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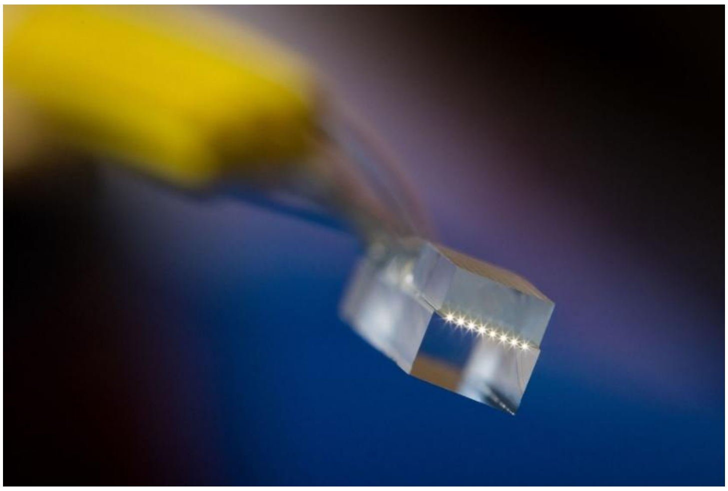
PHOTONICS ASSEMBLY

PHIX Lensed Fiber Arrays

Our PHIX lensed fiber arrays (LFAs) are a high-accuracy free space coupling solution between optical fibers, (wafers of) photonic integrated circuits (PICs), and other components. Using a high-precision additive 3D microfabrication process, PHIX can print microlenses of various shapes on the ends of optical fibers, enabling beam collimation, focusing, and even deflection. This enables mode field conversion and coupling across air gaps, for applications such as wafer-level probing and spectral gas analysis. This support document covers the specifications, technology, and validation of these products, and outlines our standard web shop offering, as well as customization options.



1 Validity and context

The capabilities and insights in this product description may be subject to change. Please find the latest version of this document online.

The optical properties advertised in this document are based on a combination of theoretical models and practical measurements. However, unforeseen variations may occur.

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2 Lensed fiber array overview

PHIX lensed fiber arrays (LFAs) are v-groove optical fiber arrays with 3D-printed lenses at the end facet of the fibers. They are intended for free space coupling to other fiber arrays, photonic integrated circuits (PICs), or other components. The printed microlenses can focus or collimate the light from (or into) the fibers, enabling mode field conversion or optical coupling across an air gap.

We support several lens shapes. Beside the straight focusing or collimating lens models, we also offer periscope lenses that deflect the light at an angle. The resulting periscope lensed fiber arrays (PLFAs) are very suitable as probes for wafer-level die testing, or for performing spectral analyses of gasses.

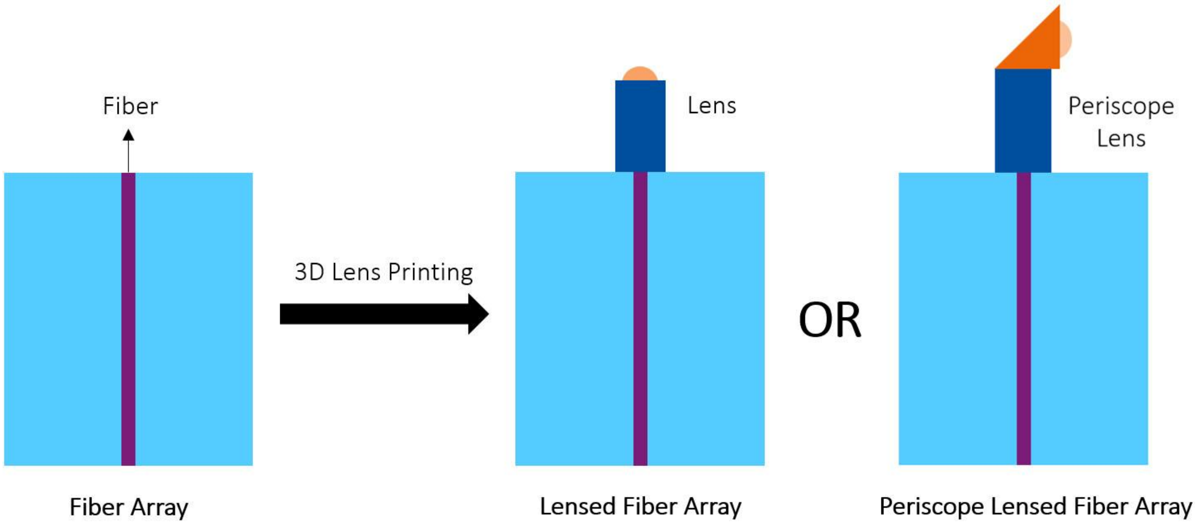

Figure 1: Schematic representation of a lens 3D-printed onto a fiber array lid

2.1 Highlighted features

- 3D-printed polymer lenses, up to 300 µm in height.
- Free space optical coupling with mode field reduction down to 1.5 µm or beam collimation over a distance of up to 250 µm.
- Supported wavelengths ranging from visible to mid-infrared (400 – 1700 nm wavelength).
- 127 or 250 µm (standard) or custom pitch.
- Fiber count of 1 to 32 (standard) or more (custom), at various fiber lengths.
- Accurate X/Y placement accuracy relative to the fiber core, down to 100 nm.
- High shape accuracy of 100 nm.

2.2 The technology

PHIX prints the 3D microlenses onto fiber arrays using a high-precision additive manufacturing process based on dip-in laser lithography (DiLL) and two-photon polymerization (2PP), in combination with state-of-the-art alignment technology. This microfabrication process enables a feature size down to 100 nanometers, with optical grade surface quality free from slicing steps.

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Figure 2: Nanoscribe Quantum X align additive manufacturing machine in the PHIX clean room

2.3 Benefits over subtractive lens creation methods

Lensed fibers are traditionally manufactured using a subtractive process, i.e. grinding, melting or etching. The resulting shapes, and their geometric accuracies, are limited by the basic process parameters of these techniques. Our additive lens printing process, on the other hand, enables a wide variety of lens geometries, such as mirroring periscopes and other asymmetric shapes, printed with far superior geometric accuracy. Furthermore, our lenses are printed when the fibers are already secured in an array. This avoids length deviations between the individual fibers.

2.4 Supported wavelengths

Our printed lenses are highly transparent for wavelengths ranging from 400–1700 nm. This is expandable to 350 – 2000+ nm with custom resins.

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2.5 Mode field diameter

We define a beam's mode field diameter (MFD) as the $1/e^2$-diameter of the Gaussian mode profile. For our focusing lens models, the MFD is measured at the focal point. For collimating lenses, the MFD is measured at the position where the collimating beam maintains a constant shape.

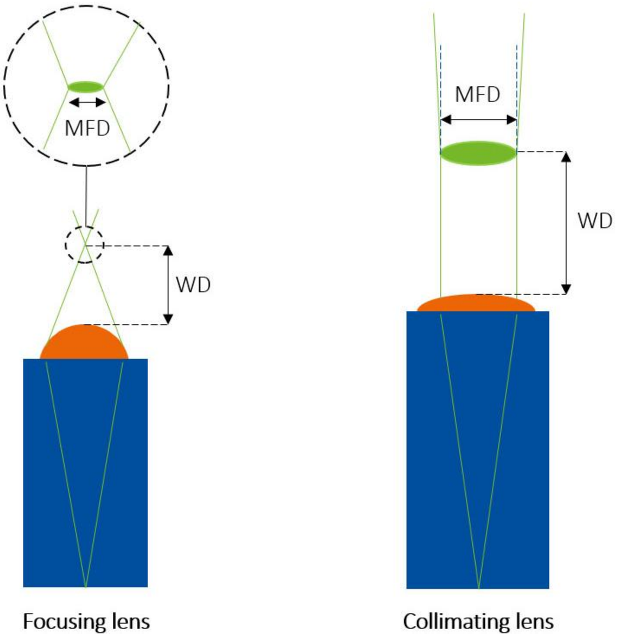

Figure 3: Definition and measurement location of working distance (WD) and mode field diameter (MFD) of LFA

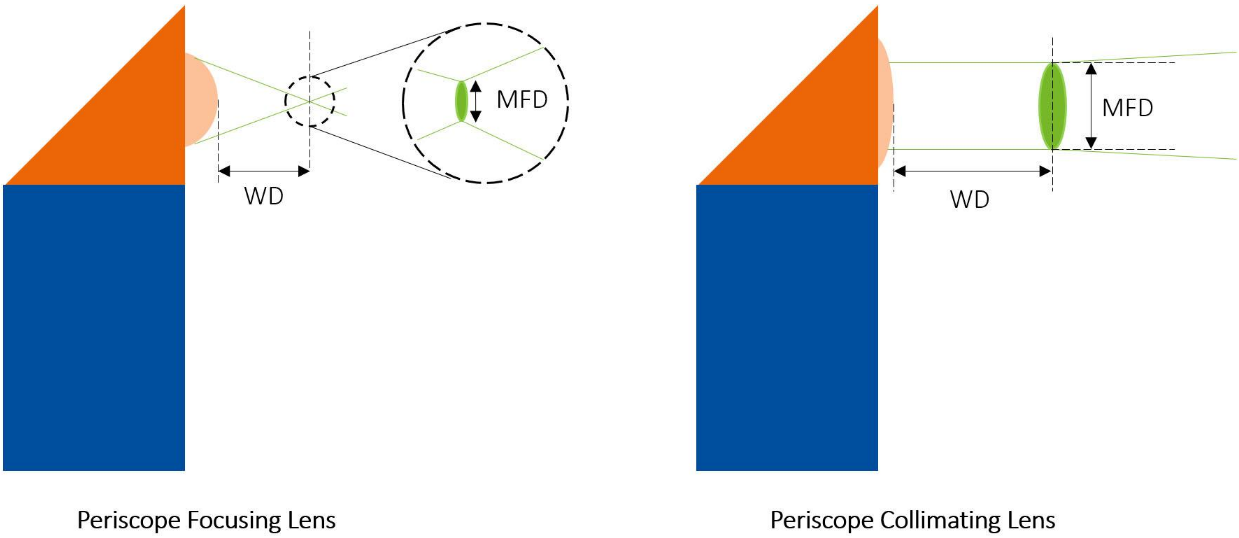

Figure 4: Definition and measurement location of working distance (WD) and mode field diameter (MFD) of PLFA

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PHIX has performed experimental validation of lens designs' MFD using the following method. A single channel (P)LFA was mounted on an XYZ-stage with a laser source of the corresponding wavelength connected to it. By moving the stage, the position of the beam waist and its MFD was then determined and measured using a beam profiler.

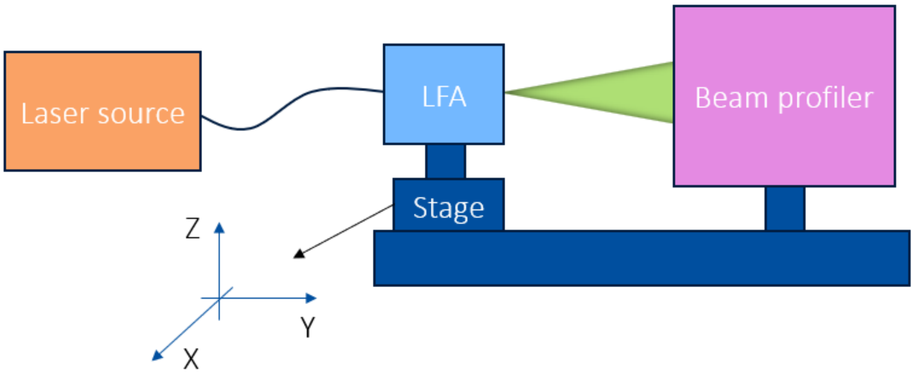

Figure 5: Mode field measurement setup

2.6 Working distance

For focusing lenses, the working distance (WD) is defined as the distance between lens top and the beam waist at the focal point. For collimating lenses, the working distance is defined as the distance between lens top and the position where the beam starts to diverge. The working distance is determined with the same MFD measurement setup described above, cross-referenced with lens simulations.

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3 Performance

This section covers several performance specifications of PHIX (P)LFAs, in relation to the geometric accuracy of the lens shapes, lens positioning, and expected coupling losses.

3.1 Lens positioning accuracy and pitch accuracy

The PHIX 3D microfabrication equipment can automatically detect fiber cores with a position accuracy down to 100 nm (X/Y).

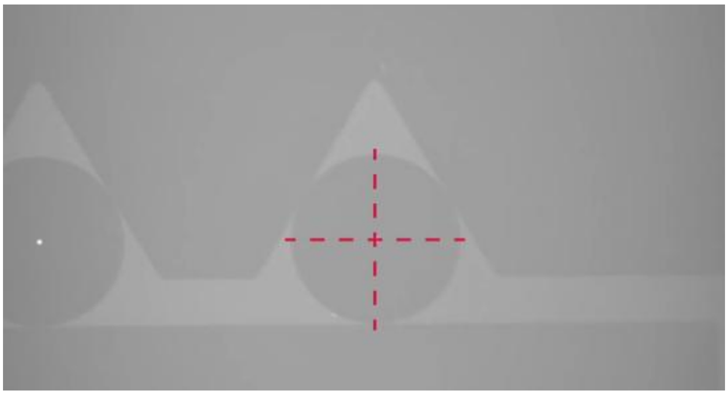

Figure 6: Auto-alignment of lens printing on fiber core

3.2 Surface roughness

The minimum average surface roughness of our 3D-printed lenses, as measured with a confocal microscope, is 5 nm, which ensures very low scattering losses. The graphs below show typical surface roughness data for the X and Y directions.

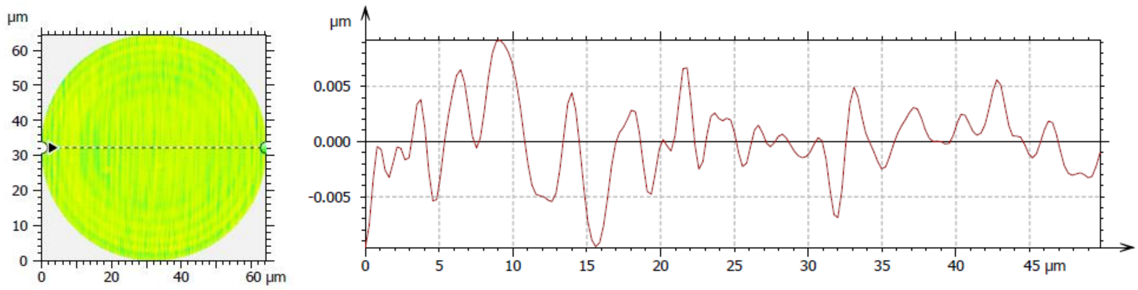

Figure 7: Lens 2D roughness in X direction

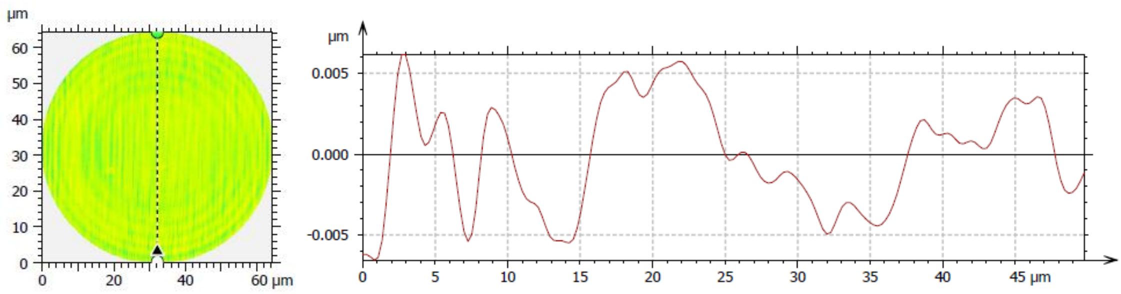

Figure 8: Lens 2D roughness in Y direction

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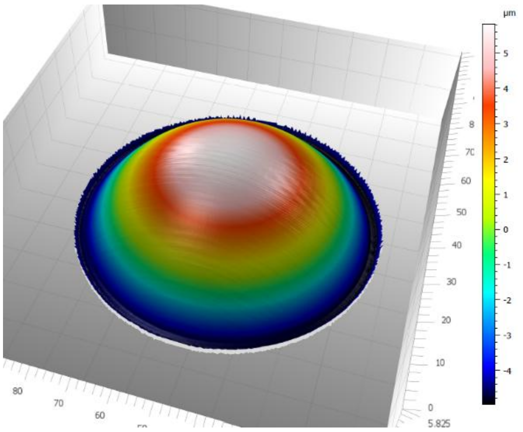
3.3 Lens shape accuracy

When comparing confocal microscope measurement data of manufactured lenses to their lens designs, the root-mean-square shape deviation is as low as 50-100 nm, ensuring excellent optical performance according to the lens design specification.



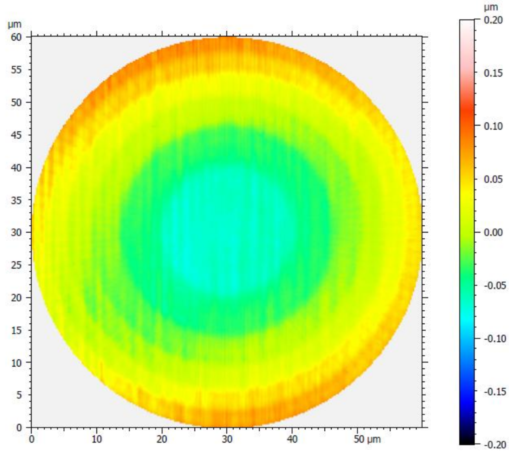


Figure 9: Lens measurement profile (left) and deviation contour plot (right)

3.4 Expected insertion loss

Including the losses caused by the fiber connector, the fiber to lens interface, propagation through the lens, and the lens to air interface, the insertion loss is below 0.8 dB. Approximately half of this loss is caused by Fresnel reflections, which can be reduced by applying antireflective (AR) coatings. This figure does not include the losses for coupling from the air to the customer's optical component, as this depends on factors beyond PHIX's control.

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4 PHIX lensed fiber array standard offering

With standardized and validated lens designs, fiber arrays, and microfabrication processes, PHIX offers a selection of LFA and PLFAs through our Fiber Array Webshop. These products involve no non-recurring engineering (NRE) costs, and our web shop provides a smooth ordering process, low handling costs, and short lead times. The supported specifications of these standard products are detailed below.

Please refer to chapter 5 for customized options.

4.1 Standard lens models

PHIX currently offers six standard LFAs and six standard PLFAs. These cater to a variety of mode fields and working distances, which are listed per wavelength in table 1. The table lists only the wavelengths for which PHIX has validated measurements of MFD and working distance. All lenses are transparent for the wide range of wavelengths covered in section 2.4.

Lens model	Wavelength (nm)	MFD (µm)	Working distance (µm)
Focusing 60	1550	10	35
Focusing 97	460	1.7	29
	520	1.9	29
	620	2.2	29
	780	2.4	31
	1060	3.1	30
	1310	3.4	25
	1550	3.6	25
Focusing 190	1550	15	150
Collimating 211	460	22	100
	520	25	
	620	24	
	780	30	
	1060	30	
	1310	25	
	1550	26	
Collimating 220	1550	30	50
Collimating 230	1550	20	250
Focusing periscope 60	1550	10	35
Focusing periscope 97		3.6	25
Focusing periscope 190		15	150
Collimating periscope 211		26	100
Collimating periscope 220		30	50
Collimating periscope 230		20	250

Table 1: PHIX LFA standard models

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4.2 Supported fiber arrays

The (P)LFAs selectable as part of our standard web shop offering can be configured according to fiber type, channel count, pitch, etc. This section describes the available standard options.

4.2.1 Fiber types

Our LFA and PLFA products support single mode and polarization maintaining fibers. The following fiber types are part of our standard offering.

Single mode fibers	Polarization maintaining fibers
S405-XP	PM-S405-XP+
HI780	PM780
HI1060	PM1310
SMF28	PM1550

Table 2: PHIX standard fibers

4.2.2 Channel counts (min and max)

The minimum channel count for (P)LFAs is 1 channel and the maximum for our standard offering is 32. We can support higher channel counts for custom orders.

4.2.3 Channel pitches

As our standard fiber arrays have 127 µm or 250 µm pitches, this applies also to our (P)LFAs. Other pitches will require a custom fiber array, and therefore a custom order.

4.2.4 Polarization orientations

For our standard (P)LFAs with polarization maintaining (PM) fibers, we offer both horizontally and vertically aligned stress rods. Figure 10 shows the alignment definition.

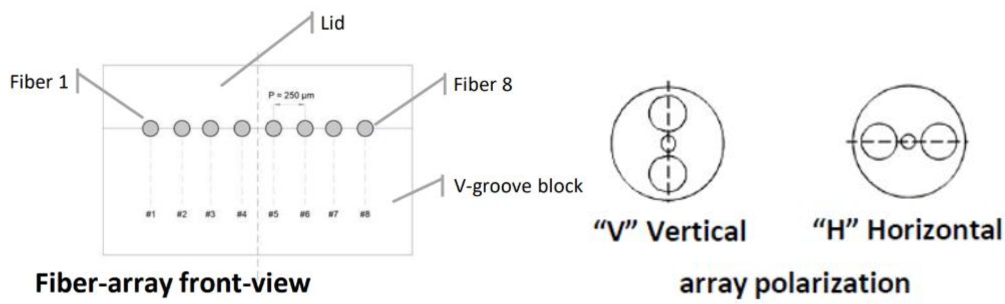

Figure 10: Definition of fiber polarization alignments

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4.2.5 Fiber length and connectors

Our standard (P)LFAs are 1 meter in length, have a tubing diameter of 900 µm, and are fitted with fiber numbering labels for your convenience. The connectors are FC-APC type, and you can select slow or fast axis to key polarization for them. Figure 11 shows this definition.

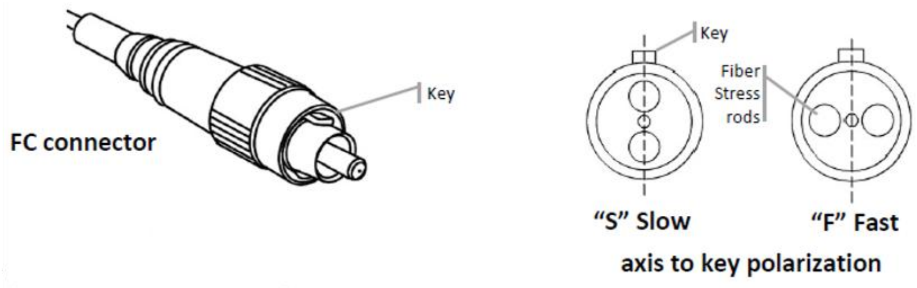

Figure 11: Definition of slow and fast axis to key connector polarization

Other lengths, connectors, and connector polarizations will require a custom order.

4.2.6 Lid types

PHIX offers several different lid thicknesses for our fiber arrays. The available options in our standard offering are shown in table 3 below. Thin lids are useful in edge coupling situations with limited vertical clearance. To maximize the positioning freedom of PLFAs, only 0.3 mm thin lids are supported for these models.

Lid type	LFA availability	PLFA availability
Standard lid, 1mm thickness	√	X
Thin lid, 0.3mm thickness	√	√
Thin lid, 0.4mm thickness	√	X
Thin lid, 0.5mm thickness	√	X

Table 3: Available fiber array lid types

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5 Custom LFAs and other 3D microfabrication solutions

The versatility of PHIX's 3D microfabrication tooling extends far beyond our standard offering of (P)LFAs. The following sections discuss the degrees of customization possible within several product areas.

5.1 Custom fiber arrays

If you require a custom fiber type, length, connector, pitch, or polarization orientation, PHIX can often create a (P)LFA for this. The most important condition is that the fiber array block is compatible with our lens printing tooling.

5.2 Custom lenses

Our 3D microfabrication tooling is flexible in dealing with custom microlens designs. We can design new lens models with variations in MFD, working distance, and deflection angle that are not covered by our standard lens model offering. The lead time for custom lenses is about 8-10 weeks after design freeze and they come at an additional NRE cost of €3850 per custom lens type.

5.3 PLFAs with fiducial structures

Aside from microlenses, PHIX can also print fiducial structures onto the lids of PLFAs to facilitate the positioning of the probe inside trenches during wafer-level PIC testing. Besides the tooth-shaped fiducials pictured in figure 12, we can support many other structures, including 3D shapes with circular and point markers.

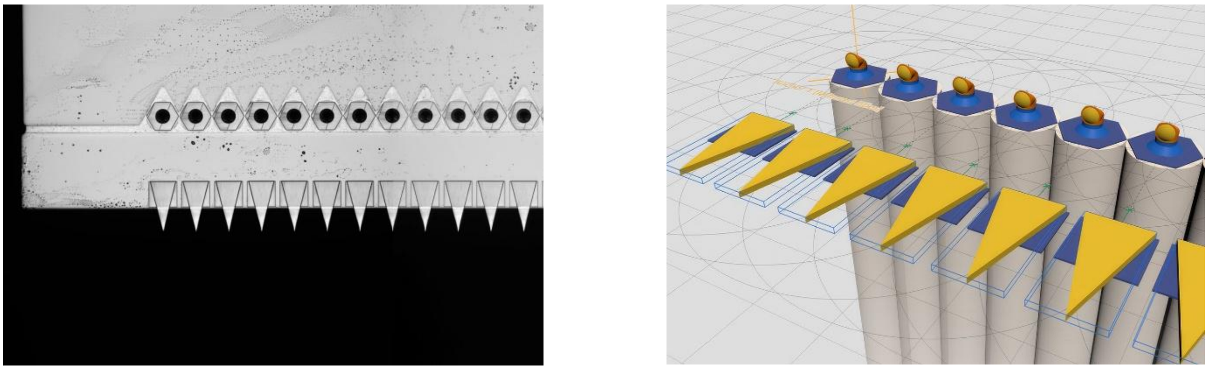

Figure 12: Fiducials printed on PLFA lid to help positioning

5.4 Other 3D microfabrication solutions

PHIX's 3D microfabrication capabilities are not limited to printing lenses on fibers. For example, we can print (arrays of) focusing or collimating microlenses on the side facets and surfaces of PICs as well, to enable edge or vertical coupling to free space.

Furthermore, our 3D microfabrication process is not limited to printing optical structures. If your product requires (micro)mechanical or microfluidic structures, feel free to contact PHIX and discuss the possibilities.

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Appendix A: LFA standard lens model dimensions

Lens model	Lens height (µm)	D (µm)	MFD @1550nm (µm)	Working distance (µm)
Focusing 60	60	35	10	35
Focusing 97	97	60	3.6	25
Focusing 190	190	80	15	150
Collimating 211	211	80	26	100
Collimating 220	220	90	30	50
Collimating 230	230	90	20	250

Table 4: LFA standard lens model dimensions

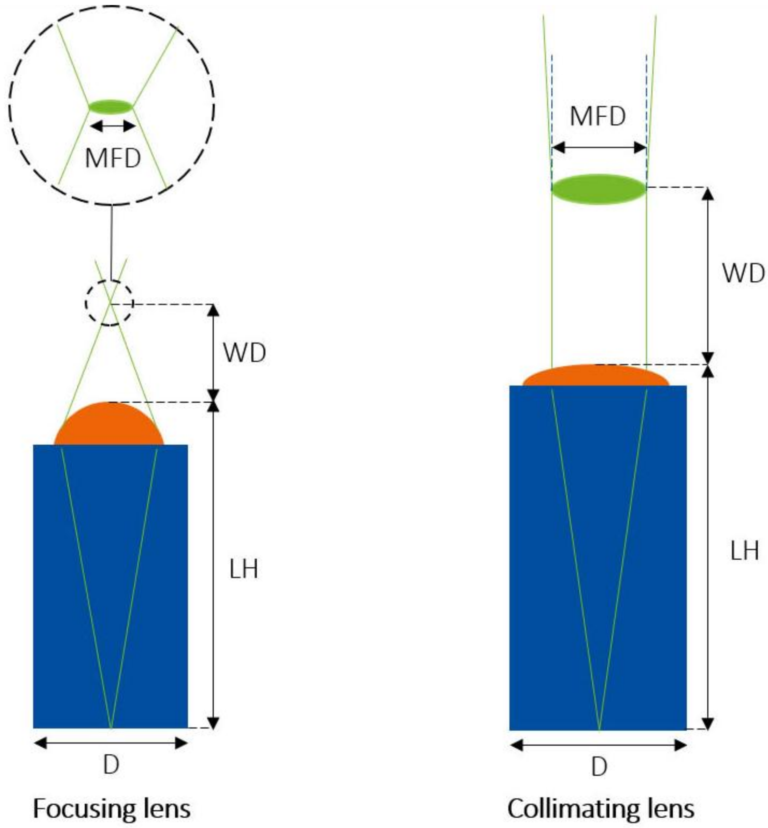

Figure 13: Lens height (LH) and diameter definitions of LFAs focusing (left) and collimating (right)

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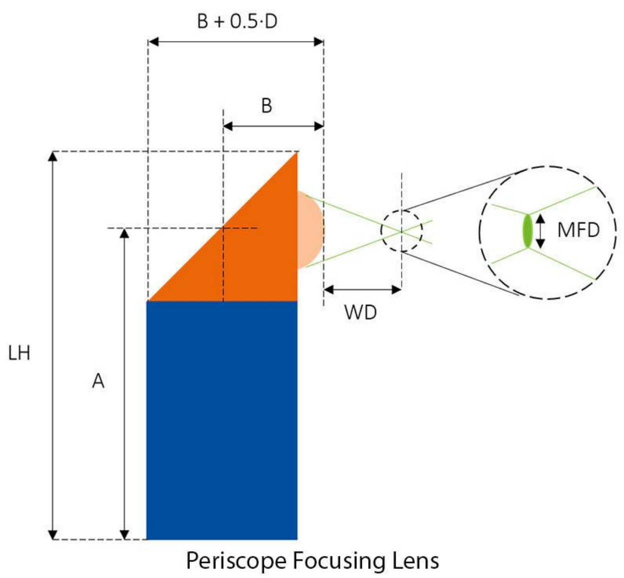
Appendix B: PLFA standard lens model dimensions

Lens model	Lens height (µm)	A (µm)	B (µm)	B+0.5D (µm)	MFD @1550nm (µm)	Working distance (µm)
Focusing periscope 60	56	38.5	21.5	50.6	10	35
Focusing periscope 97	84	61	36	58.5	3.6	25
Focusing periscope 190	168	125	65	120	15	150
Collimating periscope 211	191	148	63	118	26	100
Collimating periscope 220	200	158	62	117	30	50
Collimating periscope 230	207	165	65	120	20	250

Table 5: PLFA standard lens model dimensions



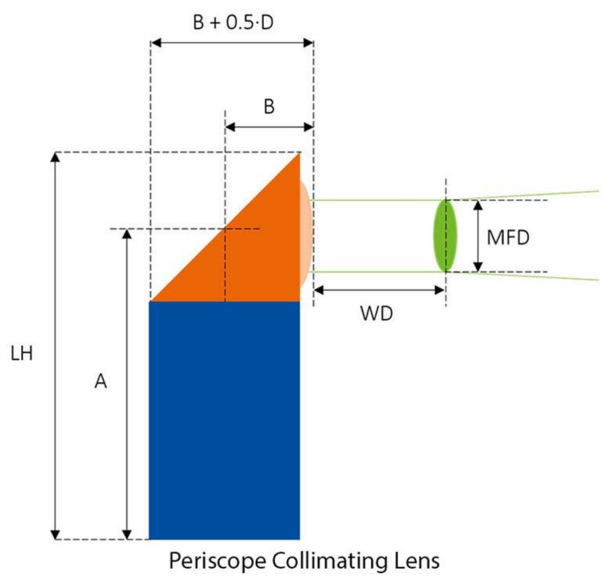


Figure 14: Lens height (LH) and diameter definitions of PLFAs focusing (left) and collimating (right)