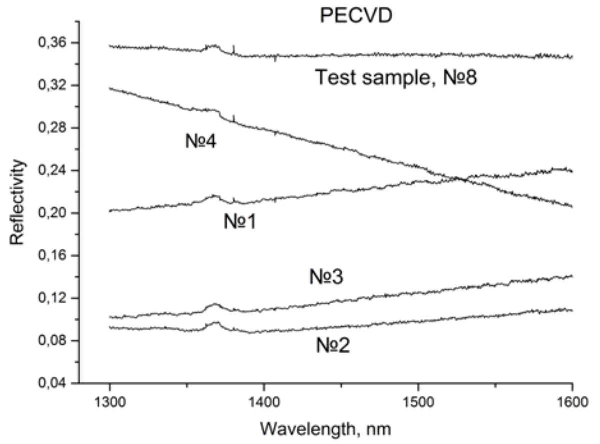


Fig. 2. Reflectivity of the samples with AR coating deposited by PECVD.

Reflection spectra for samples No.5-No.7 with IPC CVD silica nitride are represented on the Fig. 3. Samples No.7 with thickness 0.3 um deposited at low temperature had demonstrated high reflectivity about 30% at the wavelength 1550 nm close to the test sample No.8 without AR coating, at the same time sample No. 6 had demonstrated the lowest reflectivity 9% at the wavelength 1550 nm about among the all samples.

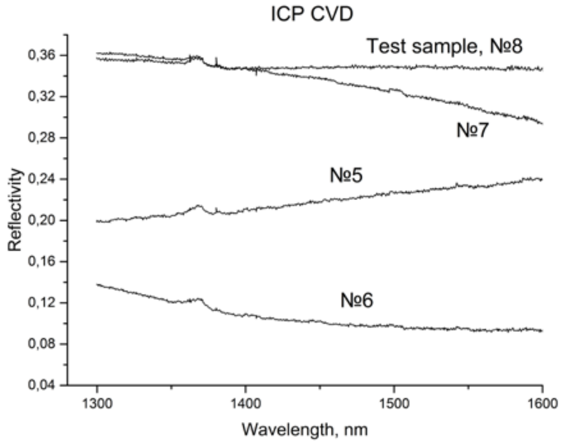


Fig. 3. Reflectivity of the samples with AR coating deposited by IPC CVD.

4. Conclusions

The single layer AR coating has been developed for use with the high-speed InGaAs/InP frontside illuminated PD. The silicon nitride (Si_3N_4) coatings with thicknesses 0.1, 0.15, 0.2 and 0.3 um were fabricated using PECVD and ICP CVD techniques. Among the samples fabricated by PECVD the sample No. 2 (250 ºC temperature deposition and 0.15 um thickness) had shown < 10 % reflected power at 1550 nm wavelength. Among the samples fabricated by IPC CVD sample No. 6 (70 ºC temperature deposition and 0.2 um thickness) had shown < 9 % reflectivity. The obtained results can be used for optimization of high-speed InGaAs/InP photodiodes operating at 1550 nm.

Acknowledgment

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