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Fabrication of mesa-type Mg_2Si pn-junction photodiode for 2 - 4 μm IR-detection

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Abstract

We have fabricated a mesa type Mg_2Si pn-junction photodiode on n-Mg_2Si substrate by a simple thermal diffusion and wet etching process. Firstly, Ag dopant was thermally diffused into the substrate to form the pn-junction, and then, this planar type pn-junction was selectively etched by diluted fluonitric acid to form the mesa structure. In the *J-V* measurement, the reverse leakage current density of the mesa type pn-junction was lowered significantly compared with that of planar type one. Consequently, photosensitivity was greatly improved under reverse bias condition, and clear photoresponse below 2 μm was obtained from the mesa type Mg_2Si photodiode.

1. Introduction

An infrared photodetector (IR detector) is one of the important devices in the field of security and safety such as monitoring in the night, thermometry and assist facility of automobile. Thermophotovoltaic (TPV) generation is also one of the interesting application fields for the IR detector.

Mg_2Si is an indirect transition type semiconductor composed of abundant and low toxic elements (Mg and Si). The forbidden band gap energy E_g of this silicide is approximately 0.6 eV at room temperature [1] and can be reduced to 0.3 eV by alloying it with Mg_2Sn [2]. These features of Mg_2Si are suitable for the mass production devices, including sensors, imagers and photovoltaic cells in IR region up to about 4 μm in wavelength.

Recently, a high-purity n-type Mg_2Si bulk single crystal with low carrier concentration (n = ~10^{15}cm^{-3}) was grown by the modified vertical Bridgman method under Ar gas pressure [1,3]. Schottky barrier junction of Au/n-Mg_2Si was also demonstrated using the high-purity n-type Mg_2Si bulk crystal [4]. Furthermore, planar type pn-junction diode of Mg_2Si was fabricated by thermal diffusion of Ag acceptor into n-type substrate, and photoresponse was observed from the diode for the incident light below 2 μm [5,6]. These progress in developing the Mg_2Si researches expanded the possibilities of Mg_2Si for the IR detectors and TPV cells. However, photosensitivity of the planar type pn-junction diode is low because the S/N ratio in the photoresponse is not sufficient due to both large reverse leakage current and deep pn-junction depth.

In this paper, we study the fabrication of the mesa type Mg_2Si pn-junction photodiode by wet etching and the electrical and optical properties of the photodiode.

2. Experimental Procedure

An n-type Mg_2Si substrate (n = 6 × 10^{15} cm^{-3}) was prepared from the high purity Mg_2Si ingot grown by the modified vertical Bridgman method. The surface of substrate was polished like a mirror face using water-free fumed silica. Ag and Au layers were evaporated onto the polished surface through a metal mask with 0.8 mm -diameter holes using a conventional resistive heating evaporator. The Ag layer was used as acceptor diffusion source, and the Au layer was used as an ohmic electrode on the p-Mg_2Si. The diffusion of Ag was performed by a rapid thermal annealing at 480 °C for 10 min in an Ar gas flow atmosphere. After formation of pn-junction by the thermal diffusion, mesa structure was made by wet etching for 2 min using the diluted fluonitric acid (HF : HNO_3 : H_2O = 1 : 2 : 20). During the etching, the Au capping layer played a role of protective layer. Cross sectional diagrams of the planar type and mesa type Mg_2Si pn-junction photodiode that investigated in this experiment are shown in Figs.1 (a) and (b), respectively.

The current density - voltage (*J-V*) characteristics were measured using DC - sourcemeter (Keithley 2400) under the dark condition. The spectral photosensitivity of the photodiodes was measured by a conventional lock-in technique using a halogen lamp chopped and passed through an IR filter (cut-off = 1.2 μm) and a monochromator (JASCO CT-50) with a focal length of 500 mm.

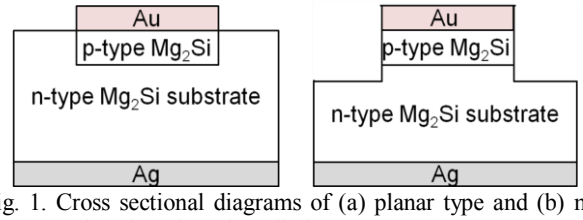

Fig. 1. Cross sectional diagrams of (a) planar type and (b) mesa type Mg_2Si pn-junction photodiode.

3. Results and Discussion

Fig. 2 shows the relationship between the etching period and etching depth of n-type Mg_2Si for the diluted fluonitric acid. The etching depth increased lineally with increasing the periods. The average rate determined from the experiment was 5.2 μm/min for the acid composition of HF : HNO_3 : H_2O = 1 : 2 : 20 at room temperature.

Figs. 3 (a) and (b) show microphotographs of the planar

type and mesa type Mg_2Si pn-junction photodiodes, respectively. In the mesa type photodiode, substrate surface looks dark because of the rough surface, and the diameter of Au electrode became small compared with that of planar one.

Fig. 4 plots the result of *J-V* characteristics measured on planar type and mesa type pn-junction photodiodes. Both diodes had a clear rectifying characteristic and a similar *J-V* curve in the forward bias region. On the other hand, in the reverse bias, saturation current density at -5V was reduced by approximately one order of magnitude for the mesa type one. This result suggests that the reverse leakage current is greatly suppressed by the mesa structure.

Fig. 5 shows spectral photosensitivity of the photodiodes measured under the reverse bias (-1V) condition. The photosensitivity of the mesa type photodiode was greatly improved and clear photoresponse below 2 μm was observed under the reverse bias condition. As similar to the previous report [5], clear photoresponse was observed in both planar type and mesa type photodiodes measured under zero bias condition. However, under the reverse bias condition, the photosensitivity of planar type was deteriorated especially around 2 μm. The results indicate that the mesa structure reduces the leakage current and greatly improves the photosensitivity under the reverse bias condition in Mg_2Si photodiode.

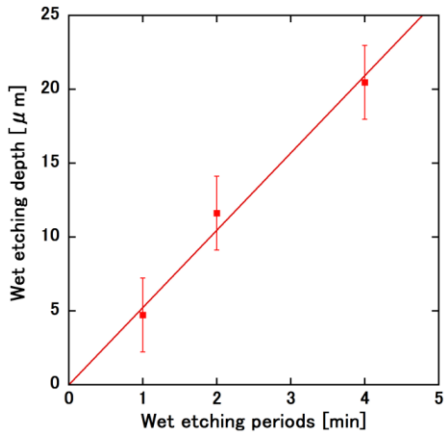

Fig. 2. Relationship between the etching period and etching depth of n-type Mg_2Si etched by the diluted fluonitric acid (HF : HNO_3 : H_2O = 1 : 2 : 20).

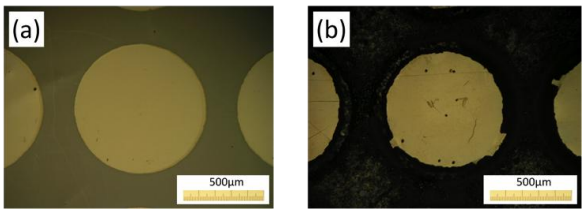

Fig. 3. Microphotographs of (a) planar type pn-junction photodiode before wet etching, and (b) mesa type pn-junction photodiode after wet etching.

4. Conclusions

We have fabricated the mesa type Mg_2Si pn-junction photodiode by wet etching and measured the electrical and optical performance of the photodiode. A significant reduction of the reverse bias current density was found in the mesa type photodiode. Spectral photosensitivity under the reverse bias was also greatly improved in the mesa type photodiode.

Acknowledgements

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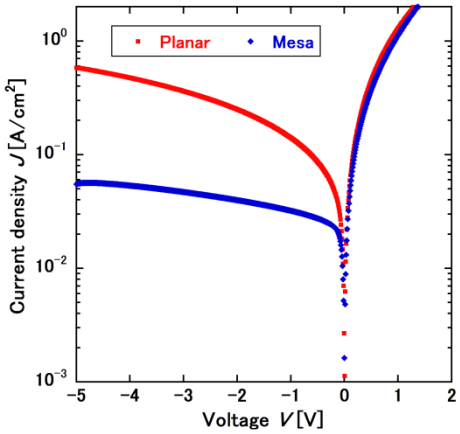

Fig. 4. The *J-V* characteristics of the planar type and mesa type Mg_2Si pn-junction photodiodes measured under dark condition at room temperature.

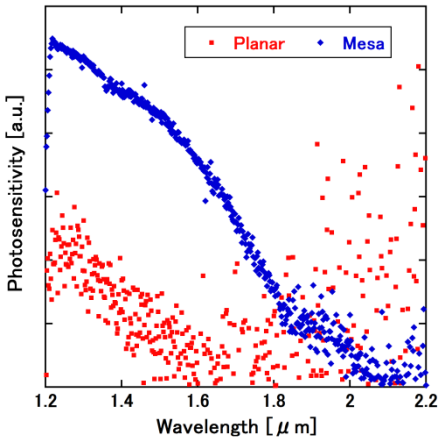

Fig. 5. Spectral photosensitivity of the planar type and mesa type Mg_2Si pn-junction photodiodes measured under the reverse bias (-1V) condition at room temperature.