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Effect of sulfide-polyamide passivation on dark currents of the InAlAs/InGaAs/InP avalanche photodiodes

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Abstract. The paper presents a study of effect the mesa structure surface passivation on performance of InAlAs/InGaAs/InP avalanche photodiodes. The mesa passivation was made by using treatment in an aqueous solution of ammonium sulfide and subsequent protection by a layer of polyamide (sulfide-polyamide passivation). As a result, avalanche photodiodes with a photosensitive area of 32 microns reproducibly demonstrate dark current below 10—20 nA at the level of 0.9 of the breakdown voltage. A homogeneous distribution of the breakdown voltage value over the sample area at -85V, as well as long-term stability of avalanche photodiode characteristics were observed.

Keywords: sulfide-polyamide passivation, avalanche photodiode, mesa structure

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Материалы конференции
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Влияние сульфидно-полиамидной пассивации на темновые токи InAlAs/InGaAs/InP лавинных фотодиодов

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Аннотация. В статье представлено исследование влияния сульфидно-полиамидной пассивации поверхности меза-структуры на характеристики лавинных фотодиодов

InAlAs/InGaAs/InP. Лавинные фотодиоды с диаметром активной области 32 мкм воспроизводимо демонстрировали темновой ток ниже 10—20 нА на уровне 0,9 от напряжения пробоя. Наблюдалось однородное распределение значения пробивного напряжения по площади при -85 В, а также долговременная стабильность характеристик лавинного фотодиода.

Ключевые слова: сульфидно-полиамидная пассивация, лавинный фотодиод, меза-структура

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Introduction

The development of modern light detection and ranging systems for pilotless vehicles requires the creation of compact, efficient, and highly sensitive detectors of laser emission in the eyes safe spectral range of 1300—1550 nm [1, 2]. One of the approaches to create such detectors is using of avalanche photodiodes (APD) arrays operating in Geiger mode [3]. APDs based on InAlAs/InGaAs/InP heterostructures have certain advantages over widely used InP/InGaAs APDs due to the large ratio of the ionization coefficients of charge carriers and their temperature stability, which reduces the noise of avalanche multiplication [4] and improves the thermal stability of the breakdown voltage [5]. The mesa structure is widely used to isolate the active area of the InAlAs/InGaAs APD in a lateral direction. A serious problem of APD designs with a mesa structure is surface leakage currents, which makes the main contribution to the dark current [6, 7]. Methods of mesa structure etching and the passivation with dielectric films have a significant effect on the surface leakage current value. For PIN photodiodes, an effective method of mesa structure passivation in an aqueous solution of ammonium sulfide ($(NH_4)_2S_x$), so-called sulfide passivation, was successfully tested [8], while an important point for obtaining a time-stable reduction of surface leakage currents is additional protection of the surface with the oxygen-free dielectric coating [9].

In this paper we present a study of the effect of passivation of the surface on performance of the InAlAs/InGaAs/InP APDs with mesa structure using treatment in an aqueous solution of ammonium sulfide and subsequent protection by a layer of polyamide (sulfide-polyamide passivation) on APDs electric characteristics.

Materials and Methods

APD heterostructures were grown by molecular beam epitaxy on semi-insulating InP(100) substrates. The structure was comprised a highly doped n-type InGaAs contact layer, a highly doped n-type InAlAs layer, an undoped InAlAs multiplication layer with a thickness of 850 nm, a p-type InAlAs charge layer, an undoped InAlGaAs gradient layer, an undoped InGaAs absorbing layer with a thickness of 1700 nm, an undoped InAlGaAs gradient layer, a highly doped p-type InAlAs layer, and a thin highly doped p-type InGaAs contact layer. After the formation of a top ring Ti-Pt-Au contact, the mesa was etched in an $H_3PO_4:HBr:K_2Cr_2O_7$ solution with penetration to highly doped n-type layers located between the multiplication layer and the substrate. Processing of the surface in an aqueous solution of ammonium sulfide followed by a protective layer of AD-9103-30 polyamide (sulfide-polyamide passivation) was studied as an alternative option for the passivation of a mesa structure sidewalls. Two groups of APD samples were made from fragments of one epitaxial heterostructure to assess the passivation effect. The first group was made by a standard technological process (type 1) and the second was made with sulfide-polyamide passivation (type 2) (Fig. 1).

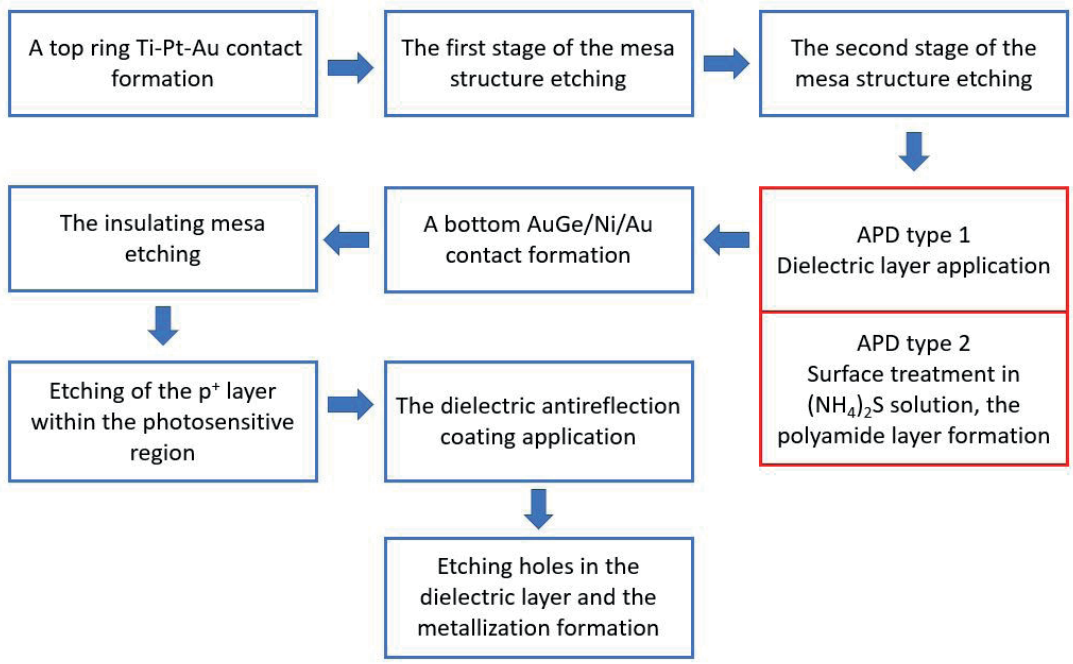

Fig. 1. Schematic representation of the APD crystal formation technological process (the difference between two types is highlighted in red)

Results and Discussion

For the second group of samples, a protective ring was formed along the perimeter of the mesa structure from a polyamide layer (Fig. 2) with sufficiently smooth edges of the walls.

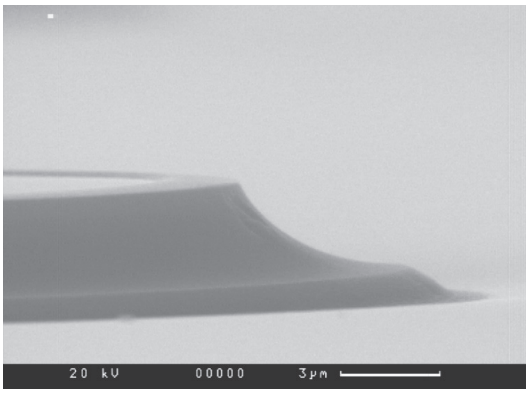

Fig. 2. Scanning electron microscopy image of the mesa structure edge after polyamide protection layer formation

The dark current and photocurrent on the applied voltage for a fabricated InAlAs/InGaAs APDs with standard technological process (type 1) and APDs with sulfide-polyamide passivation of the mesa structure (type 2) with a diameter of 32 μm at room temperature together with the corresponding dependence of the avalanche multiplication factor were measured (Fig. 1). The breakdown voltage (U_{br}) for APD was -85 V. For APD type 1 the value of the dark current was about 200 nA under $U = 0.9U_{br}$. Characteristic values of the dark current under $U = 0.9U_{br}$ of the fabricated APDs type 2 were in the range of 10–14 nA, which confirms the effectiveness of the

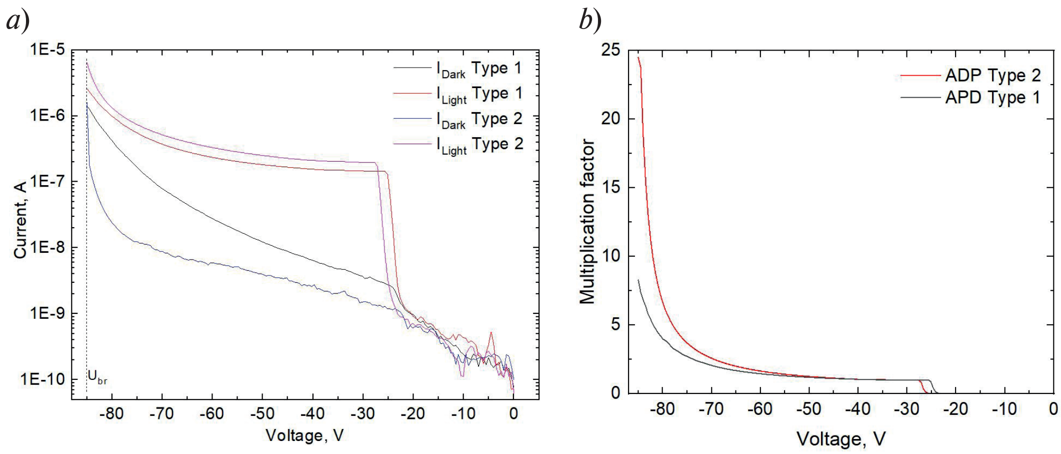

Fig. 3. The dependence of the photocurrent and the dark current on the applied voltage (*a*) and corresponding multiplication factor (*b*)

proposed passivation method. Based on these data, the sulfide-polyamide passivation of the mesa structure made it possible to reduce the dark currents of photodiodes by ~ 15 times.

An important requirement on the passivation technology is to ensure the reproducibility and long-term stability of the parameters. The fabricated devices demonstrate high uniformity of the breakdown voltage whose value is 85 V. The spectral sensitivity (photoresponse) values in 1550 nm range are 0.85–0.88 A/W ($M = 1$), and their corresponding capacitance values are 0.11–0.12 pF. The dark current of the investigated APD type 2 does not exceed 20 nA.

Conclusion

The surface passivation of InAlAs/InGaAs APDs with mesa structure design using processing in an aqueous solution of ammonium sulfide followed by a protective layer of polyamide was studied. The APDs with an active area diameter of 32 μm have shown a reproducible achievement of dark current levels of 10–20 nA under an applied voltage of 0.9 of the breakdown voltage. The uniform distribution of the breakdown voltage across the sample area at the level of -85 V, and long-term parameter stability was demonstrated.

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