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Fabrication of fine imaging devices using an external proton microbeam

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ABSTRACT

We have successfully fabricated novel microscopic imaging devices made from UV/EB curable resin using an external scanning proton microbeam. The devices are micro-structured fluorescent plates that consist of an array of micro-pillars that align periodically. The base material used in the pillars is UV/EB curable resin and each pillar contains phosphor grains. The pattern exposures were performed using a proton beam writing technique. The height of the pillars depends on the range of the proton beam. Optical microscopy and scanning electron microscopy have been used to characterize the samples. The results show that the fabricated fluorescent plates are expected to be compatible with both spatial resolution and detection efficiency.

1. Introduction

Fluorescent plates are widely used for detecting X-rays, charged particles, and neutrons. In view of imaging devices, the spatial resolution of fluorescent plates is contrary to their detection efficiency. In general, a thicker layer increases the efficiency, but has poorer resolution owing to blurring. Use of a micro-structured scintillation device is new approach for this problem. Thallium doped cesium iodide (CsI(Tl)) is a well-known scintillator for high-resolution X-ray imaging because the cubic structure of the CsI(Tl) crystals allows them to form microcolumnar films [1–3]. However, the microcolumnar structure strongly depends on deposition conditions and it is difficult to form periodic columnar structures [1,2].

In this work, we have developed a new micromachining technique using proton beam writing (PBW) and UV/EB curable resin. We report on the application of a UV/EB curable resin, in PBW for the production of micro-structured fluorescent plates. PBW is a unique technique used for the fabrication of micro- and nanostructures with high-aspect-ratios from polymeric [4–13] and inorganic [14–17] materials. On the other hand, UV/EB curable resin is a photo-curable polymer that rapidly cures in three dimensions by radical polymerization that occurs with ultraviolet (UV) light or electron beam (EB) irradiation. This resin has been widely used for various industrial applications, such as printings, paintings, material coatings and so on [18]. The resin is a liquid at room temperature; therefore, it mixes easily with functional materials, such as phosphor grains. The fabrication process is similar to lithography.

2. Materials and methods

The proton beam exposure and the post-process were performed at the Takasaki Advanced Radiation Research Institute, Japan Atomic Energy Agency. The details of the external proton microbeam system are described elsewhere [13,19,20].

2.1. Fluorescent plate materials

The base materials used are UV/EB curable resin and phosphor grains. The utilized resin is Bis-A ethylene oxide modified acrylate (ARAKAWA CHEMICAL INDUSTRIES, LTD. [18]). The resin is a pale yellow, transparent, and viscous liquid. The phosphor grains are sifted silver-activated zinc sulfide (ZnS(Ag)). The mean particle size is approximately 7 μm. ZnS(Ag) is one of the most popular phosphors as it has excellent efficiency; the maximum emission wavelength is 450 nm [21].

2.2. Fabrication process

The fabrication procedure is described below and illustrated in Fig. 1.

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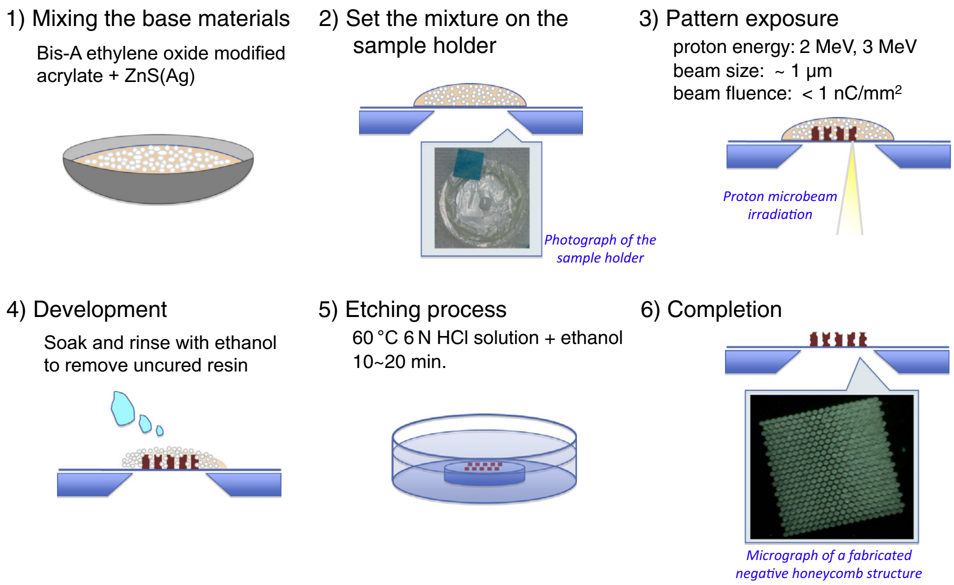

Fig. 1. Illustrations of the fabrication procedure of the micro-structured fluorescent plates.

(1) The UV/EB curable resin is mixed with the phosphor grains at a mass ratio of 1:1. The optimum mixing ratio is still under investigation.
(2) The mixture of the base materials is set on a sample holder. The holder is an annular disk of acrylic resin, and the tapered hole is 2 mm in diameter on the atmospheric side. A sample backing film (5 μm-thick polycarbonate) is attached to the holder using epoxy-type glue. The film also plays the role of a beam exit window.
(3) Pattern exposures are performed using 2 or 3 MeV proton beams approximately 1 μm in diameter. The exposures are repeated four times and the period of beam duration is 60 μs per pixel. The pixel resolution is approximately 0.7 μm. The beam fluence is of the order of 100 pC/mm^2 with a beam current of 1–2 pA. The irradiated areas are quickly cured by polymerization. The total irradiation time is approximately 2 min for a checker pattern, and 3 min for a negative honeycomb pattern.
(4) The samples are soaked in 100% ethanol for 30 min at room temperature. Then the samples are rinsed with fresh ethanol and dried.
(5) Redundant phosphor grains are still remaining among the micro-pillars, so that the samples are treated with a chemical etching. The etching liquid is a mixture of a 6 N solution

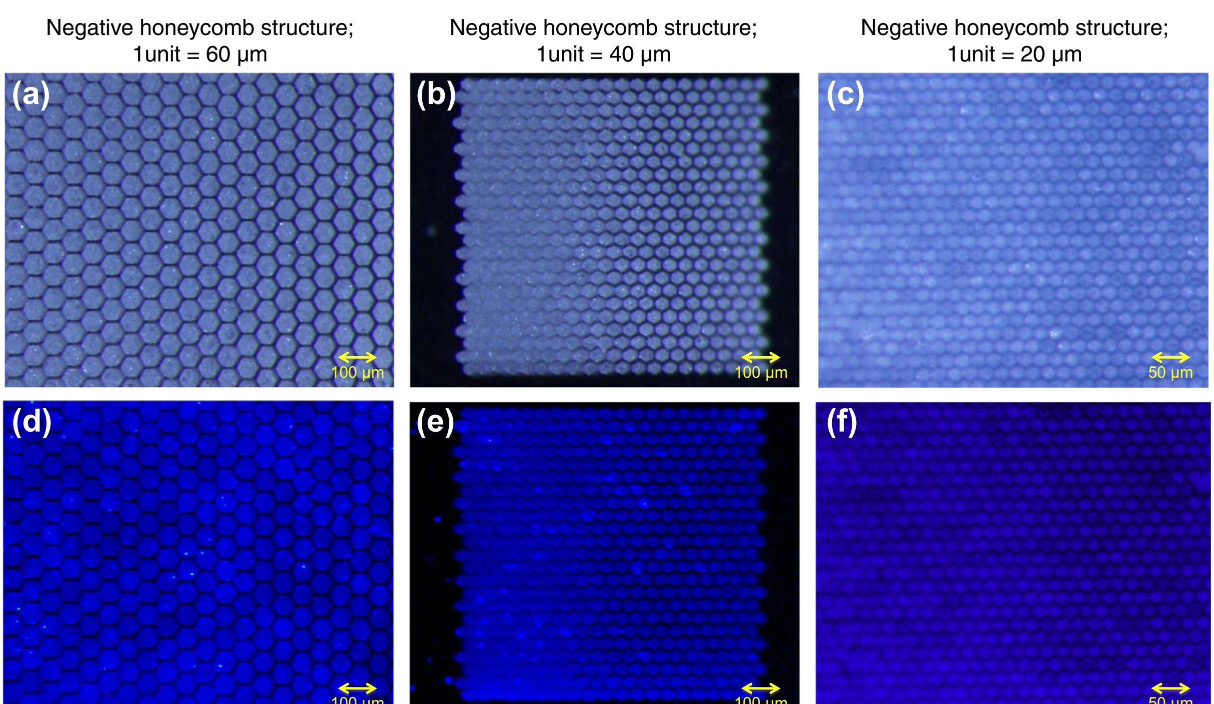

Fig. 2. Micrographs of the fabricated negative honeycomb-structured fluorescent plates. In the upper images (a–c), the samples were illuminated using visible light and in the lower images (d–f), the samples were exposed to UV light.