Electronic Supplementary Material (ESI) for Lab on a Chip.

Supporting information

Self-aligned 3D microlenses in a chip fabricated with two-photon stereolithography for highly sensitive absorbance measurement

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Calculation method of optical performance

The simulation method of 3D-MIMC (3D microlenses incorporated microfluidic chip), 2D-MIMC (2D microlenses incorporated microfluidic chip), and MC (microfluidic chip without microlens) were illustrated as followed. Considering the symmetry of optical components in the Y-Z plane (Fig.S1a and Fig.S1b) in 3D-MIMC and MC, an integration method based on equation S1 was adopted to calculate their theoretical performance. On the other hand, considering the symmetry of optical components in Z direction (Fig.S1c) in 2D-MIMC, another integration method based on equation S2 was used to calculate the theoretical performance. To better understand equation S1 and equation S2, illustrative schematics were presented in Fig.S1d and Fig.S1e. At r position in the emitter, the cyan ring and rectangular were the infinitesimal sections for each integration, in which the probability of ray recorded by the detector was considered identical.

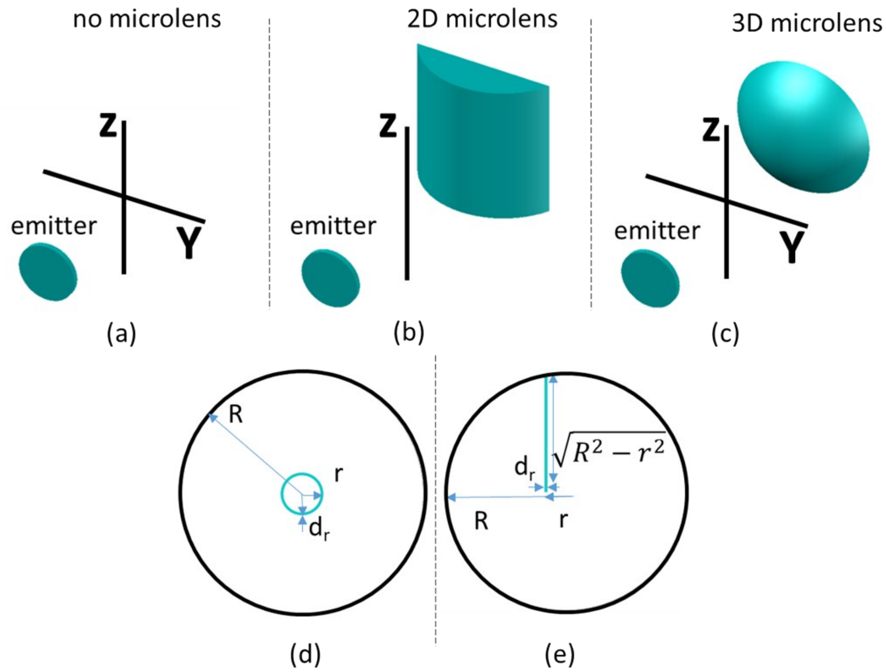

Fig.S1 Integration method for calculating the theoretical performance. The symmetry of optical components in (a) MC, (b) 2D-MIMC and (c) 3D-MIMC. The illustrative schematics of infinitesimal section for the performance calculation, (d) for MC and 3D-MIMC, (e) for 2D-MIMC.

$$F = \int_0^R 2\pi f(r) dr \quad \text{(S1)}$$

$$F = 4\int_0^R \sqrt{R^2 - r^2} f(r) dr \quad \text{(S2)}$$

where, F is the total probability of rays recorded by the detector whose area was identical to the fiber core; r is the radial variable along the radius of emitter; R is the radius of emitter (optical fiber core), in this study, $R = 52.5\ \mu m$; $f(r)$ is the probability of ray emitted from the source (located at r position) recorded by the detector in the simulation.

Main configurations in the simulation

All rays emitted from each point source was homogeneously distributed within a cone space. The cone angle was determined according to the numerical aperture (NA) of the optical fiber used and the refractive index of the medium for light transmission (Fig.S2a). As the microlens surface was curved, the mesh for the microlens had fine sizes (minimum 2 µm, maximum 5 µm), shown in Fig.S2b and Fig.S2c.

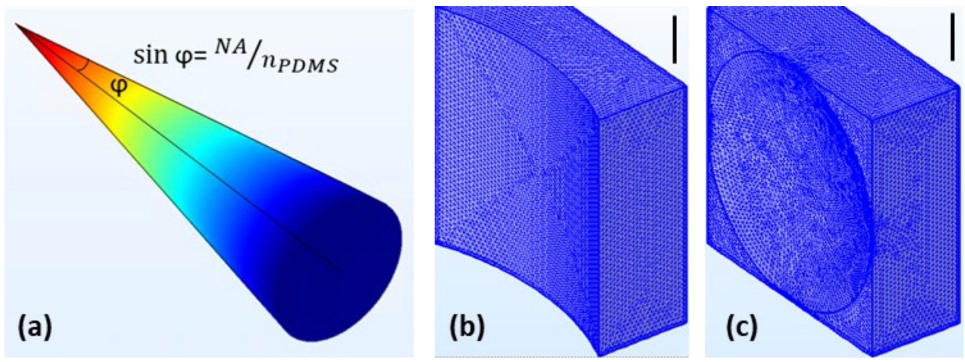

Fig.S2 (a) the cone of each ray source, the cone angel φ was calculated according to equation shown in the figure, where NA is the numerical aperture of the optical fiber, n_{PDMS} is the refractive index of PDMS. In this work, the NA value of the cone angle was 0.22 and the value of n_{PDMS} is 1.41. (b) and (c), the mesh for the 2D and 3D microlens. Scale bar in images: 50 µm.

Ray trajectories describing the optical performance

Fig.S3 indicated the ray trajectory corresponding to the cases without microlens, with 2D microlens and with 3D microlens. The ray trajectory with views in three dimensions, in XY planes and in XZ planes were all presented. The divergence of light transmitted from the fiber could not be corrected if no microlens was applied while part of the light could be converged because of the function of 2D microlens. In contrast, the light could be better corrected with the incorporation of 3D microlens. For a clear view, only the light reaching the microlens area was considered.

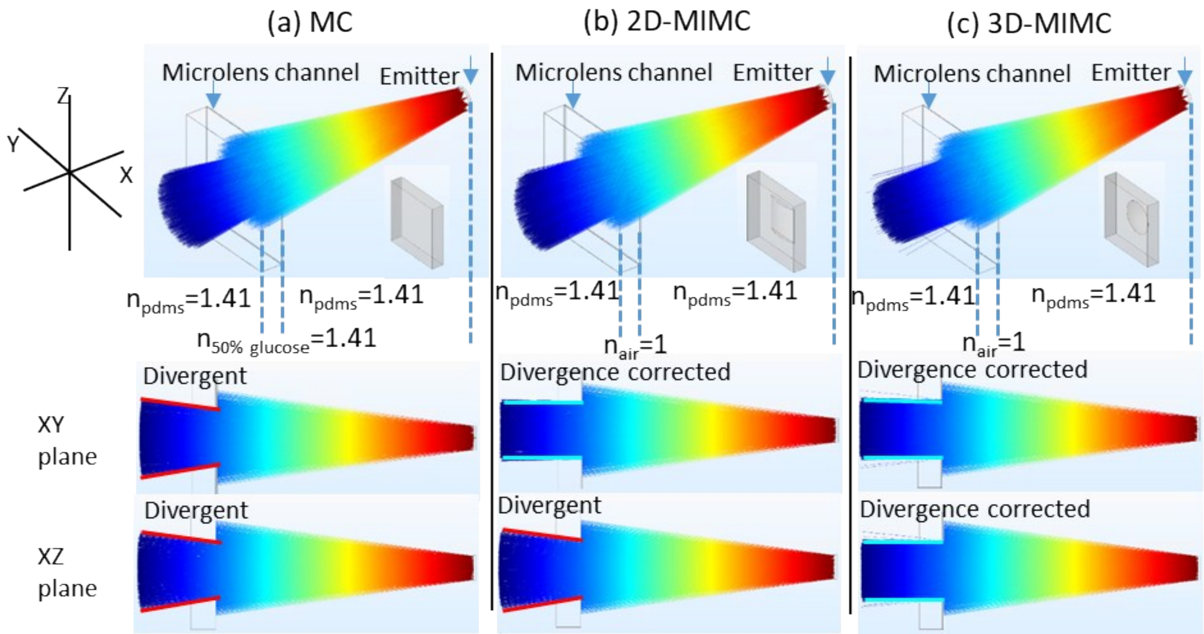

Fig.S3 Compared ray trajectory corresponding to the cases (a) without microlens, (b) with 2D microlens and (c) with 3D microlens. The divergence of light with and without corrections were schematically indicated with cyan and red profiles respectively.