Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp546-547

Photoelectric Conversion Devices based on InP Porous Structures

Ryohei Jinbo[1], Tomohito Kudo[1] and Taketomo Sato[1]

[1] Research Center for Integrated Quantum Electronics, Hokkaido Univ.
North 13, West 8, Kita-ku, Sapporo 060-8628, Japan
Phone: +81-11-706-7171 E-mail: jinbo@rciqe.hokudai.ac.jp

1. Introduction

High-density formation of semiconductor nanostructures has been intensely researched for applications such as quantum and optoelectronic devices. Among the various approaches, the electrochemical process is one of the most promising for creating semiconductor nanostructures due to its unique features such as being a low temperature process, causing low processing damage, and having a simple process and a low cost. The most well-known application of the electrochemical process is for forming a porous structure using the anodic reaction in an electrolyte [1-4]. We have recently reported that extremely low reflectance below 0.4% was observed from the InP porous nanostructures in UV, visible, and near-infrared ranges [5]. In this paper, we propose the photoelectric conversion device based on InP porous structures utilizing their large surface area and low reflectance properties.

2. Experimental

Device Structure

The device structure is schematically shown in **Fig. 1**. The proposed device is based on the electrochemically formed porous structure which has extremely large surface area due to the nature of a high-aspect-ratio structure. The potential barrier is formed on the pore walls to separate the photo-carriers generated under illumination. In this study, Pt film was used for the purpose because the large Schottky barrier is expected to n-type semiconductor interface [6]. It is expected that the photo-carriers generated under illumination is separated by the electric filed in the depletion region and collected to the ohmic electrodes formed on the top and back surfaces, as shown in **Fig. 1**.

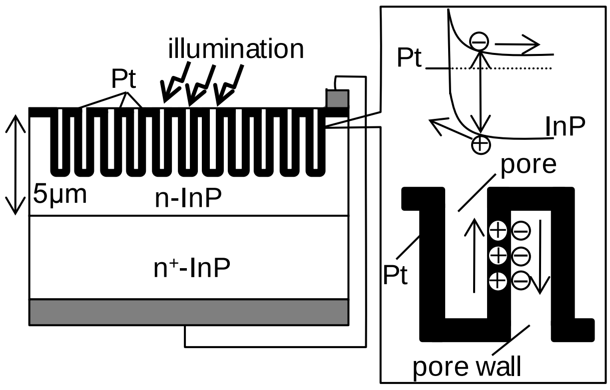

Fig.1 Schematic illustration of photoelectric conversion device based on porous structure.

Formation process

The porous structure was electrochemically formed using a standard cell with three electrodes, i.e., a (001) n-type InP electrode ($n=1x10^{17}cm^{-3}$) as a working electrode (W.E.), a Pt counter electrode (C.E.), and a saturated calomel electrode (S.C.E) for a reference. The electrolyte consists of 1 M HCl (200 ml) with HNO_3 (3 ml). To supply current, a GeAu/Ni-ohmic contact was made on the backside of the InP substrate using the conventional evaporation and annealing process. The anodic bias was firstly applied to the semiconductor electrode to obtain high-density porous structures. In this study, the anodic bias, V_a, and anodization time, t_a, were set at 20 V and 5 s. After that, the cathodic bias was applied to the sample in a H_2PtCl_6 electrolyte in order to form a thin Pt film.

3. Results and Discussion

Formation of Pt film

Figure 2(a) shows the scanning electron microscope (SEM) image of the sample after the Pt deposition on InP porous structure. During the electrochemical formation of the porous structure, a disordered irregular layer formed and remained on top of the ordered porous layer. As shown in **Fig. 2(a)**, the Pt film formed only on the irregular top layer and not formed on the wall surface inside pores. This seems to be because the pore diameter in the irregular top layer is smaller than that of Pt particles formed by the cathodic reaction. After the removal of the irregular top layer, the coverage of the Pt film on pore walls was improved. As shown in **Fig. 2(b)**, Pt film of an average thickness of nearly 130 nm was formed on the wall surface inside pores. **Figure 3** shows the plot of the average thickness of Pt film vs. the processing time of the cathodic deposition. It was found that the thickness of the Pt film formed on the pore wall can be controlled by the process time.

The effect of the structural properties on the surface reflectance was investigated, as shown in **Fig. 4**. The reflectance obtained from the porous sample was 20–30% lower than that obtained from the reference sample. Especially, the reflectance of the porous sample without the irregular top layer drastically decreased lower than 3.2% over the measurement range. It was found that the low reflectance properties of InP porous structures remained after the formation of Pt film.

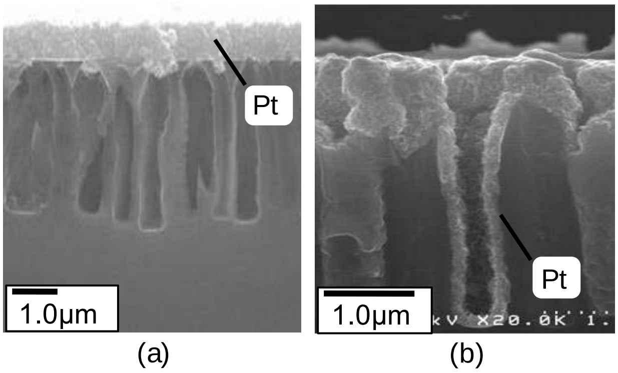

Fig.2 Cross sectional SEM images: Pt film formed on Pt film sample (a)with irregular layer and (b)without irregular layer.

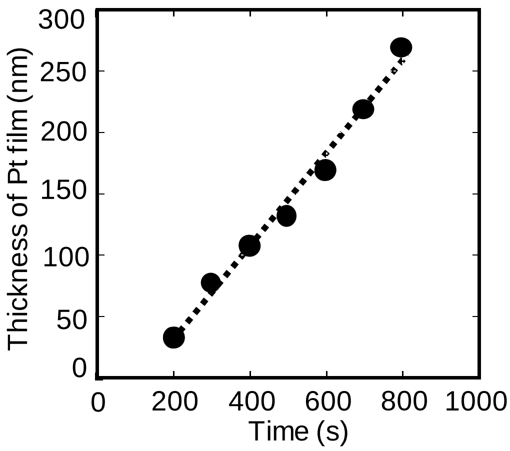

Fig3.Thickness of Pt film as s function of processing time.

Current-Voltage (I-V) Characteristics

The basic photoelectrical properties of Pt/InP porous structures were investigated. **Figure 5** shows the current-voltage (*I-V*) characteristics of the sample after the Pt deposition on the InP porous structure without the irregular top layer. Here, the forward bias was applied to the top electrode formed on the Pt films. As shown in **Fig. 5**, the measured *I-V* characteristics showed clear rectifying behavior, indicating the formation of Schottky barrier at the Pt/InP interface. Under illumination, the reverse currents increased about 180 mA whose value was 60 times larger than that of the reference sample with the planar Pt/InP contact.

The effective surface area of the porous device fabricated here was estimated about 7 times larger than that of the planar device. Therefore, the present result on the increased photocurrents can not be explained only by the effect of the increased surface area. It seems that the low reflectance properties of the porous structure led to the increase of the photocurrents under illumination by improving the light-collection efficiency.

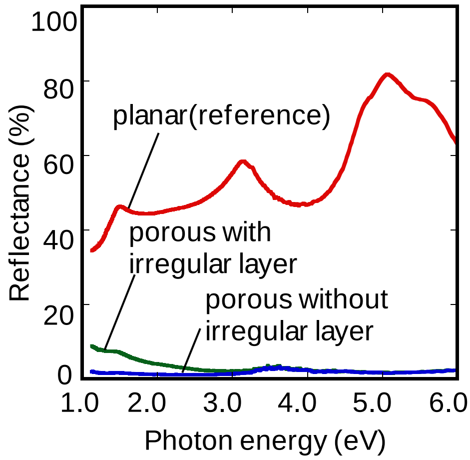

Fig.4 Surface reflection spectra of sample after Pt deposition.

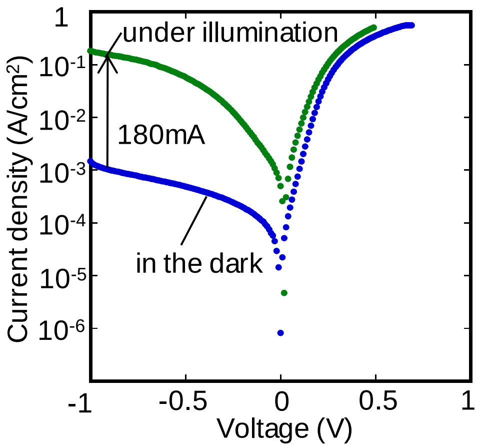

Fig.5 Current-voltage characteristics of photoelectric conversion device based on porous structure.

4. Conclusions

The photoelectric conversion device based on the InP porous structure has been proposed. The removal of the irregular top layer very effectively improved the coverage of Pt film inside pores, with the low reflectance properties remaining. The larger photocurrents were obtained on the present porous device as compared with the reference planar device. The result can be explained by the two unique features of the InP porous structures: the large surface area inside pores, and the low reflectance of the porous surface.

Acknowledgements

The work reported here was supported in part by a Grant-in-Aid for young scientists (A) - 21686028 from the Japanese Ministry of Education, Culture, Sports, Science, and Technology (MEXT).

References

[1] R. L. Smith et al., J. Electron. Mater., **17** (1988) 533.
[2] P. Schmuki et al., J. Electrochem. Soc., **143** (1996) 3316.
[3] A. Hamamatsu et al., J. Electroanal. Chem., **473** (1999) 223.
[4] S. Langa et al., Appl. Phys. Lett., **82** (2003) 278.
[5] T. Sato et al., Thin Solid Films, **518** (2010) 4399.
[6] T. Sato et al., Jpn. J. Appl. Phys. **36**(1997) 1811.