High-speed moth-eye structure formation using foamed polyimide

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The moth-eye structure, which consists of nanoscale conical shapes densely arranged and has anti-reflection properties. Our group previously fabricated moth-eye structures by self-organization using oxygen ion beam irradiation on glassy carbon and polyimide (PI) [1,2]. Expandable polyimide is a material that has attracted attention for its applications in heat insulation and soundproofing, but here we have devised a way to reduce the volume and improve processing speed by adding nano-pores. Powdered polymethyl methacrylate (PMMA) was dissolved in anisole to prepare a 16 wt% solution. This solution was then mixed with polyimide at a weight ratio of 1:1. The mixed solution was spin-coated onto a Si substrate and baked at 100°C for 15 minutes to volatilize the anisole. Finally, the polyimide was baked at 400°C to volatilize PMMA and generate pores, producing a foamed polyimide. Figure 1 shows SEM photo of foamed polyimide. Nano pores were formed uniformly. This foamed polyimide was etched using an ECR type ion shower device under the conditions of an accelerating voltage of 400V, an oxygen gas flow rate of 4 sccm, a microwave power of 100W, and processing times of 15, 30, and 60 minutes. For comparison, unfoamed polyimide was also processed in the same manner. Figure 2 shows SEM photos of the moth-eye structure when PI and foamed PI are used. The needle-like structures with diameters of less than 100 nm were densely packed. The height of the needles increases as increasing etching time. At all times, the needle height was higher for foamed PI than for PI. Furthermore, the foamed PI has nanopores even within the moth-eye structure. After 60 minutes of processing, the needle height was 248 nm for PI and 835 nm for foamed PI, 3.4 times higher. Next, these moth-eye structures were used as molds and Ultraviolet nanoimprint lithography (UV-NIL) was performed. Figure 3 shows the cross-sectional view of transferred moth-eye structures using UV curable resin. When the PI moth-eye mold was used, the height of the transferred UV-cured resin was 242 nm, whereas when the foamed PI mold was used, the height was 488 nm. This value was lower than the mold height of 835 nm. This was because the resin was not fully filled due to the release treatment. Figure 4 shows the reflectance of the transferred moth-eye structures. The moth-eye structure made from foamed PI had low reflectance even in the near-infrared region. The data for wavelengths of 850 to 900 nm was noise caused by detector switching. Moth-eye structures can be rapidly fabricated by irradiating foamed PI with an oxygen ion beam

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1. T. Okabe *et al.*, Microelectron. Eng., **242-243**, 111559 (2021)
2. K. Kato *et al.*, Nanomaterials, **13**, 1591 (2023)

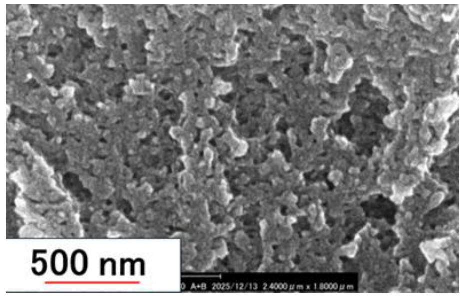

Figure 1: SEM photo of foamed polyimide.

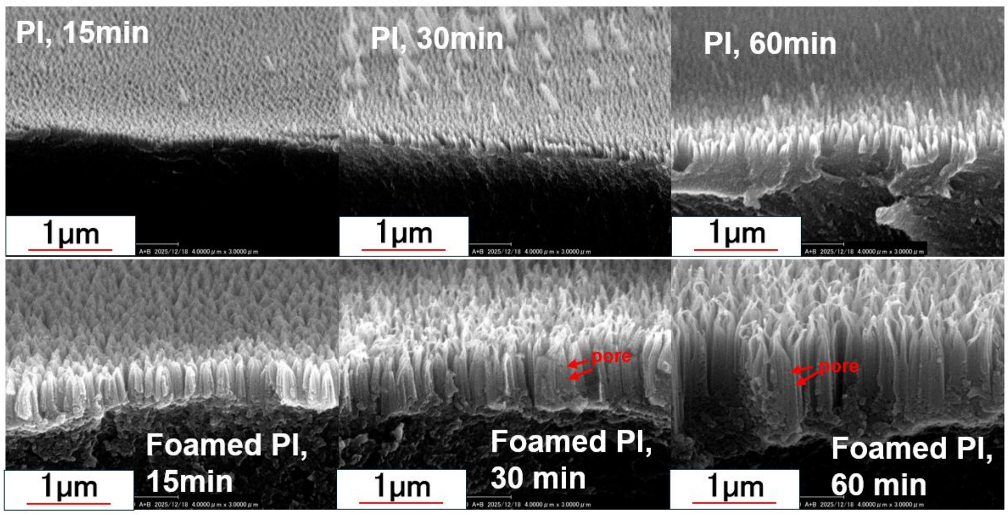

Figure 2: SEM photos of the moth-eye structure using PI and foamed PI.

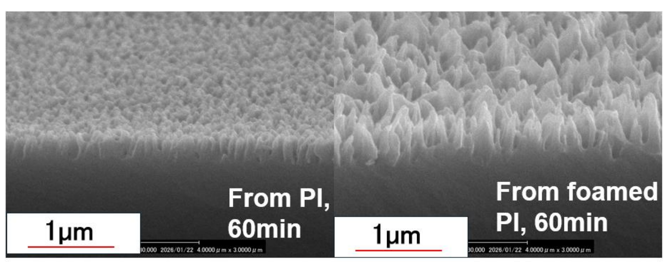

Figure 3: The cross-sectional view of transferred moth-eye structures using UV curable resin.

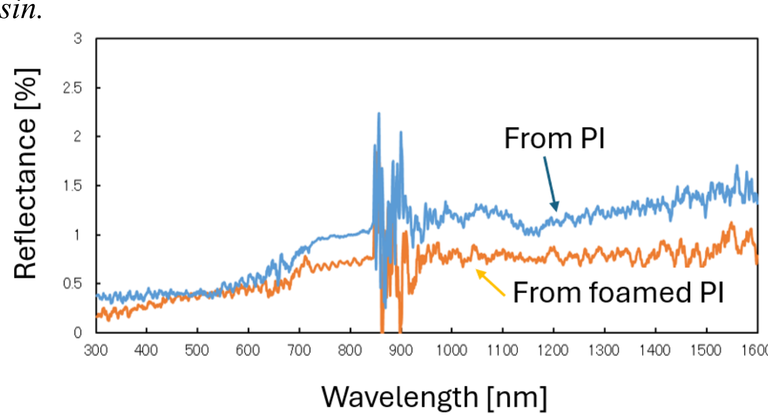

Figure 4: The reflectance of transferred UV-curable moth-eye structures.