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Beta particle detection efficiency of the radiation sensor made from a mixture of polyaniline and titanium oxide

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ABSTRACT

We developed a new real-time radiation sensor using an organic semiconductor and measured its β-particle detection sensitivity. This sensor is fabricated by simply combining a p-type semiconductor, polyaniline (Pani), with an n-type semiconductor, TiO_2, and processing the compound. Since Pani and TiO_2 are both inexpensive materials, the sensor can be fabricated at a lower cost than inorganic semiconductor sensors. The signal of each fabricated sensor was measured by a charge sensitive ADC for the irradiation of β-particles. The response signal data of the ADC for each irradiation was measured to calculate the detection efficiency of the detector. The maximum detection efficiency measured as β-particle sensitivity of the sensor was 1%. This β-particle sensitivity is higher than that reported of Pani sensors in the past.

1. Introduction

Semiconductor radiation detectors provide higher energy resolution than other types of radiation detectors. They have thus come to be used for various applications. However, most of them are fabricated from expensive high-purity inorganic crystals, such as silicon and germanium. There is a limit to how large the detection areas of such detectors can be made, disadvantageously restricting such detectors to relatively small sizes.

In conventional electronics fields using such inorganic semiconductors, the development of various organic-electronic devices has been advancing by using organic semiconductors based on pi-conjugated systems in recent years [1–6]. A wide variety of organic semiconductors can be designed freely by organic synthesis. They have several advantages over inorganic semiconductors: they do not rust like metals, they are inexpensive, and they are flexible. Organic semiconductors are accordingly used to ensure large areas and reduce costs for display devices [7,8] such as organic EL (Electro Luminescence), capacitors, and other devices [9,10].

Organic semiconductors are expected to contribute to realizing inexpensive, flexible radiation detectors with large detection areas. A real-time radiation detector is now under development using the electroconductive polymer, polyaniline (Pani). Pani, a type of organic semiconductor, has high environmental stability and is industrially producible. This real-time radiation detector has successfully detected α and β-particles [11,12]. However, its detection sensitivity is still low. In particular, its β-particle detection sensitivity needs to be improved before it can be used for practical purposes.

Most electroconductive polymers have electronic states and charge transport characteristics unique to p-type semiconductors, allowing them to be used to mimic the pn-junction structure of inorganic semiconductor devices. Electroconductive polymer devices that readily induce charge separation at their bonded interfaces have been used in solar cells and other applications [13–17]. Pani is also capable of being bonded to other n-type semiconductors. Since it is highly soluble in solvents and other solutions, studies on the formulation of compounds Pani with various n-type materials have been reported [18,19].

A variety of chemical compounds have been proposed as materials with n-type characteristics. One of the most commonly used materials is titanium (IV) oxide (TiO_2) [20–23]. TiO_2 is safe, can be produced at low cost, and has already been used as a catalyst and photocatalyst in various areas. It has been reported that Pani's performance as a photocatalyst for high-energy light such as X-rays is similar to its performance for ultraviolet rays [24].

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In this study, we combined the n-type semiconductor, TiO_2, with the p-type semiconductor, Pani, and thereby attempted to improve β-particle detection sensitivity.

2. Radiation sensor fabrication

Pani is known as a material that takes various forms under oxidation, reduction, and treatment using acids or bases [25]. The kind of Pani used in this study is an emeraldine base (Pani-EB) provided by Japan Carlit Co., Ltd. Pani-EB has excellent solubility and environmental stability.

TiO_2, which was used as the n-type semiconductor, is also reported to be a material that exhibits various characteristics depending on its crystal forms and other conditions [26]. In this study, we used industrially available photocatalytic TiO_2 (Grade ST-01: ISHIHARA SANGYO KAISHA, LTD.), which is small in crystal size and large in specific surface area.

Fabrication into Pani sensors requires dissolution of powder Pani in a solvent and drying of the solution. In the development of this sensor, we used N,N′-dimethylpropylene urea (DMPU), which has high Pani-EB dissolving power [27]. Since dissolution of Pani in DMPU increases its viscosity and lowers its dispersiveness, 20 wt% TiO_2 was dissolved in the DMPU first with an ultrasonic disperser. Pani-EB was subsequently added to the TiO_2 dispersion so that the dispersion would contain 20 wt% Pani-EB. The dispersion was then stirred until the dissolution formed a paste containing Pani-EB and TiO_2 in the same mass proportion.

When placed in a PTFE-resin container and rapidly heated at 150 °C for 20 min, the paste turned into a gel plate. Finally, drying the plate by further heating for six hours produced a solid Pani/TiO_2 sheet containing uniformly distributed TiO_2 (Fig. 1). The Pani/TiO_2 sheet produced in this study was 1–2 mm in thickness.

SEM (Scanning Electron Microscope) images of cross-section of the manufactured Pani/TiO_2 sheet sample are shown in Fig. 2. A lot of grain of TiO_2 exists between Pani. We cut out a round shape sensor plate 12 mm in diameter from the solid sheet and formed Au electrodes 10 mm in diameter and 0.3 μm in thickness on both faces of the sensor plate by sputtering (Fig. 3). One Au-electrode face was used as the cathode (Gnd) face and was attached to a small printed circuit board with silver paste. The other Au-electrode face was used as the anode face; one end of an Au-plated W wire 150 μm ϕ was attached to this face with silver paste, and the other end was connected to the terminal of the circuit board by soldering. Lead wires with pins for connection to a readout circuit were attached to the circuit board to complete the radiation sensor.

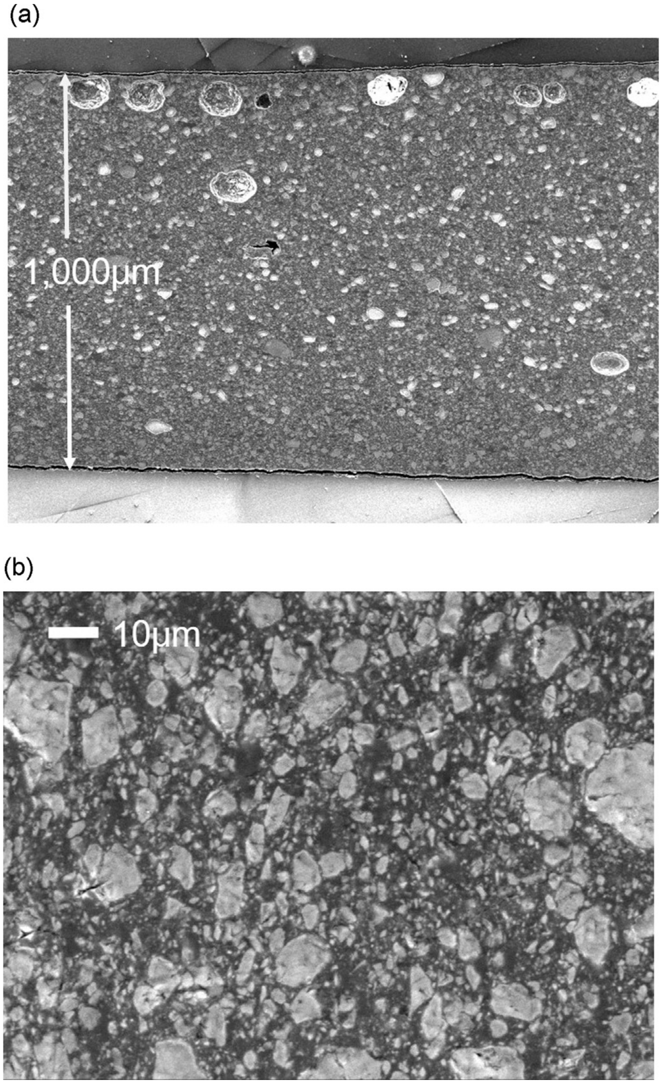

Fig. 2. SEM images of cross section of the manufactured Pani/TiO_2 sheet sample with magnifications × 80 and (b) × 1000.

3. Experimental results

3.1. Readout circuit and observed signal

The β-particles from a ^{90}Sr source (2.2 MBq) were used and the setup shown in Fig. 4 was prepared to evaluate the performance of the sensors. The output signal shown in Fig. 5 was observed using an oscilloscope, irradiated by β-particles. The signals were not observed without the source.

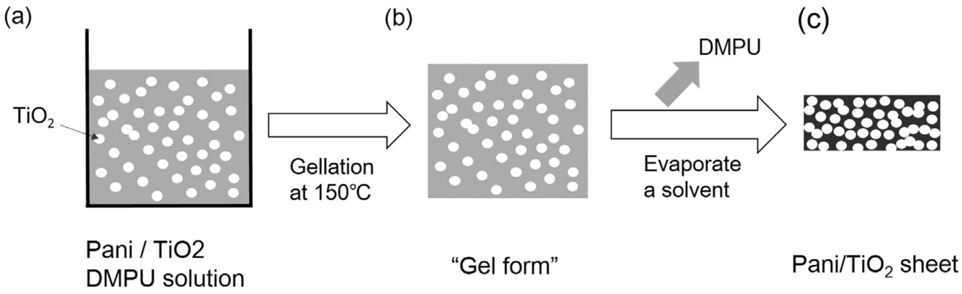

Fig. 1. Production process of Pani/TiO_2 sheet. (a) Pani dissolved in the dispersing TiO_2 DMPU solution, (b) the mixture changed a gel at 150 °C, and (c) the gel became the Pani/TiO_2 sheet by evaporation of DMPU.