PHOTONICS ASSEMBLY

PHIX Spot Size Converters

The PHIX Spot Size Converters (SSCs) are optional attachments for fiber arrays that improve optical coupling to photonic integrated circuits (PICs). These compact optical interposers between PICs and fiber arrays strongly improve the mode field matching between these components and therefore minimize insertion losses. This document describes the SSCs being offered by PHIX.
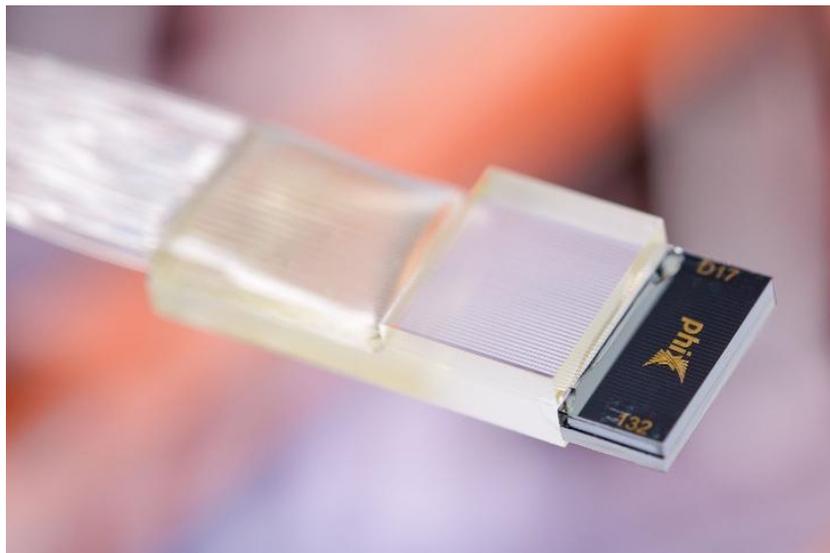
Figure 1:   Fiber array with attached 32-channel spot size converter

1   Validity and context

Given the rapid pace of technological advancements, the capabilities and insights in this product description are 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   Choosing a spot size converter solution

When faced with a mode field mismatch between your photonic integrated circuit (PIC) and a fiber array that would cause unacceptable optical losses, several solutions are possible. The mode field mismatch may be (partially) addressed by on-chip spot size converters, specialty fibers, or SSC interposers like those offered by PHIX. This section will help you find the most fitting solution for your application.

2.1   The need for mode field matching

Photonic integrated circuits (PICs) often need to be coupled to optical fibers to become part of a functional optoelectronic module. A major factor contributing to the coupling losses between an optical fiber and the waveguide of a PIC is the mismatching of their mode fields. With a typical fiber mode field of 10 x 10 µm and a PIC waveguide mode field of 3 x 3 µm, the optical losses due to this mismatch can easily amount to 5dB, considering the outcome of an MFD overlap calculation alone. Spot size converting solutions aim to match these mode fields at the interface, minimizing the loss of light.

2.2   On-chip solutions

The first possible approach to reduce mode field mismatch at the fiber to PIC interface is to include a spot size converting waveguide section on the PIC as a functional building block. If your PIC platform and foundry support this, then this usually is the most cost-effective, scalable, and best performing solution. This approach is recommended even if it cannot fully enlarge the PIC mode field to the size of the fiber mode field, because having a larger mode field at the waveguide facet can drastically increase alignment tolerances for further assembly. If silicon photonics (SiPh) suspended edge couplers are used to enlarge the MFD, we recommend you read our PIC Design Guidelines to understand how this may affect the packaging later on.

2.3   Conventional fiber solutions

Once the possibilities for mode field conversion on the PIC itself have been exhausted, further options are available on the fiber side. A traditional solution for mode field matching is the use of ultra-high numerical aperture (UHNA) fibers. This is feasible for single fibers or fiber arrays of up to roughly 8 channels, but coupling performance will decrease when such solutions are applied to higher fiber counts. The potential for high losses due to alignment difficulties caused by variations in core true positioning and V-groove tolerance is amplified by the small mode fields.

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2.4   PHIX Spot Size Converters

To address these challenges, PHIX offers spot size converter (SSC) chips that are placed between fiber array and PIC. They can couple light from fiber arrays to PICs of any platform with minimal losses. PHIX offers these SSCs as optional attachments to our fiber arrays, or as building blocks for our photonics packaging service.
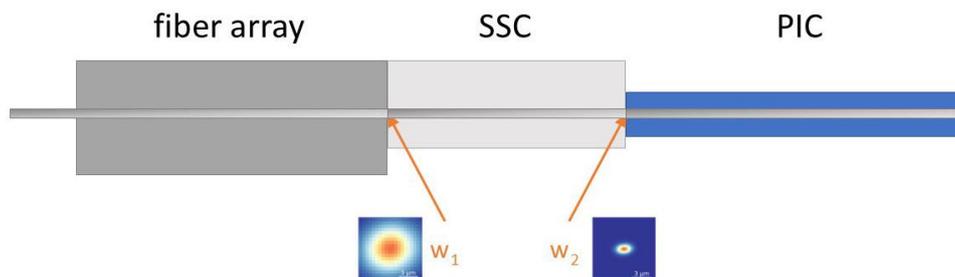

Figure 2:   Side view of the light's mode changing from the big mode within the fiber (w1) to the small mode in the PIC (w2).

The PHIX SSCs are silicon nitride (SiN) photonic chips with lithographically defined waveguides. SiN enables a relatively short taper length and therefore provides mode field conversion in a compact and high-performance product. For each channel the waveguide is tapered to reduce the mode field diameter of the light on the PIC side. The waveguides within the PHIX SSCs are positioned with lithographic accuracy, so higher channel counts do not increase alignment issues such as in an array of UHNA fibers. The PHIX SSCs offer circular or elliptical mode fields down to 1.5 µm in diameter for the C-band or O-band.

The PHIX SSCs come in a variety of standard models. These vary in channel count, mode field dimensions, waveguide pitch, waveguide angle, and wavelength application. The standard models are designed to cater to most PIC platforms and customer use cases in domains such as datacom, telecom, and sensing.

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2.5 Spot size conversion decision tree

To help you decide which spot size converting solution would work best for your situation, you can follow the flow of the decision tree below. It is intended as a guideline for prototyping applications. If you have high volume requirements, please contact PHIX for guidance.
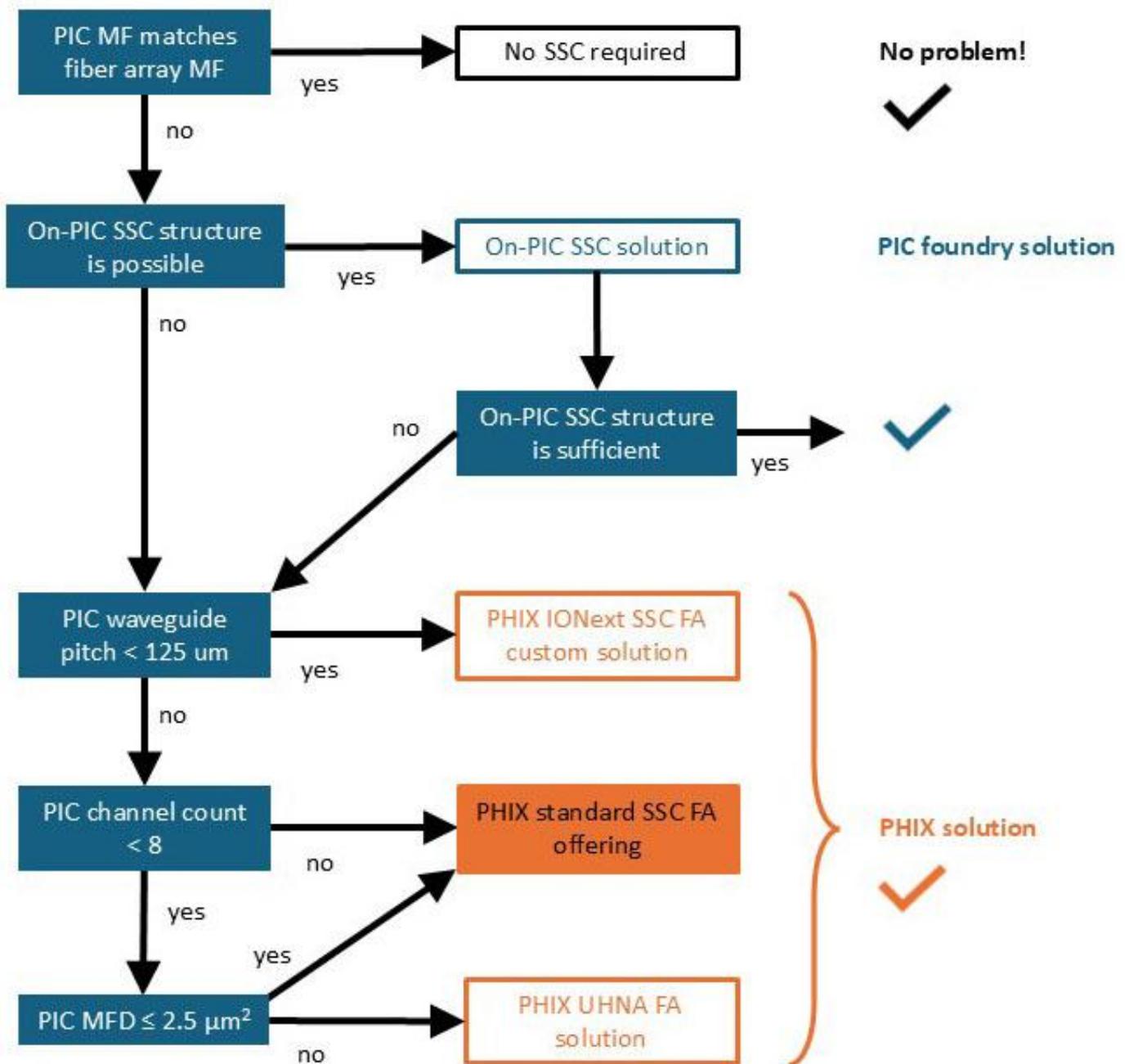

Figure 3:   Spot size converter solution decision tree

For channel counts below 8, the choice between UHNA fibers and a PHIX SSC isn't always obvious and may depend on several factors. Choosing a PHIX SSC may still be a viable option.

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2.6 PHIX SSCs supply chain and volume manufacturing capabilities

PHIX SSCs are an excellent mode field matching solution for devices manufactured in high volumes. These chips are produced at wafer scale, which means that the cost per unit can become very low at high production volumes. PHIX has partnerships with several SiN foundries, which provide us with a potential output capacity up to millions of units per month, catering to high-volume datacom applications. Our supply chain for SSCs is entirely European and North American.

We have automated processes for attaching the SSCs to fiber arrays and PICs with active alignment and a level of reproducibility that is unmatched by UHNA fiber solutions.

3 PHIX SSC Fiber Array standard offering

Table 1 below shows the PHIX SSC standard offering. These models come attached to a single mode or polarization maintaining fiber array, or as part of our photonics packaging service. They tailor to a variety of PIC platforms, channel counts, waveguide pitches, and waveguide angles, in the C-band or O-band, and are optimized for transverse electric (TE) polarization.

In the rest of this section, each parameter is explained in detail. Please read this carefully to avoid misunderstandings.

Section 4 covers custom options to consider when the standard offering does not fit your application.

3.1 Standard models

Item number	Wavelength	Channel count (N)	Mode field size (µm)	Facet pitch (µm)	Waveguide angle
D15	C-band	16	2.9 x 2.9	250	0°
D16	C-band	16	1.5 x 1.5	127	0°
D17	C-band	32	1.5 x 1.5	127	0°
D18	C-band	16	2.9 x 2.9	127	0°
D19	C-band	32	2.9 x 2.9	127	0°
D20	C-band	16	2.6 x 2.6	127	0°
D21	C-band	32	2.6 x 2.6	127	0°
D22	C-band	16	3.3 x 1.0	125	14.49°
D23	C-band	16	3.3 x 1.0	250	14.49°
D24	C-band	32	3.3 x 1.0	127	14.49°
D25	O-band	16	3.4 x 0.9	250	14.49°
D26	C-band	48	1.5 x 1.5 or 3.0 x 3.0	127	0°
D27	C-band	64	1.5 x 1.5 or 3.0 x 3.0	127	0°
D28	O-band	16	3.0 x 3.0	250	0°
D29	O-band	16	3.0 x 3.0	127	0°
D30	O-band	32	3.0 x 3.0	127	0°
D31	O-band	64	3.0 x 3.0	127	0°

Table 1: PHIX SSC standard models

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3.2   Supported wavelengths

The standard PHIX SSCs tailor to the C-band and O-band (1550 nm and 1310 nm, respectively), because they are adapted to the appropriate single mode (SM) and polarization maintaining (PM) fibers for those wavelengths. Silicon nitride is suitable for a much broader wavelength range, but this is not supported by our standard offering at the moment.

3.3   Channel count

The channel count parameter refers to the numbers of channels (N) of the SSCs on the PIC side. If you require PHIX to assemble the spot size converting fiber array to the PIC, four of these channels need to be reserved for waveguide loops on the PIC to enable active alignment. This would leave N-4 channels for the PIC's functionality.

Because PHIX also uses four alignment loops to attach the SSC to the fiber array, the total fiber count on the connector side is N+4. For example, for a SSC design with N=16 the fiber array will have 20 channels, while N=32 will result in a 36-channel fiber array*.

These channel counts are illustrated in figure 4 below. Please refer to our [PIC Design Guidelines](#) for additional information on active alignment at PHIX.
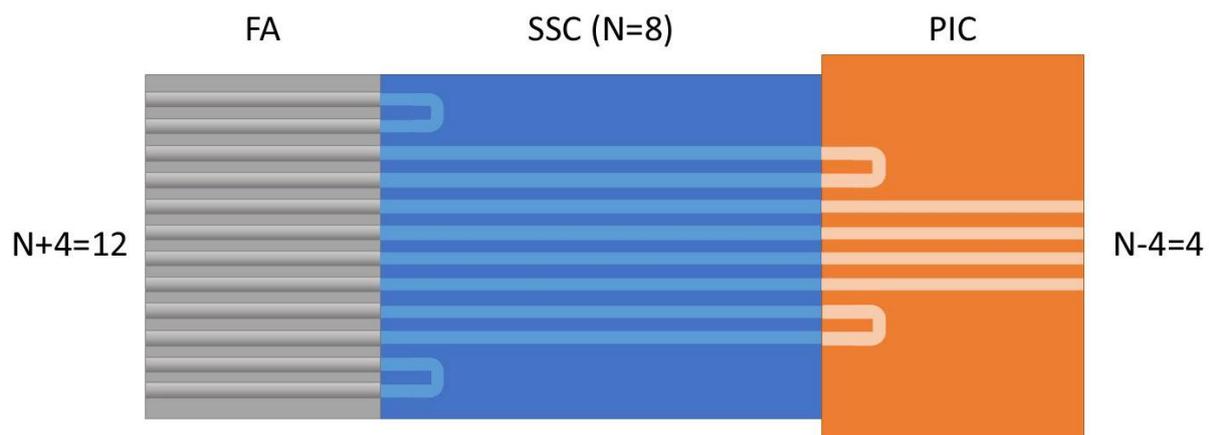

Figure 4:   Channel counts and alignment loops

in volume manufacturing, PHIX can use automated equipment that can do without these 4 extra fibers, which will result in a cost reduction of the spot size converting fiber array.

3.4   Mode field sizes

The standard PHIX SSCs offer a variety of mode fields sizes, both circular and elliptical, to match your PIC waveguide modes as closely as possible. Models D26 and D27 have two circular mode fields sizes to choose from, depending on how PHIX polishes the facets.

3.5   Facet pitch

The facet pitch is the pitch between the waveguides as measured straight along the facet that interfaces to the PIC. This definition is illustrated in figure 5. 127 µm and 250 µm are the common pitches used for straight waveguides. Note that for angled waveguides designed to

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couple with indium phosphide (InP) PICs, this distance may slightly deviate from those standard values, in order to compensate for the angled waveguides on the PIC itself.
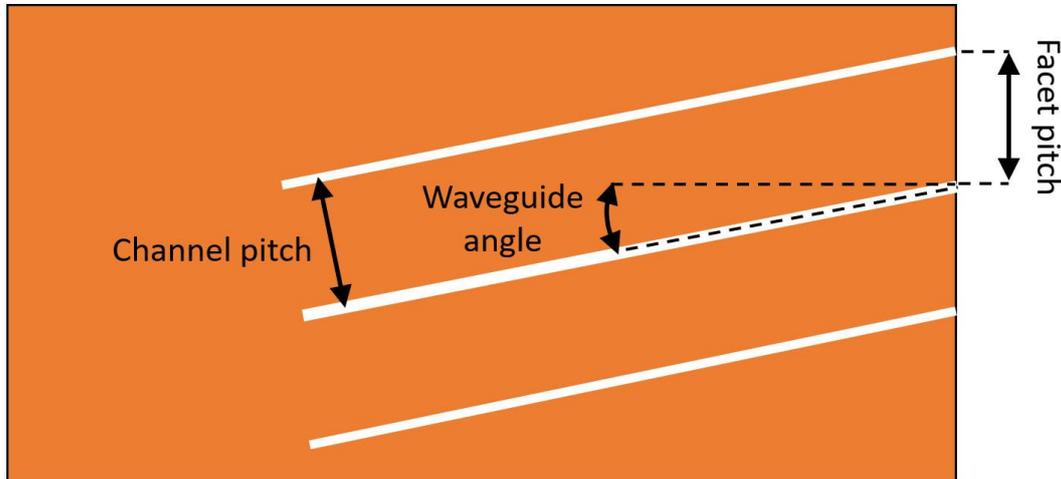
Figure 5:   The definitions of facet pitch and waveguide angle

3.6 Waveguide angle

The definition of the waveguide angle is also shown in figure 5. The SSC models where this angle is not 0° but 14.49° are intended for coupling with indium phosphide (InP) PICs that have 7° waveguide angles. They are compatible with the Smart Photonics multi-project wafer (MPW) platform and any other matching InP foundry platforms.

3.7 Top-down facet angles

The top-down angle of the SSC facets is flat (0°) by default. This is achieved through etching, stealth dicing, or polishing, depending on the SSC model. If desired, and appropriate for your PIC platform, PHIX can also offer a top-down polishing angle of 8° as a customization. This can eliminate back reflections at the SSC to PIC interface. Please refer to appendix A to see which SSC models support this.

3.8 Shape and length

The SiN SSCs are between 2.8 and 4.9 mm in length and between 3.5 and 9.5 mm in width. Please refer to Appendix A to see the dimensions of all standard SSC models (SSC only).

3.9 Markings on the SSC

The PHIX SSCs have alignment markers on them that are compatible with automatic assembly equipment. In addition, each SSC is marked with its item number (see table 1) and a unique ID to trace its position on the wafer.

3.10 Propagation loss

The light loss as it propagates through the SSC chip is a function of material and length. The silicon nitride platform used for the PHIX SSC has a propagation loss of 0.1 dB/cm. The lengths of the SSC standard models can be found in appendix A.

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3.11 Coupling loss

Coupling loss can occur at two interfaces, that between the fiber array and the SSC, and that between the SSC and the PIC.

The coupling loss between the fiber array and the SSC is measured by PHIX during assembly and reported at delivery of the spot size converting fiber array. The typical losses measured at this interface (per loop and including the connector) range between 1.0 and 3.0 dB. Typical values can be expected to be as follows:

- Models D15 to D25: ≤ 2.0dB per loop
- Models D26 and D27: ≤ 3.0dB per loop
- Model D28 – D31 ≤ 2.5dB per loop

These are expected to be worst-case scenarios for post-bond values. As each loop crosses the interface twice, the expected loss per channel can be estimated by dividing the above values by two.

At the interface between the SSC and the PIC, the coupling loss also depends on the mode field distribution and facet quality of the PIC. It therefore cannot always be precisely estimated or measured by PHIX.

4 Custom SSC solutions

Outside of the standard offering PHIX has two SSC solutions that can tailor to custom channel counts, waveguide pitches, waveguide angles, or wavelengths.

4.1 Ion exchanged glass (IONext) SSCs

Our IONext SSCs are optical interposers with same lithographic waveguide positioning accuracy as our standard SiN SSCs, but they are made of ion exchanged glass. They become an attractive option if you require a channel count, pitch, or angle that is not offered by our standard SSCs.
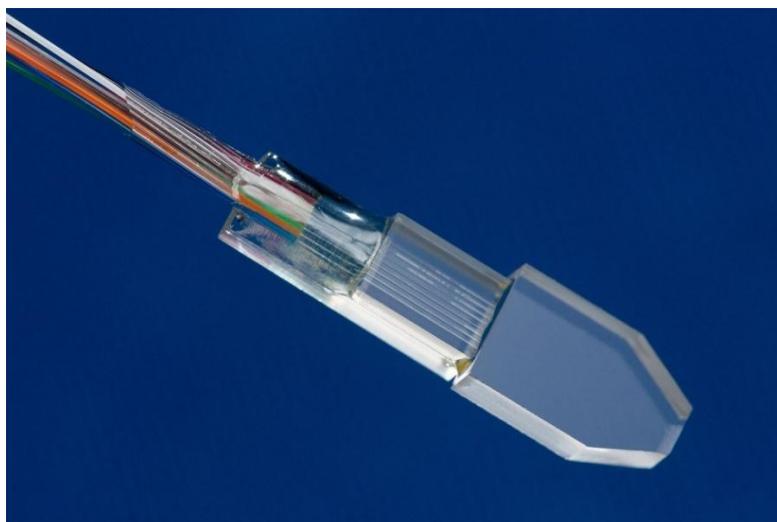

Figure 6:   Fiber array with IONext SSC

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Pros

- Customizations do not significantly increase cost or lead time.
- Large channel counts are possible.
- Waveguide pitches down to 20 μm are supported.
- Suitable for the C-band and the O-band.

Cons

- Smallest possible mode fields are 4.2 x 3.2 μm² (C-band).
- Greater in size than SiN SSCs due to longer taper length and alignment loop radius.
- Other wavelengths are not yet supported

4.2   Custom SiN SSC wafer run

We can leverage the flexibility of the SiN platform to manufacture SSCs that tailor to your exact needs.

Figure 7:   Wafer of PHIX SSCs

Pros

- Support for large range of wavelengths, down to visible light.
- Flexible mode fields, circular or elliptical.
- Scalable to high volumes, with highly repeatable automated assembly and significant cost reduction per unit.

Cons

- Not economical at low volumes, due to the setup costs of a dedicated wafer run.

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Appendix A – Standard model dimensions (SSC only)

Table 2 shows the dimensions of the PHIX SSCs. This does not include the dimensions of the fiber array. Also indicated is the availability of an 8° top-down polishing customization.

Item number	Length (mm)	Width (mm)	Thickness (mm)	8° top-down polishing
D15	3.0	5.8	1.0	yes, custom
D16	3.0	3.7	1.0	yes, custom
D17	3.0	5.8	1.0	yes, custom
D18	3.0	3.7	1.0	yes, custom
D19	3.0	5.8	1.0	yes, custom
D20	3.0	3.7	1.0	yes, custom
D21	3.0	5.8	1.0	yes, custom
D22	4.0	3.7	1.0	not available
D23	4.0	5.8	1.0	not available
D24	4.0	5.8	1.0	not available
D25	4.0	5.8	1.0	not available
D26	4.9	7.8	1.5	yes, custom
D27	4.9	9.5	1.5	yes, custom
D28	2.8	5.4	0.75	yes, custom*
D29	2.8	3.5	0.75	yes, custom*
D30	2.8	5.4	0.75	yes, custom*
D31	2.8	9.2	0.75	yes, custom*

Table 2:   Standard SSC model dimensions and custom polishing options

The polishing will affect the mode field sizes and may therefore increase coupling losses on both sides of the SSC. Please contact PHIX for more information.