Investigation of Surface Roughness in 3D Printed Optical interconnect Structures Using Atomic Force Microscopy

N. Xu[1], Y. Zeng[1], S.M. García Blanco[1] and L.Chang[1]

[1] Integrated Optical Systems Group, MESA+ Institute for Nanotechnology, University of Twente, 7500 AE Enschede, The Netherlands

The surface roughness of 3D printed structures plays a crucial role in determining their performance in optical interconnect applications. In this study, Atomic Force Microscopy (AFM) was employed to investigate and quantify the surface morphology and roughness of 3D printed structures designed for optical interconnects. By precisely measuring surface roughness at the nanoscale, the AFM analysis offers valuable insights into the topographical features that influence optical performance. This work aims to correlate surface roughness with the printing process parameters especially on sloped and curved surfaces. This kind of AFM measurement also provided an accurate method to evaluate curved surface smoothing techniques that may be applied to the printed structure in the future.

Introduction

Surface quality is a critical factor for optical interconnects[1], where smooth surfaces minimize light scattering and enhance efficiency. Previous studies have demonstrated that surface roughness directly affects optical performance, with smoother surfaces leading to reduced scattering losses. This study focuses on surface roughness in 3D-printed optical interconnects fabricated via two-photon polymerization (TPP)[2], a technique known for its high-resolution capabilities in producing complex microstructures. There are several characterization methods are available to access the printed quality, and have their own advantages and disadvantages. Scanning Electron Microscopy (SEM) offers high-resolution imaging, which is great to look at the overall shape. However, it lacks accurate depth measurement capability. Confocal microscope is a great tool to measure the profile however, it has difficulty to detect features and roughness below the diffraction limit [3]. AFM provides sub-angstrom accuracy for surface roughness measurement[4]. However, AFM faces challenges in measuring non-flat samples. To address this, we propose a sample preparation method enabling AFM measurements on curved and sloped surfaces.

Method

The 3D-printed optical interconnects were designed as stand-alone mirrors with pillared supports, as shown in Figure 1. Both flat and curved mirrors were examined, with the reflecting surfaces (orange parallelogram in Figure 1) being the location of AFM

measurements. The rectangle base was designed to enhance adhesion to the substrate during sample printing and developing.

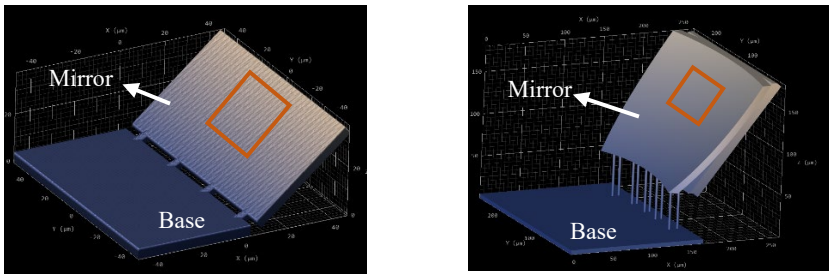


Figure 1(a) flat mirror model (b) curved mirror model

After fabrication, a glass needle probe (Figure 2a) was used to break the pillar supports, allowing the mirror portion to lie flat on the substrate for AFM measurements (Figure 2b), after which the measurement can be realized.

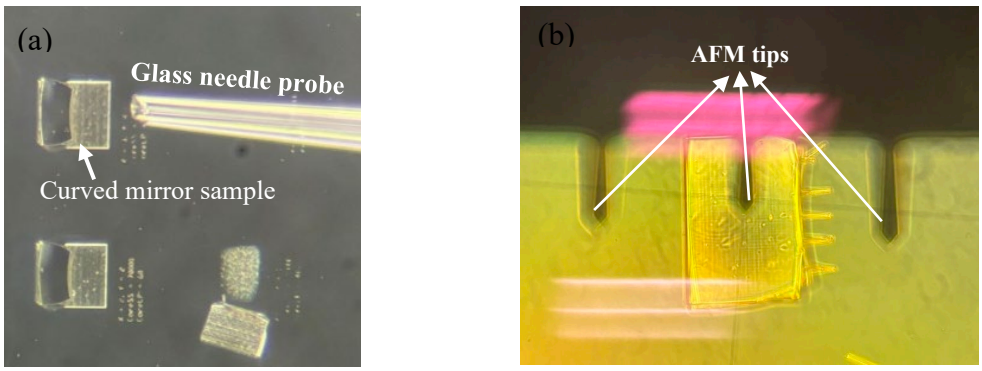
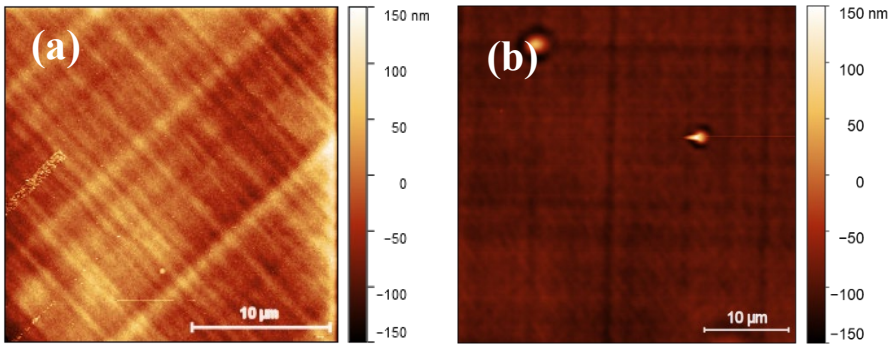


Figure 2 Process of breaking the samples (a) Glass needle probe (b) AFM measurement of the sample. The middle AFM tip is used for this particular measurement. Note, when pushing the mirror down to flat, it moves away from the base, thus the base is outside this field of view.

Results and Analysis

Mirror surfaces fabricated under varying printing parameters was measured. Morphological images are presented in Figure 3, and root mean square (RMS) roughness values are summarized in Table 1.



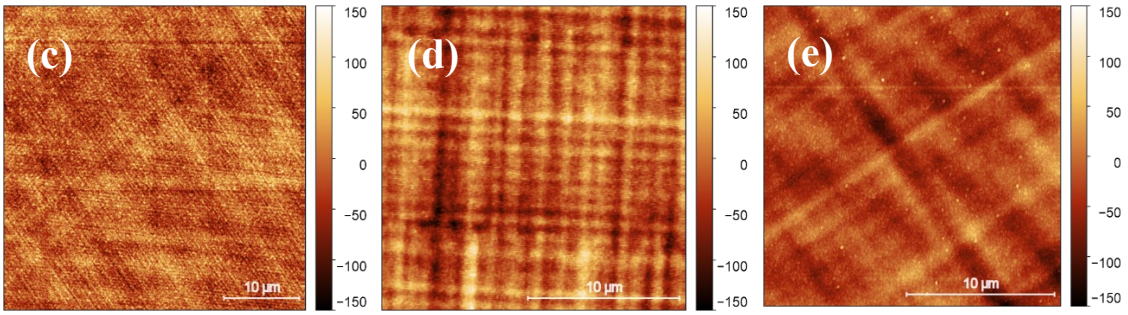


Figure 3 AFM images of (a) flat mirror, printed by 25x objective, 0° hatching angle offset (b) flat mirror, printed by 25x objective, 131.67° hatching angle offset (c) flat mirror, printed by 63x objective, 131.67° hatching angle offset (d) curved mirror, printed by 25x objective, 0° hatching angle offset (e) curved mirror, printed by 25x objective, 0° hatching angle offset coated with 400 nm Al

	a	b	c	d	e
s_q(nm)	12.53(±0.54)	9.25(±0.86)	12.33(±0.83)	15.65(±1.34)	14.65(±1.22)

Table 1 Root mean square area surface roughness

The grid-like pattern observed in the printed structures rotates based on the offset angle parameter. By comparing sample b and c, it shows the 25x objective exhibit smoother surfaces compared to the 63x objective. Curved samples generally display rougher surfaces than flat ones. Within the measurement error, the thin metal coating does not change much the surface roughness.

Conclusion

This study successfully demonstrated a method for measuring surface roughness of 3D-printed structures using AFM without requiring customized holders or specialized AFM probes. This approach is widely applicable for surface roughness assessment of 3D-printed microstructures. Future work will focus on optimizing support structure designs for easier detachment and exploring this method's applications to other complex optical components requiring precise surface quality control.

References

[1] Luana Persano, Francesco Cardarelli, Arkadii Arinstein, Sureeporn Uttiya, Eyal Zussman, Dario Pisignano, Andrea Camposeo, "3D printing of optical materials: an investigation of the microscopic properties," Proc. SPIE 10529, Organic Photonic Materials and Devices XX, 105290V (21 February 2018); https://doi.org/10.1117/12.2290495

[2] Xiaoqin Zhou, Yihong Hou, Jieqiong Lin; A review on the processing accuracy of two-photon polymerization. *AIP Advances* 1 March 2015; 5 (3): 030701. https://doi.org/10.1063/1.4916886

[3] Udupa, G., Singaperumal, M., Sirohi, R. S., & Kothiyal, M. P. (2000). Characterization of surface topography by confocal microscopy: I. Principles and the measurement system. *Measurement Science and Technology*, *11*(3), 305–314. https://doi.org/10.1088/0957-0233/11/3/320

[4] Covalent Metrology Services. (2020). *Atomic force microscopy for advanced optical components*. https://covalentmetrology.com/wp-content/uploads/2021/06/Covalent_AFM-for-Advanced-Optical-Components_whitepaper_V2.0.pdf