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3D printed on-chip parabolic mirror for chip-to-fiber and chip-to-chip coupling

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Reflection of light by a 3D printed aluminum coated micro parabolic mirror overcomes the in-plane limitation of waveguide end facet coupling between two photonic devices. Its application includes broad wavelength range wafer-level testing and inter-chip coupling. Design, fabrication and preliminary characterization of 3D printed micro-mirrors on optical waveguide chips will be described in this work.

Keywords: *Optical connectivity, 3D print, micro mirror, wafer-level photonic packaging*

INTRODUCTION

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Wafer-level testing of optical waveguide devices is an important enabling technology to reduce cost. It is also a great tool to reduce testing time in comparison with die-level testing, which leads to faster developing cycle. In the Si waveguide platform, grating couplers have been used to couple the light out of the wafer plane for wafer-level testing [1]. However, it is challenging to use grating coupler in lower contrast waveguide material platforms due to the relative small bandwidth (i.e., typically spanning only a few tens of nanometers) [2]. In this preliminary study, a reflection-based micro-mirror is proposed to reflect the light out of the wafer plane. Depending on the applied coating, a parabolic mirror can work over a very large wavelength range (e.g., from the UV to the infrared for an aluminum coating) compared to a grating coupler. A metal coated reflection layer is an interesting alternative to the previously proposed total internal reflection based mirrors[3], especially in certain applications in which air cavities need to be removed during packaging. The technology proposed in this work has the potential to be used with many material platforms since it has low dependency to the substrate. Structure design, 3D printing, and the aluminum coating process will be discussed in detail in this paper.

PARABOLIC MICRO MIRROR FABRICATION

There are two main steps to fabricate the parabolic micro mirrors, namely, 3D printing of the mirror structure and aluminum coating forming the reflecting surface. 3D printing is based on two-photon lithography (2PL), which is a powerful way for manufacturing prototypes of micro size optical components [4]. Most structural materials fabricated by 2PL are photopolymers. The 3D printer (Photonic Professional GT) developed by Nanoscribe is used in this project. The photoresist, IP-S, is used to produce a smooth surface quality and dimensional accuracy [5]. Aluminum coating is chosen in this project due to its high reflectivity over a large spectrum range (i.e., from UV to IR). A ~200 nm thick Al coating is fabricated by e-beam evaporation (BAK600) directly on the 3D printed mirror. A SEM image of a coated mirror is shown in Fig. 1.

MIRROR CHARACTERIZATION WITH A BARE FIBER

In order to test the mirror performance without the complexity of a waveguide mode, standalone mirrors (i.e., without waveguide) have been fabricated on a flat Si wafer. The mirror is then tested with a bare fiber at a wavelength of 976 nm. The testing schematic is shown in Fig. 1. The optical mode profile of a cleaved bare fiber is measured, without the micro mirror, with a beam profiler (Thorlabs BP209IR1(/M)) at location 1. By inserting the micro mirror into the beam path, the light is reflected vertically up. The corresponding beam profile is then measured by moving the beam profiler to location 2. A side view camera image is shown to indicate the relative position between the bare fiber and the micro mirror. Since the entire wafer surface acts itself as a mirror, the mirrored image of the micro mirrors and the fiber is clearly visible in the picture.

The reflected beam profile (i.e., shape and size) depends on the alignment between the bare fiber tip and the micro mirror. The reflected beam profile shown in Fig. 1 corresponds to the case in which the fiber tip is positioned close to the mirror focal point. The nice beam profile indicates that the parabolic mirror surface works as expected.

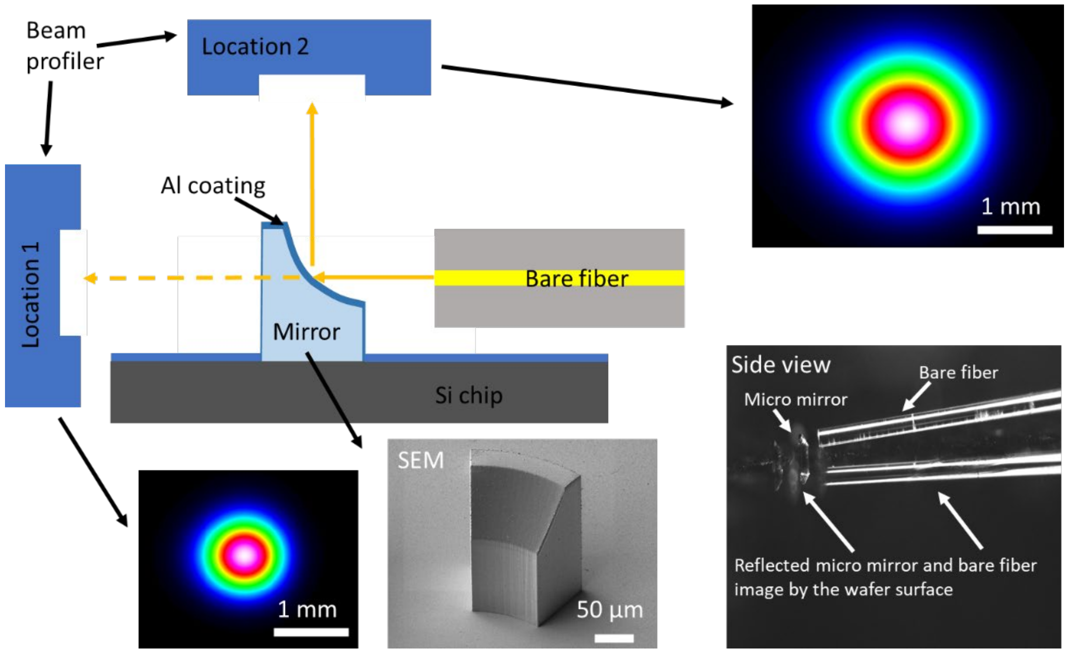
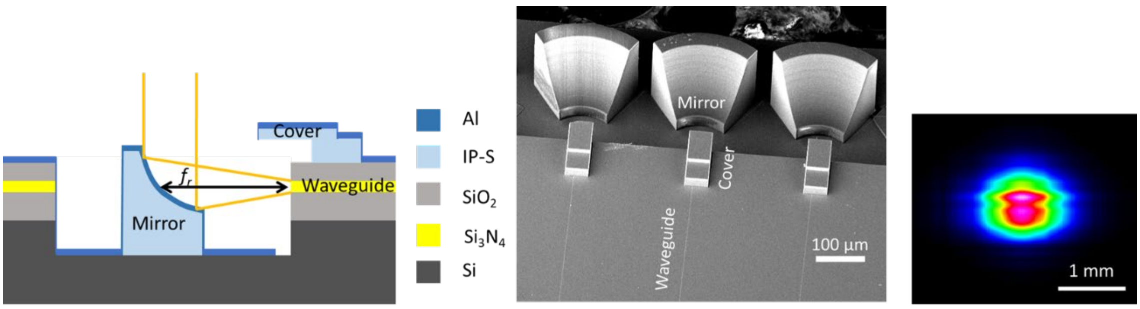


Fig. 1. Schematic of the setup utilized to test the standalone mirrors. A bare fiber is used in order to bring the fiber tip close enough to the printed mirror. The reflected beam profile is measured by the beam profiler at location 2. It has a similar shape as the profile measured in the case of no mirror (i.e., lowering the chip and moving the beam profiler to location 1). A SEM image of the printed and aluminum coated mirror is shown. A side view indicates the relative position between the fiber tip and the mirror.

PRINTED MIRROR ON A WAVEGUIDE CHIP

In this section, we first describe the addition fabrication processes needed to combine the mirror on a Si_3N_4 waveguide chip. Then present the fabrication result and preliminary optical characterization.

There are three main steps during the fabrication. First, in order to align the mirror focal point to the waveguide end facet, a deep reactive ion etched platform is needed as shown in Fig. 2(a). The detailed etching process is described in our early work [6]. Second, both the parabolic mirror as well as a cover above the waveguide end facet are 3D printed. The cover is used to prevent deposition of aluminum on the waveguide end facet in the next step. If an aluminum layer forms at the waveguide end facet, it will prevent light exiting or entering the waveguide. Third, an aluminum layer is deposited by e-beam evaporation. This deposition is very directional. The chip surface normal is pointed to the Al target. Thus the area under the cover will not be coated. A SEM image of fabricated mirrors is shown in Fig. 2(b).



(a) (b) (c)

Fig. 2. (a) Printed mirror on a waveguide chip schematic. (b) SEM image of 3 fabricated mirrors aligned with corresponding waveguides. (c) Measured beam profile of light exit from a waveguide and reflected by the corresponding mirror at 976 nm.

For testing purposes, the other end of the waveguide, not shown in Fig. 2(b), has been diced for butt coupling before steps 2 and 3. Thus, that end facet has a thin layer of Al coating. This Al layer is removed by dipping this end facet (half of the diced chip) into aluminum etchant. The sample is then measured by butt coupling the light from a fiber into the waveguide. The light exit the waveguide, is reflected by the mirror and then is measured by a beam profiler located on top of the chip. A measured beam profile is shown in Fig. 2(c). It matches our expectation except the horizontal features. This mainly due to the waveguide end facet roughness in the horizontal direction. Therefore, a optimization of a deep reactive ion etch process is needed to improve the end facet.

CONCLUSIONS AND OUTLOOKS

In this work, we demonstrate the fabrication process and preliminary characterization results of 3D printed micro parabolic mirror on a Si_3N_4 waveguide chip. It shows the potential to be used for wafer-level testing and inter-chip optical connections.

In the future, further fabrication development is needed to remove the aluminum coating on the locations from which is not needed.

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