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Fabrication of Mg_2Si pn-junction Photodiode with Shallow Mesa-structure and Ring Electrode

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We fabricated Mg_2Si pn-juncion photodiodes with a shallow mesa structure and a ring electrode using a conventional photolithography process and investigated their electrical and optical character. Dark current densities of about 0.18 and 9 × 10^{-4} A/cm^2 were obtained at room temperature and 100 K under the reverse bias at -3 V. Photoresponse below about 2.1 µm was observed in the shallow mesa-type PDs at room temperature operation. The photosensitivity at 1.31 µm was determined about 22 mA/W and 42 mA/W for the bias voltage at 0 and -0.1 V, respectively.

1. Introduction

Photodetection in the short wavelength infrared (SWIR, 0.9 - 2.5 µm) region is attracting much attention as one of the key technologies for a night vision system, an automated vehicle operation and a biological monitoring system [1]. InGaAs/InP and HgCdTe/ZnTe detector arrays are already developed for SWIR imaging [2]. However, they are unsuited for the commercial use and mass consumption, because they contain toxic materials and rare chemical elements.

Magnesium half-silicide (Mg_2Si), having aniti-CaF_2 type structure, is an interesting material for the detector in the SWIR region because its band gap energy is 0.61 eV and varies up to 0.3 eV by making an alloy compound of $Mg_2Si_xSn_{1-x}$ [3,4]. Characteristics of nontoxicity and abundance of Mg_2Si are suitable for the commercial use and mass consumption.

Recently, we have reported Mg_2Si pn-junction photodiodes (PD) fabricated by the thermal diffusion of Ag dopant into the n-type Mg_2Si substrate and their clear photoresponse below 2 µm [5-8]. However, their sensitivity is needed to improve for practical device applications. In this study, we report the fabrication of Mg_2Si pn-junction PDs with a shallow mesa structure and a ring electrode by using a conventional photolithography process.

2. Experimental

The PDs of Mg_2Si homo-junction with a shallow mesa structure and a ring electrode were fabricated on n-type Mg_2Si substrates by a conventional thermal diffusion and photolithography process. Figure 1 shows the schematic diagrams of the fabrication process. The substrates with the typical electron density n = 6×10^{15} cm^{-3} were prepared from bulk crystals grown by modified vertical Bridgman method under Ar gas pressure [4]. Diffusion source of Ag layer with the diameter of 700 µm, 900 µm, and 1100 µm was deposited on the as-polished surface, and then the p-type region was formed by the thermal diffusion at 450 °C for 10 min. Subsequently, mesa structure, SiO_2 passivation layer and Au-ring electrode were formed by the lithography process.

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The shallow mesa structure with the diameter of 600 μm, 800 μm, and 1000 μm was formed by Ar^+ dry etching. The 100 nm-thick SiO_2 passivation layer was deposited on the top surface by chemical vapor deposition method. Device performance of the PDs were characterized by current density - voltage (*J*-*V*) measurement and spectral photosensitivity measurement at room temperature.

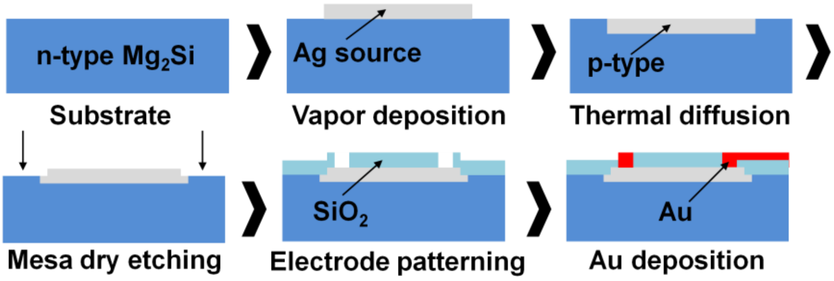

Fig. 1. Schematic diagrams of photolithography process for the fabrication of Mg_2Si pn-junction PD with shallow mesa and ring electrode.

3. Results and discussion

The PDs with three different size of ring electrode were fabricated on the n-type Mg_2Si substrate as shown in Figs. 2. The inner diameters (ID) of the ring electrode, which corresponded to the detection area of incident light, were ID = 800, 600 and 400 μm. The depth of mesa structure fabricated by Ar^+ dry etching was about 0.4 μm. The value of mesa depth was about 1/150 of the estimated pn-junction depth [9]. The size of fabricated PDs are listed in Table I.

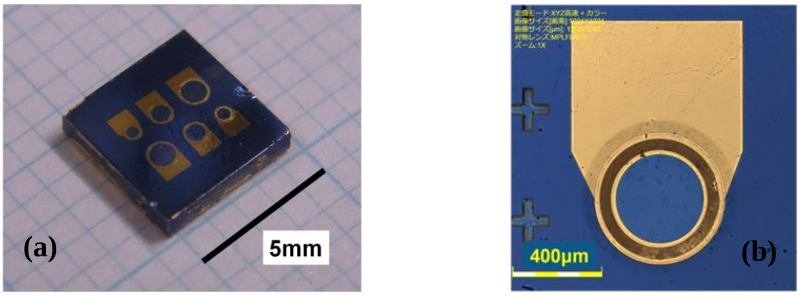

Fig. 2. (a) Birds-eye view of Mg_2Si pn-junction PDs fabricated on the n-type Mg_2Si substrate. (b) Microphotograph of the Mg_2Si pn-junction PDs with shallow mesa and ring electrode. The ID of the ring electrode is 400 μm.

Table I. Size of fabricated PDs.

Diffusion Diameter (μm)	Mesa Diameter (μm)	Mesa depth (μm)	Ring Electrode ID (μm)
700	600		400
900	800	0.4	600
1100	1000		800

Figure 3 (a) shows *J*-*V* characteristics of Mg_2Si PDs with different ID. The measurement was carried under dark condition at room temperature. Clear rectification behavior confirms the formation of depletion layer and potential barrier at pn-junction of Mg_2Si PDs. In the forward bias, the current density increased exponentially at lower voltage below about 0.2 V, while at higher voltage above about 0.2 V, the current increased linearly due to the large series resistance. The ideality factor n determined from the slope at the lower voltage region was n = 1.95 and identical for all measured PDs. In the reverse bias, current density was increased as the ID becomes larger. This behavior indicates that the bulk leakage current would be dominant in the reverse biased leakage current [7,10]. Figure 3 (b) shows *J-V* characteristics of planar-type (ID = 200 μm) [7] and shallow mesa-type (ID = 400 μm) Mg_2Si PDs with ring electrode. The reverse bias current density of shallow mesa-type PD was achieved about 0.18 A/cm^2 at -3 V, which is smaller than the planar-type one, even though the shallow mesa-type had larger ID. These results of *J-V* characteristics indicate that the shallow mesa structure effectively prevents the surface leakage current that could pass from the Au-electrode to the substrate through a surface conductive layer formed unintentionally by surface contaminations, oxidations or damages.

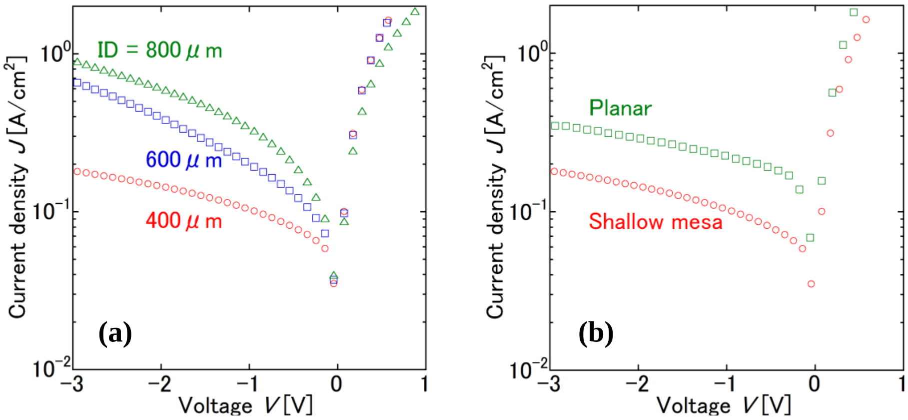

Fig. 3. *J-V* characteristics of Mg_2Si PDs measured under dark condition at room temperature. (a) Shallow mesa-type Mg_2Si PDs with ID = 400, 600, 800 μm. (b) Comparison of planar-type [7] and shallow mesa-type Mg_2Si PDs with ring electrode.

The shallow mesa-type PDs showed clear photoresponse. Figure 4 (a) plots the photocurrent of shallow mesa-type PD (ID = 400 μm) measured under a light irradiation of 1310 nm laser diode with the laser power of 2 mW. The photosensitivity of the PD at 1310 nm was about 22 mA/W and 42 mA/W for the bias voltage at 0 and -0.1 V, respectively. The photosensitivity was improved by applying a reverse bias. Figure 4 (b) shows spectral photosensitivity of shallow mesa-type Mg_2Si PD (ID = 400 μm) measured at 0 V. The photosensitivity of the shallow mesa-type PD increased monotonically with the photon energy above about 0.6 eV.

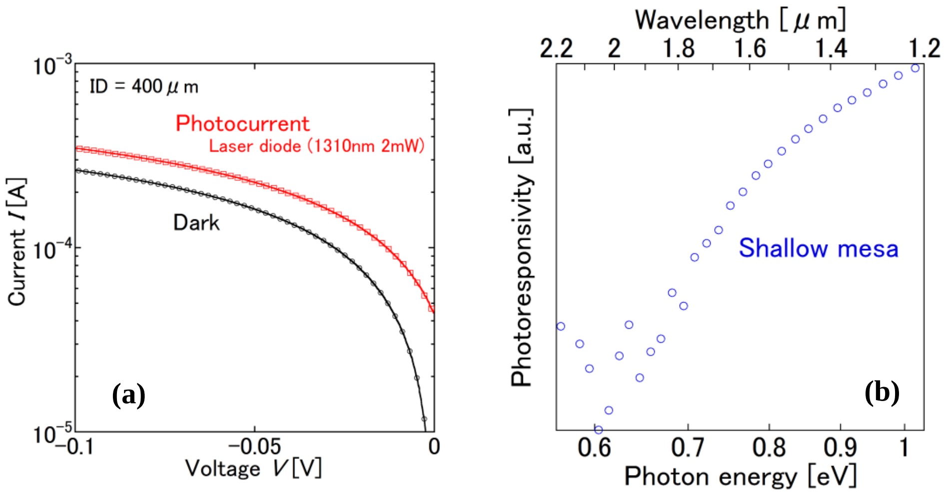

Fig. 4. (a) Photocurrent of shallow mesa-type Mg_2Si PD with ID = 400 μm under irradiation of 1310 nm, 2 mW laser diode. (b) Spectral photosensitivity of shallow mesa-type Mg_2Si PD measured at 0 V.

Figure 5 (a) shows *J-V* characteristics of shallow mesa-type Mg_2Si PD (ID = 400 μm) between 100 K and 350 K. The leakage current in reverse bias decreased rapidly with decreasing the temperature. The current density at -3 V reached to about 9 × 10^{-4} A/cm^2 at 100 K. Figure 5 (b) shows an Arrhenius plot of the saturation current density at -1 V. The saturation current density aligned two slopes, indicating that the PD may work in generation limited condition above about 250 K [11,12].

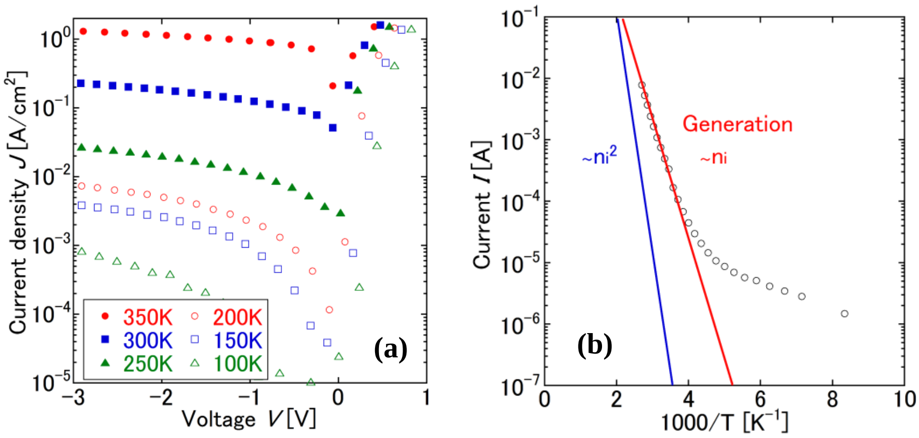

Fig. 5. (a) *J-V* characteristics of shallow mesa-type Mg_2Si PD (ID = 400 μm) measured from 100 K to 350 K. (b) Arrhenius plot of saturated dark current density at -1 V.

4. Conclusion

We have fabricated Mg_2Si pn-junction PDs with shallow mesa structure and ring electrode by the conventional photolithography process. The depth of shallow mesa structure of about 0.4 μm was formed on the surface of p-type region by Ar^+ dry etching. The PDs showed the clear rectification behavior in their *J-V* characteristics. The ideality factor n= 1.95 and reverse biased current density of about 0.18 A/cm^2 were obtained for the PD with ID = 0.4 mm. Significant reduction of the reverse bias current density was found in the shallow mesa-type PDs. Spectral photosensitivity under the zero bias was also observed in the shallow mesa-type PDs below about 2.1 μm.

Acknowledgments

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