Investigating factors influencing the reflectivity of aluminum thin films on 3D printed micromirrors

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Photonic packaging constitutes over half of the total production costs of photonic modules. In response to this challenge, we introduce a novel 3D printed free-form micro-mirrors designed for chip-level photonic interconnections. This study focuses on how the reflectivity of aluminum thin films on the micro-mirrors, a key determinant of coupling efficiency, is affected by two factors: the thickness of the aluminum film and the mirror's oblique angle. Our findings reveal that films which are too thin or too thick demonstrate reduced reflectivity. Additionally, the oblique angle of the mirror has a marginal impact on reflectance, especially at extreme film thicknesses.

Introduction

Photonic packaging, responsible for both optical and electrical interconnection with external systems, is estimated to account for 70-80% of the total production cost of a photonic module[1]. This significant cost is primarily induced by stringent alignment requirements necessary for establishing optical connections. To address this "packaging bottleneck" in photonic devices, we introduce a 3D printed free-form reflector tailored for chip-level photonic interconnection[2]. This reflector is versatile, capable of reflecting light across different wavelengths while also adjusting the light beam's width. This flexibility eases the alignment prerequisites for optical connections. The coupling efficiency of this reflector depends on the micro-mirror's reflectivity. This paper delves into two factors that influence the reflectivity of aluminum thin films on 3D printed micro structures: the aluminum thin film's thickness and the mirrors' oblique angle. In the second section, we present the experimental methods including the 3D printed micromirrors and the reflectivity measurement setup. The third section presents measurement results on the mirrors' surface morphology and reflectivity, discussing the two influencing factors. Finally, the conclusions are presented in the forth section.

Experimental methods

Figure 1 illustrates the design and dimensions of 3D printed micro-mirrors. Three right triangular prisms, each with a different cross-section, were fabricated on a silicon substrate. To reduce printing time, each prism incorporates a through-hole. The prisms' faces, highlighted in teal, serve as reflective surfaces in this study. A base supports each prism, elevating the micromirror to mitigate artifacts from substrate reflection.

The prisms were produced using IP-S photoresist on silicon substrates with a Nanoscribe Photonic Professional GT 3D printer. Each design from Figure 1 was printed once per silicon substrate. After exposure, the prisms were developed using RER 600 and isopropanol. Subsequently, aluminum layers of varying thicknesses were deposited on the substrate surfaces with a Balzers BAK 600 Evaporator. We experimented with three different aluminum layer thicknesses, measured using a Veeco

Dektak 8 surface profiler. The completed micro-mirrors were examined using a JEOL JSM 7610F scanning electron microscope.

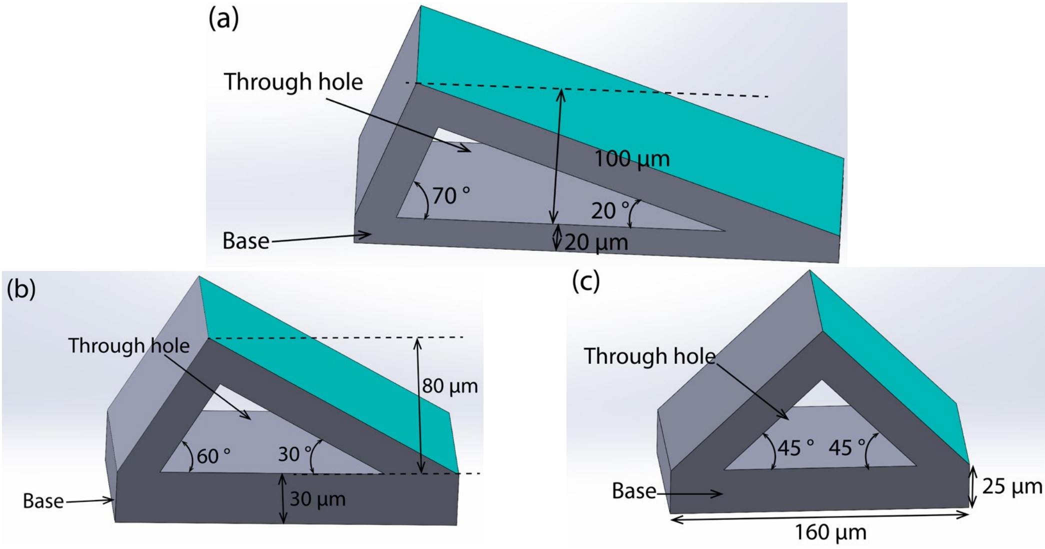

Figure 1. Design of 3D printed prism micro mirrors with dimensions. Mirror faces, coated with aluminum, are marked in teal. Angles between reflective faces and substrate in (a), (b), and (c) are 20°, 30°, and 45°, respectively. Each prism features a through-hole and is placed on a base.

Figure 2 presents the setup for measuring reflectivity. A 635 nm laser from a Thorlabs S1FC635 fiber-coupled source focused on the micro-mirror, with an incident beam power measured to be 0.35 mW. Power measurements for both the incident and reflected beams were conducted using a Thorlabs PM16-140 integrating sphere power meter. The micro-mirrors were positioned on a rotary stage to facilitate reflectance measurement at various angles. This study exclusively measured the reflectivity of the P-polarized laser beam.

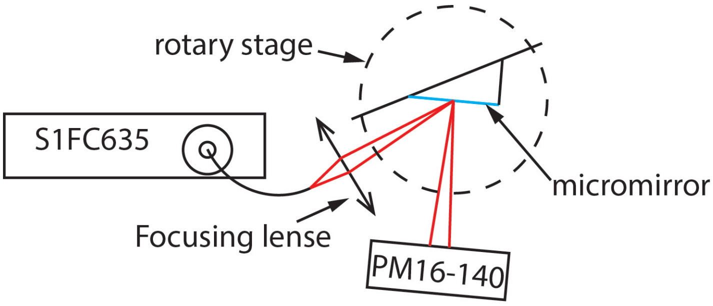

Figure 2. Reflectivity Measurement Setup Schematic. A 635 nm laser beam from an S1FC635 source is focused onto the micro-mirror, with its reflected intensity measured by a PM16-140 power meter. Red lines depict the laser beam path, while the blue line indicates the micro-mirror's reflective surface.

Results and discussions

Figure 3 (a), (b), and (c) show SEM images of the devices illustrated in Figure 1. These images closely align with the original design, revealing mirror surfaces that are predominantly flat, with minor grooves resulting from the 3D printing process.

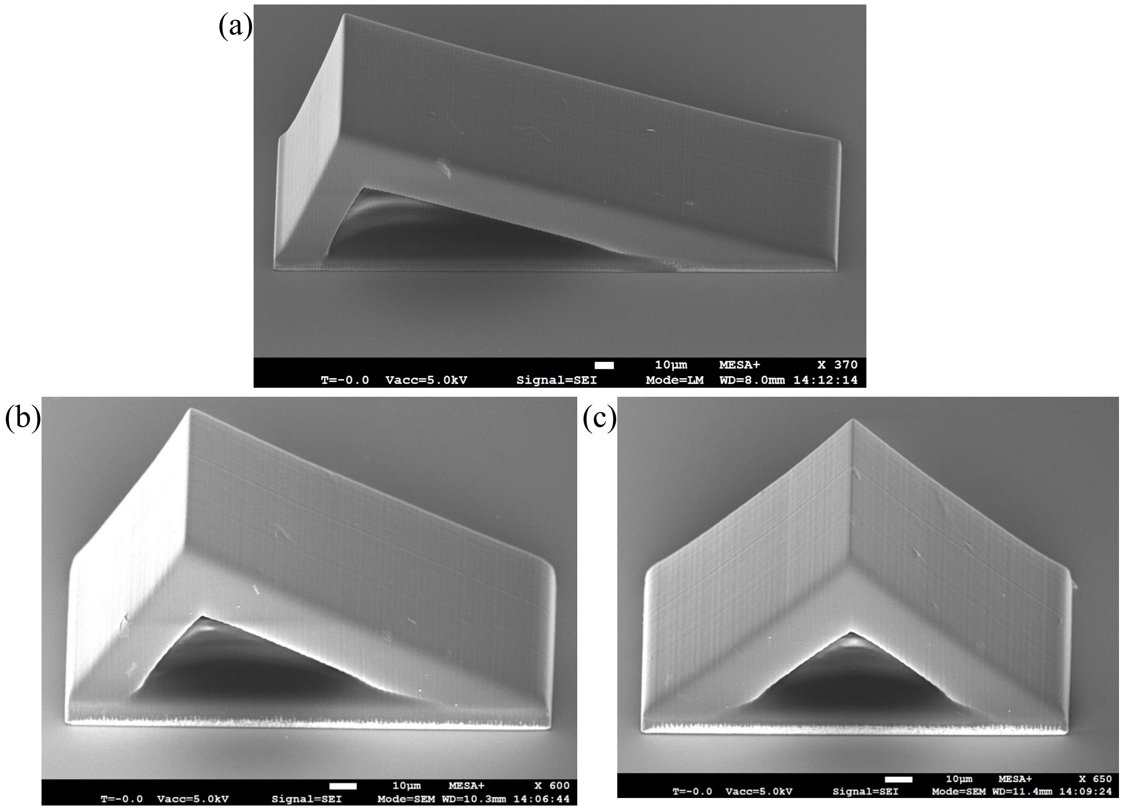

Figure 3. SEM image of the 3D printed mirrors. (a), (b) and (c) correspond to the design shown in Figure 1 (a) (b) and (c)

We prepared three samples, each with a different aluminum layer thickness: 200 nm, 400 nm, and 600 nm. Figure 4 demonstrates the relationship between the measured reflectivity, aluminum film thickness, and the mirrors' slope. The reflectivity is measured with 40° Incidence Angle.

Figure 4 reveals that the aluminum layer's thickness is the most crucial factor affecting reflectance. Across all slopes, the 400 nm thick aluminum layer exhibits the highest reflectance. For micro-mirrors with thinner aluminum layers, their limited reflectance is attributed to light transmittance through the layer[3]. Conversely, in micro-mirrors with thicker aluminum layers, reflectance may be constrained by the aluminum layer's surface roughness, which increases with film growth due to its columnar nature[4]. Notably, the reflectance for the sample with a 45° oblique angle and 200 nm aluminum thickness is lower than those with 20° and 30° oblique angles, likely due to its relatively thinner aluminum layer[5]. The reflectance of samples with a 45° oblique angle and 600 nm thick aluminum film is also lower than the rest of the samples, likely owing to the enhanced roughness of the aluminum layer at higher oblique angles[6].

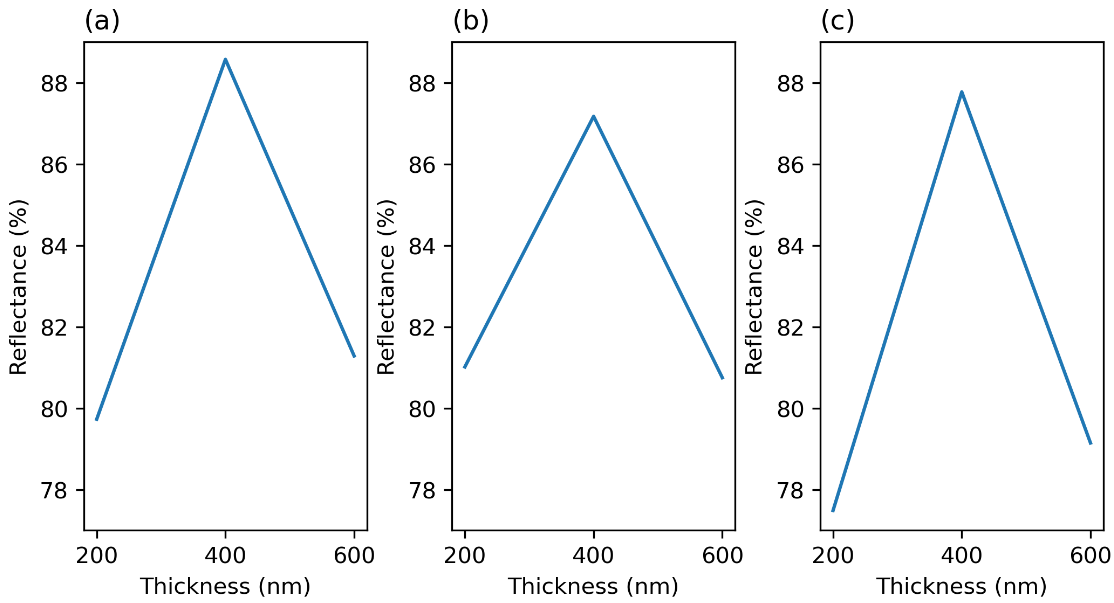

Figure 4. Reflectance of Micro-Mirrors at 40° Incidence Angle. (a), (b), and (c) depict reflectance for 20°, 30°, and 45° oblique structures, respectively, as a function of aluminum thin film thickness.

Conclusions

In this study, we explored two key factors affecting the reflectance of aluminum thin films on 3D printed micro-mirrors: the oblique angle of the mirror and the thickness of the aluminum film. Our findings indicate that the film's thickness significantly impacts reflectance. Meanwhile, the mirror's oblique angle plays a minor role in reflectance, particularly when the aluminum film is either excessively thin or thick.

References

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