



Advanced Photonics Packaging and System Integration Services within EUROPRACTICE

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Version: 1.5 (May 2019)



EUROPRACTICE

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1 SUMMARY

1.1 Objective

The Photonics Packaging Group at the *Tyndall National Institute* in Ireland is a *EUROPRACTICE* partner, and offers packaging and integration services for the Silicon Photonic Integrated Circuits (Si-PICs) fabricated in the MPW runs. We are conscious of the fact that a *EUROPRACTICE* MPW run is often the first instance in which a researcher or SME ventures into the field of fabricating real integrated photonic devices. This document has been developed as a guide and tutorial to help design Si-PICs that are compatible with standard packaging technologies offered by *Tyndall*, to develop Si-PICs into viable photonic devices.

1.2 Goals

The three goals of this document are - (i) to educate new users to the basic principles and terminology of photonics packaging, (ii) to help users design Si-PICs that are compatible with the packaging technologies available at *Tyndall*, and (iii) to list the different packaging options that *Tyndall* can offer to *EUROPRACTICE* users. In order to understand the reasons behind the restrictions and conventions in standard photonics packaging, it is necessary to have a basic familiarity with fibre-coupling, electrical wire-bonding, and thermo-electric cooling, so we provide a short tutorial on these topics in Section 2. This tutorial also describes the *Tyndall*- PCB, which has been designed by the *Photonics Packaging Group* to enable users to realise a low-cost fully- packaged module (optical, electrical, and thermal) for their Si-PICs. The six Si-PIC generic packaging options available to *EUROPRACTICE* MPW users are given in Section 3. These options can be tailored to the user's Si- PIC, by specifying the fibre-type, fibre-array pitch, and number of fibre-array channels.

1.3 Glossary

The following are a list of abbreviations frequently used in this document:

<i>AOI</i>	Angle of Incidence (defined with respect to the surface-normal of the Si-PIC)
<i>MPW</i>	Multi-Project Wafer
<i>PCB</i>	Printed Circuit Board
<i>PIC</i>	Photonic Integrated Circuit
<i>PLC</i>	Planar Lightwave Circuit
<i>PMF</i>	Polarisation Maintaining Fibre (assumed to also be single-mode)
<i>SOI</i>	Silicon on Insulator
<i>SMF</i>	Single Mode Fibre
	TEC Thermoelectric cooler
<i>TOX</i>	Top Oxide
<i>QPC</i>	Quasi-Planar-Coupling

2 TUTORIAL

This section provides a basic overview of the principles of fibre-optics, grating-couplers, a fibre-array with optical-shunt, wire-bonding, and thermo-electric control. It concludes by describing the Tyndall-PCB, which has been developed to allow new users to develop a fully-packed photonic-module that offers easy optical and electrical access to their Si-PIC, without the need of a custom-designed housing.

2.1 Fibre Optics

Tyndall offers fibre-packaging of the Si-PIC to either single-mode fibres (SMFs) or polarisation-maintaining fibres (PMFs). The SMFs consist of a 8.4 μm -diameter inner-core of high-index glass surrounded by a 127 μm - or 250 μm -diameter outer-core. The PMFs have the same inner- and outer-core cross-sections as SMFs, with the addition of stressor rods integrated into the outer-core, to break the circular symmetry of the SMFs, and so support mode propagation of only one polarisation - see *Figure 1*.

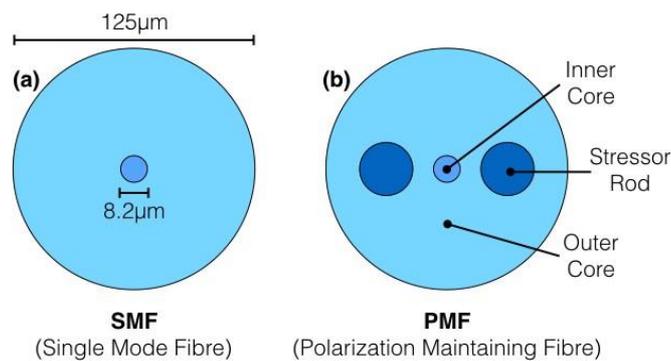


Figure 1 - Cross-sections of (a) single-mode fibre (SMF) and (b) polarization-maintaining fibre (PMF)

For both PMFs and SMFs, the mode-field diameter (MFD) of the light exiting the fibre is 10.4 μm at 1550nm (and 9.2 μm at 1310nm). Since the PMFs are more expensive than the SMFs, they are generally only used when a photonic design specifically calls for them. Users with Si-PIC designs incorporating two-dimensional grating-couplers (2D-GCs) should be especially careful in choosing the correct fibre-type, as their designs may be fundamentally incompatible with PMFs. By default, Tyndall uses FC/APC terminations for its single-fibres and fibre-arrays.

2.2 Fibre-to-Grating Coupling

In general, Fibre-to-PIC coupling can be achieved in two ways - (i) edge-coupling, and (ii) grating-coupling. At present, Tyndall only provides fibre-to-grating packaging services to EURO PRACTICE, but aims to offer single-fibre edge-coupling in the future. There are two fibre-geometries for grating-coupling - (i) vertical/butt-coupling, and (ii) quasi-planar-coupling (QPC) - see *Figure 2*. Since it offers a lower profile, better mechanical stability, and has a smaller footprint on the PIC, Tyndall has standardised to QPC for EURO PRACTICE packaging.

For QPC, the fibre must be polished with an angle that launches the totally-internally reflected light onto the grating-coupler(s) of the Si-PIC with the correct angle-of-incidence (AOI). A deviation from the designed AOI of the grating-coupler causes a shift in the coupling spectrum away from target-wavelength (usually 1550nm). The shift is typically of the order of 10nm per 1deg, and is therefore significant, given the typical 30nm 1dB

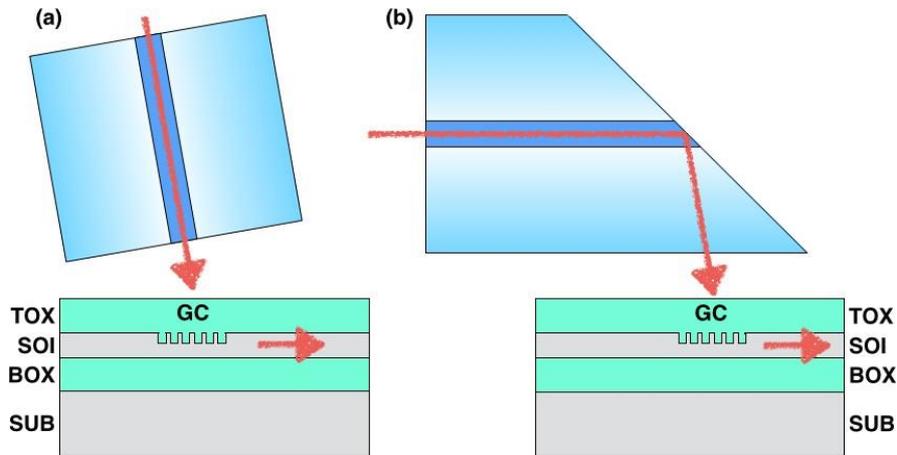


Figure 2 - Schematic of fibre-to-grating coupling using (a) vertical/butt-coupling, and (b) quasi-planar-coupling (QPC).

bandwidth of the grating-coupler. In wafer-scale testing, light is usually coupled from the fibre to the grating without in air, i.e. without adding any index-matching layer between the fibre and the Si-PIC. For packaging, a UV-cured index-matching epoxy is used to bond the fibre to the PIC, and this has the effect of removing refraction at the Air-TOX interface, see Figure 3.

For the QPC geometry used at Tyndall, adding the epoxy does not affect the AOI on the grating-coupler, because there are two compensating refraction at the Fibre-Air and Air-TOX interfaces. However, many users probe their Si-PICs in the vertical/butt-coupling geometry, and in this geometry the addition of epoxy can result in a significant change in the AOI, and so the target-wavelength. Users should carefully consider the effect of the bonding epoxy on the performance of their grating-couplers, before submitting designs for packaging.

The standard transverse-electric (TE) grating-couplers from IMEC and CEA-Leti are designed for packaged- AOIs of 6.5deg and 8deg, respectively (corresponding to 10deg and 12deg in Air). Tyndall has standardised on a packaged-AOI of 7deg as a compromise solution. Users are welcome to submit custom grating-coupler designs for packaging, but they must have operate with a packaged-AOI = 7deg.

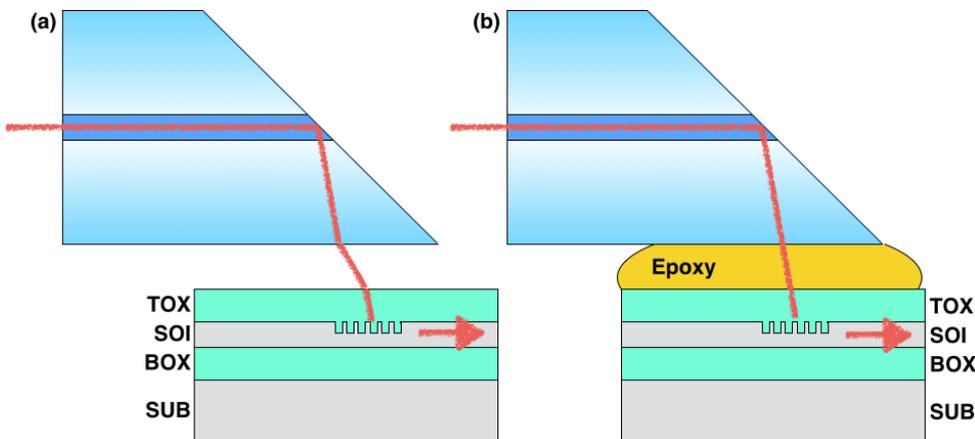


Figure 3 For QPC, adding index-matching epoxy does not change the AOI of light incident on the grating-coupler.

2.3 Single Fibres & Fibre Arrays

Tyndall offers QPC of both single-fibres and fibre-arrays. In both cases, the fibres will be bonded to the surface of the Si-PIC using a UV-cured index-matching epoxy. Users must ensure that there is (i) sufficient area between the edge of the PIC-die and the location of the grating-coupler(s) to allow for mechanical bonding between the fibre(s) and PIC, and (ii) no phase-sensitive components close to the grating-couplers that would be negatively impacted by the inevitable flow of epoxy from onto the PIC surface. A trade-off must be made between the mechanical quality of the fibre-packaging, and the amount of “real-estate” used for the bonding.

For single-fibre QPC, *Tyndall* requires that the grating-coupler be placed no closer than $750\mu\text{m}$ from the edge of the PIC-die, and recommends that users leave an “exclusion zone” of $500\mu\text{m}$ around the grating-coupler to allow for epoxy flow - see *Figure 4*. Please note that for single-fibre QPC, *Tyndall* uses a “straight through” active-alignment scheme, and so requires two single-fibres on opposite sides of the PIC with a light path between them.

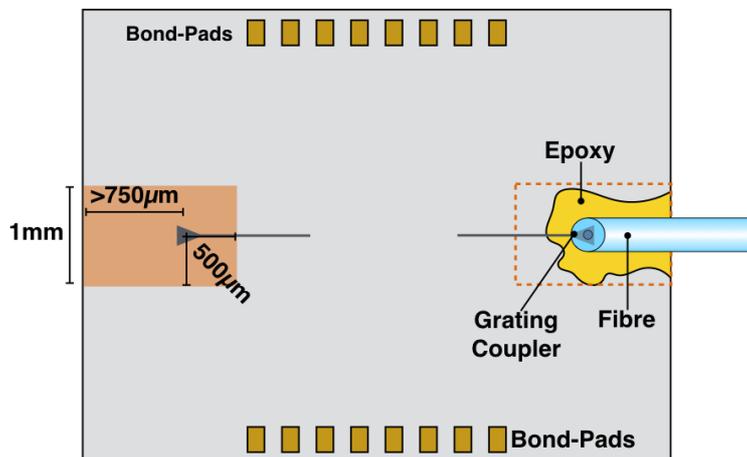


Figure 4 - Schematic showing the exclusion zone around the fibre and grating-coupler needed for mechanical bonding of the fibre to the PIC. No phase-sensitive components should be located in this zone.

In fibre-array QPC, multiple fibre-channels are aligned to multiple grating-couplers on the PIC at the same time. *Tyndall* uses active alignment through an “optical-shunt” to align the first and last channels of the fibre-array with the first and last channels in the grating-array. Given the high concentricity of the inner-cores of the fibres in the array ($<500\text{nm}$), this approach ensures that all intermediate fibre-channels are aligned to their corresponding grating-couplers. There is no need to have a light-path across the PIC, so it is possible to have a single array on one side of the PIC.

To facilitate shunt alignment and good mechanical bonding between the fibre-array and PIC, *Tyndall* requires that the grating-coupler array be located no closer than $750\mu\text{m}$ from the edge of the PIC, and that the array runs parallel to edge of the PIC. We recommend users to leave a $500\mu\text{m}$ exclusion zone around the 5mm footprint of the fibre-array, to allow for epoxy flow - see *Figure 5(a)*. The pitch of the grating-coupler array on the PIC must be exactly $250\mu\text{m}$ or $127\mu\text{m}$, to match the QPC arrays offered by *Tyndall* - see *Figure 5(b)*. Since the first and last channel of the fibre-array and grating-array are used for the optical-shunt, users requiring N - channels for the operation of their PIC must choose a fibre-array with at least $N+2$ channels.

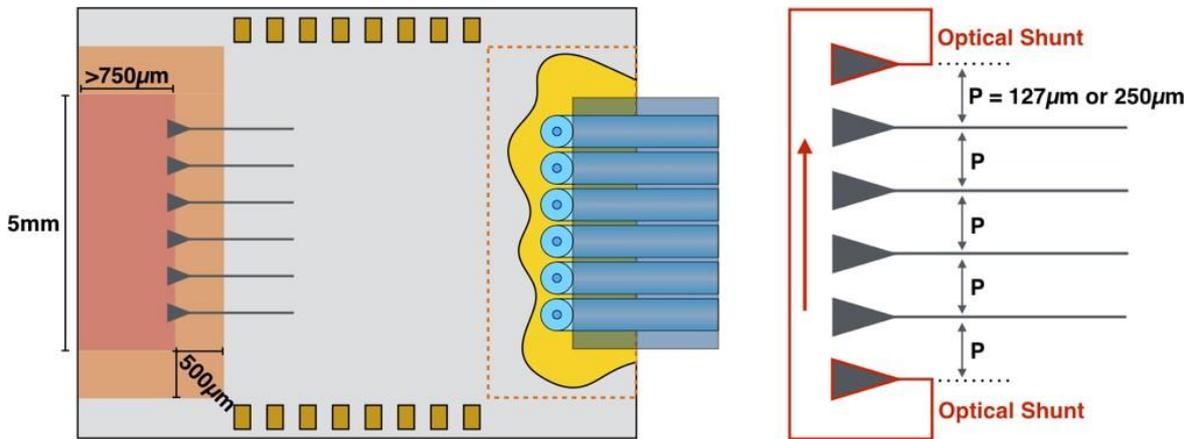


Figure 5 - (a) Schematic showing the exclusion zone around the fibre-array and grating-array needed for mechanical bonding of the fibre to the PIC. No phase-sensitive components should be located in this zone. **(b)** Schematic of the optical-shunt needed to align the fibre-array onto the Si-PIC. The first and last channel of the fibre-array and grating-array are reserved for the optical-shunt, and are not available for users to access the Si-PIC

Single-fibre QPC can only be made across opposite sides of the Si-PIC. Tyndall cannot provide coupling single-fibre QPC between orthogonally orientated fibres. Similarly, if two fibre-arrays are needed to package a PIC, they must be arranged on opposite sides of the PIC. For *EUROPRACTICE* packaging, fibre-coupling cannot be made from an PIC-edge that also needs wire-bonding (see Section 2.4). If wire-bonds are needed, they must be made along an edge of the chip that runs parallel to the fibres.

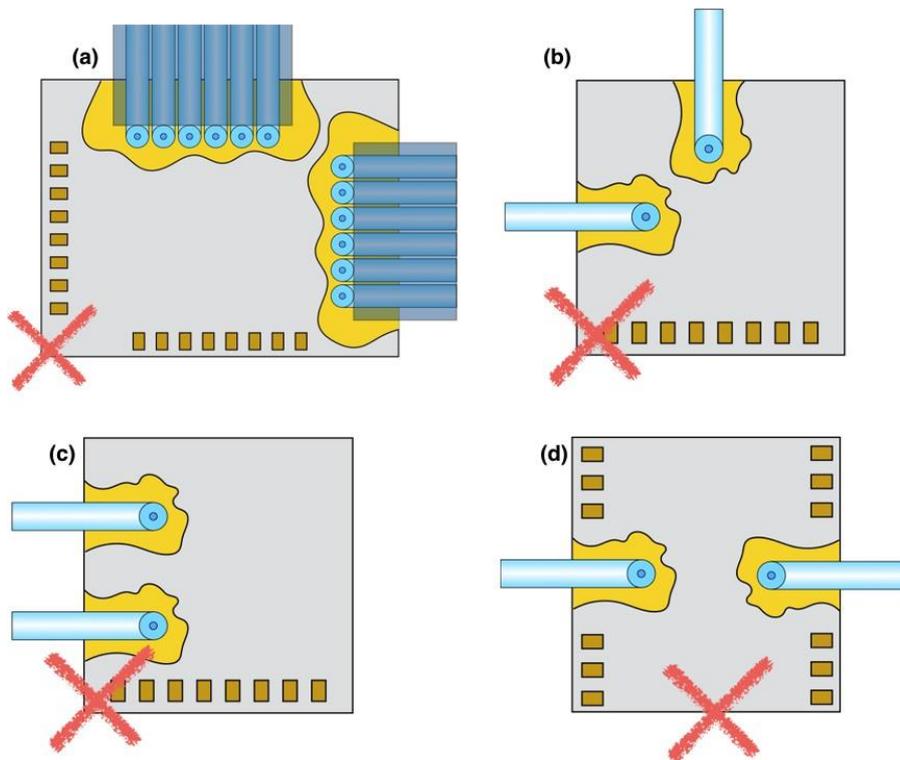


Figure 6 - Schematic showing four PIC designs that are not compatible with the *EUROPRACTICE* packaging offered by Tyndall. Orthogonally orientated single-fibre or fibre-array QPCs are not permitted, and fibre-coupling cannot be made from an PIC-edge that also needs wire-bonding. We do not offer multiple single-fibre coupling to the same side of the PIC.

2.4 Electrical Connections

To help users access integrated electrical components on their Si-PIC, *Tyndall* provides wire-bonding as part of the *EUROPRACTICE* packaging. Bond-pads on the Si-PIC must have a minimum pitch of $150\mu\text{m}$, and may not be staggered - see *Figure 7*. Bond-pads may not be located along the a PIC-edge on which single-fibre or fibre-array QPC is also to - see *Figure 7(c)* as an example. *Tyndall* can make wire-bond connections to all standard bond-pads offered by *IMEC* or *CEA-Leti*. If users opt for custom bond-pads, they must have a minimum footprint of $50\mu\text{m} \times 70\mu\text{m}$. All bond-pads for wire-bonding must have a Au-capping layer that is at least 100nm thick. *Tyndall* uses circular-section $18\mu\text{m}$ -diameter Au-wire for DC wire-bonds, and $50\mu\text{m} \times 12\mu\text{m}$ tape-section Au-wire or RF wire-bonds. Si-PICs operating with RF signals (in the $10\text{-}25\text{GHz}$ range) generally require sophisticated simulation and design of both the Si-PIC and custom-PCB, in order to avoid significant transmission-line losses. *Tyndall* cannot provide technical assistance with RF design to *EUROPRACTICE* users.

For new users, the Tyndall-PCB (see Section 2.6) can offer a convenient and low-cost means of creating a connection between the wire-bonds from their PIC to the instruments in their lab. Of course, users are welcome to provide their own custom PCBs or ceramic-mounts for packaging (subject to review and prior acceptance by *Tyndall*).

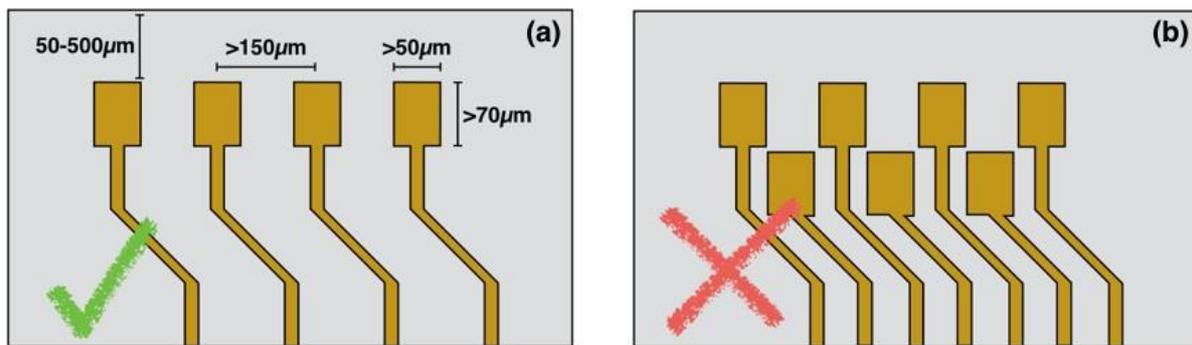


Figure 7 - (a) Bond-pads must have a minimum pitch of $150\mu\text{m}$, and be located between $50\mu\text{m}$ and $500\mu\text{m}$ from the edge of the PIC. If users opt for a custom bond-pad design, then the pad must have a minimum footprint of $50\mu\text{m} \times 70\mu\text{m}$.
(b) Staggering of bond-pads is not acceptable for *EUROPRACTICE* packaging.

2.5 Thermal Management

Si-PICs are much more temperature sensitive than electric-ICs. A temperature increase of 10deg can result in a micro-ring resonator shift of 1nm , or a 2dB gain drop in a semiconductor optical amplifier (SOA). For most photonic applications, active cooling of the Si-PIC is required to ensure stable operation. This is usually achieved using a thermoelectric cooler (TEC). In the most common configuration, the PIC is thermally-coupled to the cold-side of the TEC using a heat-spreader, and the hot-side of the TEC is coupled to a heat-sink for enhanced air-cooling. A thermistor or thermocouple close to the Si-PIC provides a signal to a proportional- integral-differential (PID) TEC-controller, which adjust the power to the TEC in order to reach and stabilise at the desired temperature set-point. For many Si-PICs, the TEC-controlled temperature can be stabilised to $\pm 0.01\text{deg}$ after a few minutes of cooling.

2.6 Tyndall-PCB and Module

Tyndall has developed a generic “Tyndall-PCB” that allows *EUROPRACTICE* users to access a low-cost fully packaged module with optical & electrical coupling and thermal management. The Tyndall-PCB module allows for both single-fibre and fibre-array QPC fibre-coupling, offers 10 DC wire-bonds on either side of the PIC, and has an integrated thermistor and TEC - see both *Figure 8* and the fully-packaged described in Section 3.

The pitch of the bond-pads on the Tyndall-PCB are 300µm, and can be matched to 150-300µm pitch bond-pads on the PIC, provided the PIC-side bond-pads are centred on the PIC. A 10kOhm thermistor is integrated into the PCB, and a 3W TEC is thermally-bonded to the bottom-surface of the PCB and the aluminium base-plate. With an external TEC-controller, users can stabilise the temperature of their Si-PIC (please note that this controller is not included in the fully-packaged modules). The Tyndall-PCB is designed to accept single-block and mini-blocks from the MPW runs at *IMEC* and *CEA-Leti*.

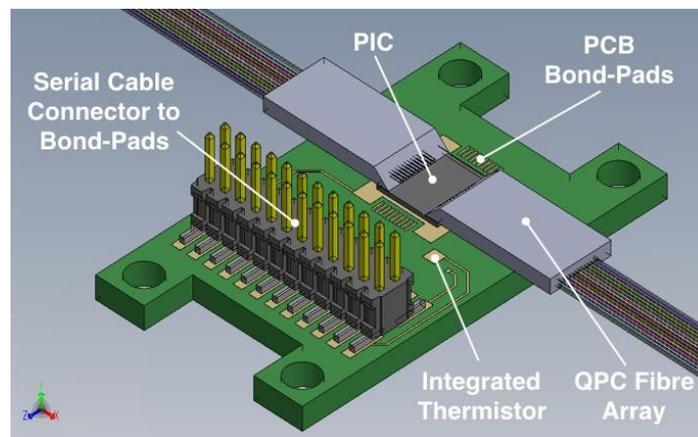


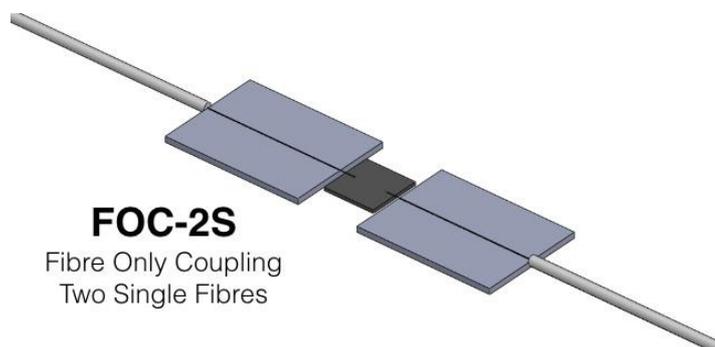
Figure 8 - Schematic of the Tyndall-PCB showing how optical and electrical coupling is made to the Si-PIC, and where the integrated thermistor is located. The PCB can be integrated into a low-cost fully-packaged module (see Section 3.2) with a TEC and a mechanical base-plate.

3 PACKAGING OPTIONS

This section describes the six different packaging-options available to *EUROPRACTICE* users, and how they can be customised to best match the Si-PIC being packaged, by specifying the fibre-type, fibre-array pitch, and fibre-array channels.

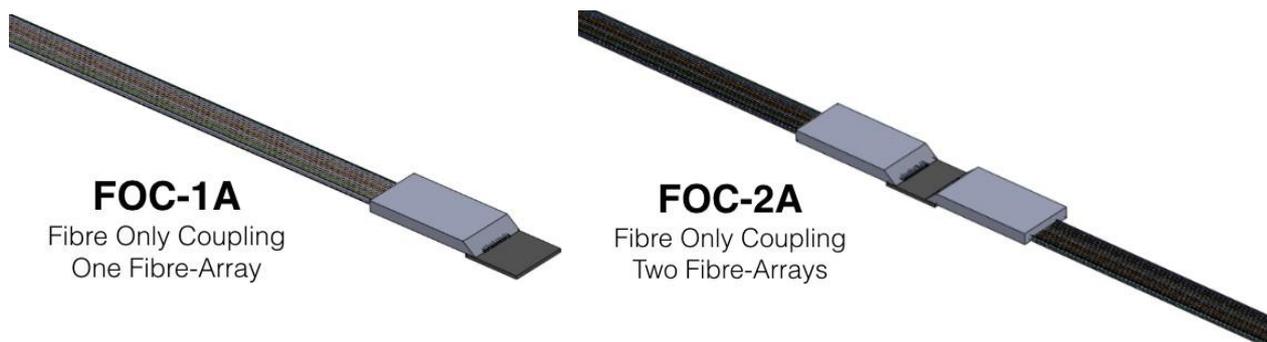
3.1 Fibre-Only Coupling

Fibre-only Coupling (FOC) packaging is suited to simple Si-PICs that do not have any integrated electrical components, such as those from the *IMEC* “passives-only” MPW run. Alternatively, FOC assemblies allow users to perform flexible electrical probe-tests on a stable optical platform. If users does not plan on actively cooling the FOC assemblies, we strongly recommend directly bonding them to a high-capacity heat-sink.



3.1.1 Two-Single-Fibres (FOC-2S)

The two-single-fibre FOC option is the simplest packaged assembly, and is available with either SM- or PM- fibres. For both SMF and PMF options, the fibres are terminated in FC-APC connectors. The single-fibres are simultaneously actively aligned to the grating-couplers on the Si-PIC, by maximising the fibre-to-fibre transmission between the two fibres. Consequently, a light-path with a loss of less than -20dB is needed across the PIC, or it will be impossible to package the PIC.



3.1.2 One-Fibre-Array (FOC-1A)

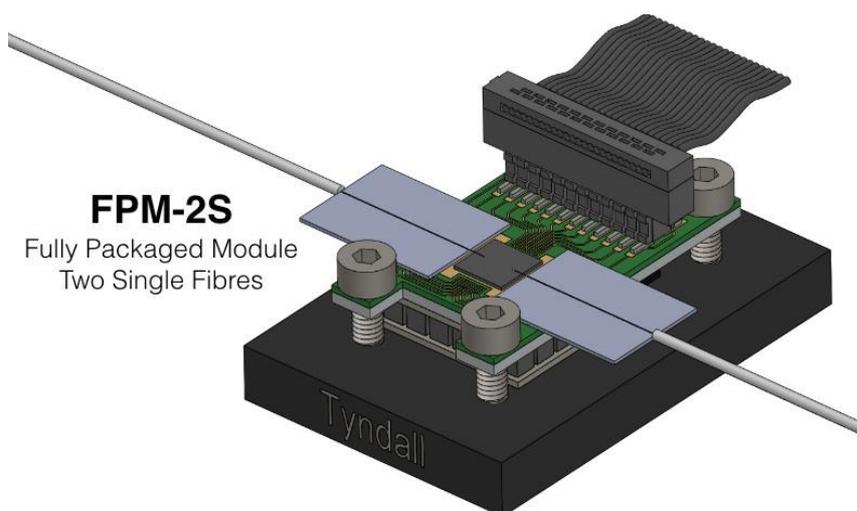
The one-fibre-array FOC option allows multiple user fibre-channels to be coupled to the Si-PIC. The fibre-array is aligned to the Si-PIC using an optical-shunt between the first and last couplers on the PIC-side grating- array. There are options for either 8 or 14 user-channels on the PIC (corresponding to 10 and 16 channel fibre- arrays with optical-shunt alignment). Users may also choose a 250µm or 127µm pitch on the grating-array, and SMF or PMF fibres (both terminated in FC/APC connectors).

3.1.3 Two-Fibre-Array (FOC-2A)

The two-fibre-array FOC option is essentially the symmetric application of 2x one-fibre-array FOCs. Both fibre- arrays are independently aligned using separate optical-shunts. In principle, a user may specify different fibre- types, user- channels, fibre-pitch for both arrays, but paired arrays are the most common configuration, and the pricing matrix here is for paired arrays. Again, SMF and PMF fibre-arrays are terminated in FC-APC connectors.

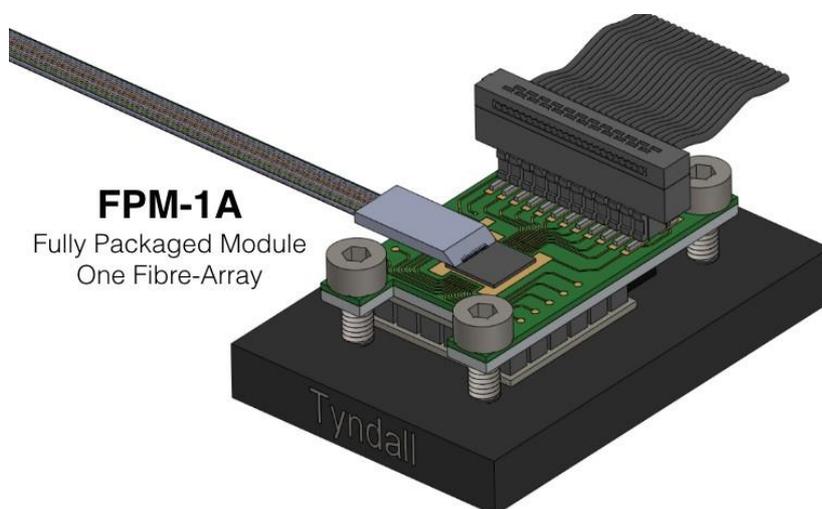
3.2 Fully Packaged Modules

Fully packaged modules (FPMs) offer fibre- and optical- connectivity, as well as thermal stability. They are based on the Tyndall-PCB module described in Section 2.6, and offer users a low-cost “off the shelf” solution to a fully packaged device for demonstrations and prototyping. FPMs allow for up to 20 DC connections to the Si-PIC and a range of single-fibre and fibre-array QPC options. The integrated thermistor and TEC ensures thermal stability of the PIC, when connected to an external PID controller (not supplied with the module).



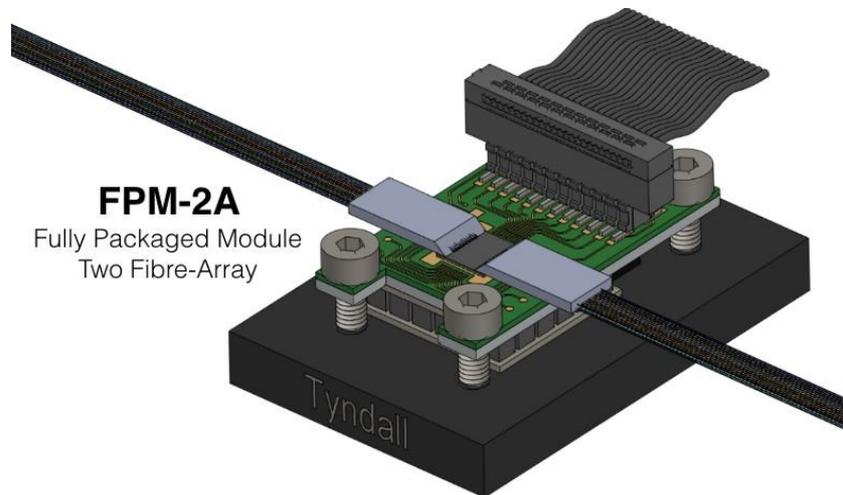
3.2.1 Two Single Fibres Option (FPM-2S)

The two single-fibre fully-packaged option is available with either SM- or PM-fibres. For both SMF and PMF options, the fibres are terminated in FC-APC connectors. Note that the single-fibres are simultaneously aligned with respect to the grating-couplers on the Si-PIC by maximising the fibre-to-fibre transmission between the two fibres. Up to 10 DC wire-bond connections can be made to the two opposite sides of the Si-PIC. A 10kOhm thermistor is integrated in the Tyndall-PCB and a 3W TEC transfers heat from the PIC into the aluminium-body of the module



322 One Fibre-Array Option (FPM-1A)

The one-fibre-array FPM option allows multiple user fibre-channels to be coupled to the Si-PIC, as well as two sets of 10 DC wire-bond connections, and thermal management. There are options for either 8 or 14 user-channels on the PIC (corresponding to 10 and 16 channel fibre-arrays with optical-shunt alignment). Users may also choose between a grating-array pitch of 250 μm or 127 μm , and SMF or PMF fibres. Both the SMF and PMF fibre-arrays are in FC/APC connectors. Thermal management is provided by the integrated thermistor in the Tyndall-PCB and the 3W TEC, which couples heat from the PIC into the mechanical body of the module, for heat-sinking to the ambient



323 Two Fibre-Arrays Option (FPM-2A)

The two-fibre-array FPM option allows for twice the optical connections of the FPM-1A option, as well as two sets of 10 DC wire-bond connections, and thermal management. Users can choose between a pair of fibre-arrays offering 2 x 8 or 2 x 14 user-channels on the PIC (corresponding to pairs of 10 and 16 channel fibre-arrays with optical-shunt alignment). Users may also choose between a grating-array pitch of 250 μm or 127 μm , and SMF or PMF fibres. Both the SMF and PMF fibre-arrays are in FC/APC connectors.

3.3.0 Non-Standard [Customised] Packaging

We recognise that novel applications and prototypes sometimes need custom solutions, as such EURO PRACTICE offers a wide range of custom solutions, ranging from simple custom wirebonds to complex multilayer optoelectronic sub-assembly. Further guidelines for non-standard photonics packaging and hybrid integration will be updated here soon. Get in touch with us so we can figure out the best solution for your technology and applications.

3.3.1 Other Packaging and System Integration Services

We are continuing to develop our capabilities and grow the service, so tune back soon for further updates to the services we offer.

4 CONTACT

This document is designed to anticipate the most frequently asked questions of MPW users wanting to access packaging and integration services. Both *Tyndall* and *EUROPRACTICE* welcome user feedback that can be used to improve future versions.

Questions regarding technical solutions, pricing, delivery and non-standard advanced packaging techniques should be addressed directly to *EUROPRACTICE* (ramsey.selim@tyndall.ie) who is part of the [Photonics Packaging Group at Tyndall](#), a *EUROPRACTICE* partner.

