PHOTONICS PACKAGING AND SYSTEM INTEGRATION SERVICES WITHIN EUROPRACTICE

PACKAGING DESIGN RULES and SERVICE

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Version updated by Photonics Packaging and Systems Integration Group, Tyndall National Institute, EUROPRACTICE Partner

Tyndall National Institute
Institiúid Náisiúnta

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. To develop Si-PICs into viable 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. We strongly encourage users who are interested in using our standard packages, to review this document and design rules.

1.2. Goals

The three goals of this document are

(i) to educate new users on 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.

(iii) to list the different packaging options that Tyndall can offer to Europractice users.

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. Therefore, we provide a short tutorial on these topics in ***Section 2***. This tutorial also describes the standard Tyndall-PCB modules, which have 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 two Si-PIC generic packaging options available to Europractice MPW users (or non-Europractice users wanting compatible packaging services) 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 the number of fibre-array channels. At the end, you can find an overview of Tyndall's new packaging service, Multi-Project Packaging Run (MPP-Run), which is designed to lower the cost barrier for packaging within the scope of Europractice.

1.3. Glossary

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

AOI : Angle of Incidence (defined with respect to the surface-normal of the Si-PIC)

APC: Angled Physical Contact

FC : Ferrule Connector

MPW : Multi-Project Wafer

PCB : Printed Circuit Board

PDR : Packaging Design Rules

PIC : Photonic Integrated Circuit

PLC : Planar Lightwave Circuit

PMF : Polarisation Maintaining Fibre (assumed to also be single-mode)

QPC : Quasi-Planar-Coupling

SMF : Single Mode Fibre

SOI : Silicon on Insulator

TEC : Thermoelectric cooler

TOX : Top Oxide

2. Tutorial

This section provides a basic overview of the principles of a general PIC layout, fibre optics, grating and edge couplers, a fibre array with optical-shunts, wire-bonding, and thermo-electric control. It concludes by describing the Tyndall-PCB modules, which have been developed to allow new users to develop fully packaged photonic modules that offer easy optical and electrical access to their Si-PIC, without the need for a custom-designed housing.

2.1. General PIC layout

To facilitate clear discussions with the user, we use a compass-coordinate system to unambiguously label each side of the PIC-die. We can provide packaging solutions to all Si-PIC dies under Europractice, both for those fabricated within a Europractice MPW service or not, as long as the provided PDRs are correctly followed. In all cases, we strongly recommend reviewing your PIC design with your chosen packaging partner before submission to a foundry, and for the Europractice Photonics Packaging Services, you can contact Tyndall for review.

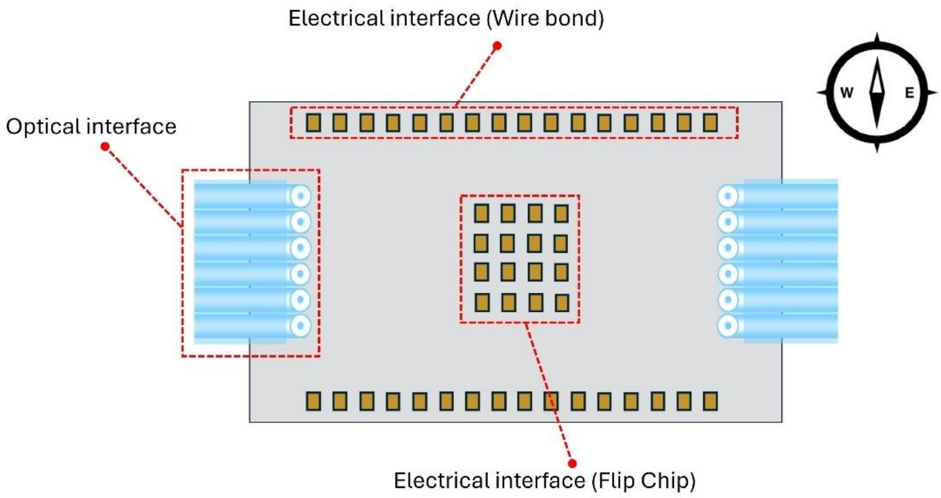

Figure 1. General PIC design and layout guidelines. Allows compatibility with Europractice standard photonic packaging and assembly processes.

To avail of the packaging and assembly processes at Tyndall, we recommend that users design the optical and electrical interface of their PIC according to the layout outlined in ***Figure 1***. This layout provides the user with the option of using generic packaging solutions that can be more cost-effective with reduced process development times. Optical interfaces are typically where an optical fibre is coupled to the PIC via an edge coupler or grating coupler. Electrical interfaces are where wire bonds or a BGA connect the PIC to an external carrier.

For optimised packaging, one side of the PIC should be designated for the optical interface (either the West or East side). If more than one optical interface is required, this should be at the opposite side of the PIC to facilitate parallel optical alignment using standard packaging equipment. More detailed design guidelines for the optical interface will be described in ***Section 2.2***, including the concept of the optical "shunt" or "loop-back" which is important for fast and efficient optical alignment.

Electronic connections between the PIC and the outside world are typically made by wire bonding to a PCB. To ensure reproducible and reliable wire bonding, the location and pitch of the bond pads on the PIC must be controlled. Specific design guidelines will be detailed below. In general, we recommend that optical and electronic assembly processes should not be made from the same side of the PIC-die. By default, bond pads are located along the North- and South-side edges of the PIC. If it is not being used for optical coupling, then bond pads can also be placed along the East-side edge of the PIC-die. The electrical bond pad arrays should be centred with respect to the PIC. Some of these optical and electrical design rules are summarized graphically in – see ***Figure 4***. In the following sections, more detailed specific design rules for electrical and optical packaging are given.

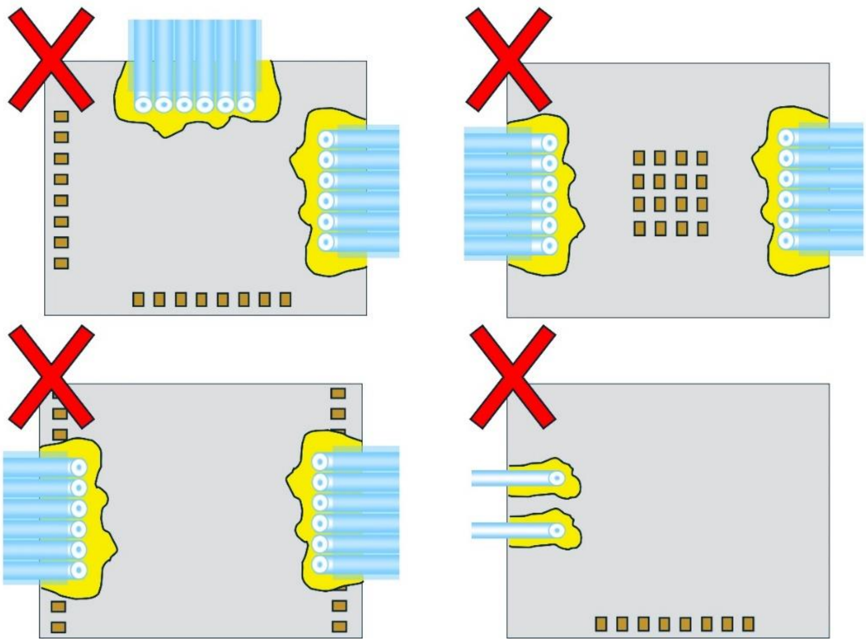

Figure 2. Examples of some best-practice rules that users should be aware of when designing a PIC. Adhering to these rules allows compatibility with standard packaging and assembly processes. Orthogonally orientated fiber alignment is not permitted, and fibre coupling cannot be made from a PIC edge that also needs wire bonding. We do not offer multiple single fibre coupling to the same side of the PIC. Yellow parts illustrate the possible epoxy flow that is mentioned in the below sections.

2.2. General Information and Rules for Optical Packaging

In Europractice, Tyndall offers a range of optical-coupling solutions for Si-PICs and applications. In general, these offers include packaging of single-fiber and fiber arrays; single-mode fibers (SMFs) or polarization-maintaining fibers (PMFs); and work with either grating-couplers or edge-coupler schemes. The more relaxed optical alignment tolerances of grating-couplers, compared to edge-couplers, often make them preferred choice for optically-packaging PICs. However, for optical packaging of edge-emitting laser chips or optically-broadband / polarization-agnostic PICs, edge-coupling can be the better choice. Whatever coupler option is chosen, we recommend carefully following PDRs, to ensure that a PIC can be optically packaged. Some general information about fiber types and coupling is given below.

2.2.1. Fiber Optics

Tyndall offers fibre-packaging of the Si-PIC to either single-mode fibres (SMFs) or polarisation-maintaining fibres (PMFs). The SMFs consist of an 8.2μm-diameter inner-core of high-index glass surrounded by a 127μm- or 250μm-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 3***.

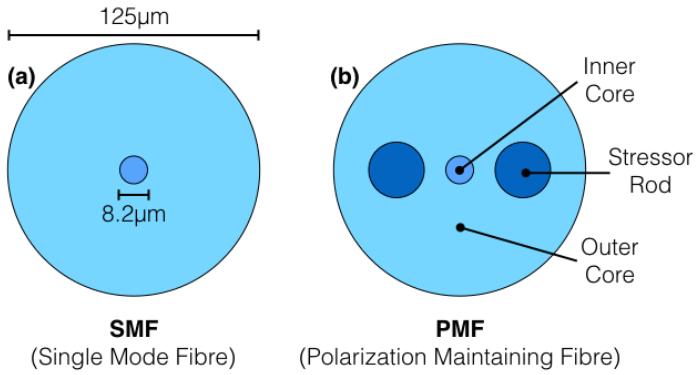

Figure 3. Cross-sections of (a) single-mode fibre (SMF) and (b) polarization-maintaining fibre (PMF)

For both PMFs and SMFs, the mode-field diameter (MFD) of the light exiting the fibre is 10.4μm at 1550nm (and 9.2μm 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.

2.2.2. Edge Coupling

Edge coupling typically offers low insertion-loss (IL), large spectral bandwidth (BW), and low-sensitivity to polarization compared to grating coupling approaches. It is one of the more convenient means of coupling light from an edge-emitting laser or PIC waveguide into an optical fiber and is well established for commercial packaging. The alignment tolerances for edge coupling are typically more stringent than for grating coupling.

In Europractice, we offer edge coupling of fiber array(s) and single-fiber(s) to user provided PICs in our standard packages.

Single-fiber coupling

For single-fibre edge-coupling to a laser chip, we typically use a lensed optical fibre (spot size $3\mu m$) which is mounted in a metallic ferrule. The complete metallised assembly is locked into the optimum alignment position by means of laser-welding (to a Kovar submount). This prosses is commonly referred to as "fiber pigtailing" and is a critical step in the manufacturing of LD (laser diode) modules. This is accomplished with the optical alignment and laser welding process. The welding process produces a robust attachment fixture and is commonly used for high-end photonic devices used in extremely harsh environments (eg. space applications). An example of the laser welding packaging process is shown in ***Figure 4***.

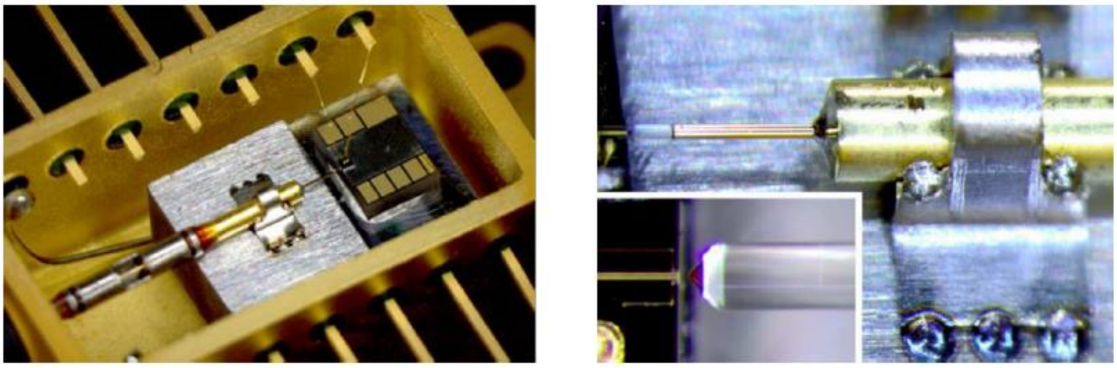

Figure 4. Representative image of laser welding within a photonic package.

For single-fiber edge coupling to a PIC, we offer two standard options:

- Optical packaging with a lensed fiber to an inverted-taper on the PIC
- Optical packaging with a flat fiber to a $10\mu m$ mode-converter on the PIC

It is the responsibility of the user to ensure that their edge-coupler structure is sufficiently close to the edge of the PIC-die to allow for fiber access.

Fiber-array coupling

Edge coupling to PICs typically requires a mode-adapter to match the PIC mode field diameter (MFD) with that of the edge coupled fiber. For many applications, multiple fiber connections to the same PIC are needed. Instead of sequentially aligning several individual fibers, the solution is to use a fiber array. The tight alignment tolerances of edge coupling make it challenging to couple fiber-arrays to PICs unless the waveguide MFD can match that of the fiber. Advancements in photonic packaging technology have seen fiber arrays using ultra-high numerical aperture (UHNA) fiber being used for coupling to large channel count Si and InP PICs with MFD of $3\mu m$. These fibers provide good mode matching to small MFD PICs and can be spliced to SMF28 fiber with minimal excess losses. For PICs with $10\mu m$ MFD waveguides, standard fibre arrays can provide low-loss coupling using standard packaging processes. An example package showing the alignment of such a fibre array to Si-PIC is shown in ***Figure 5***.

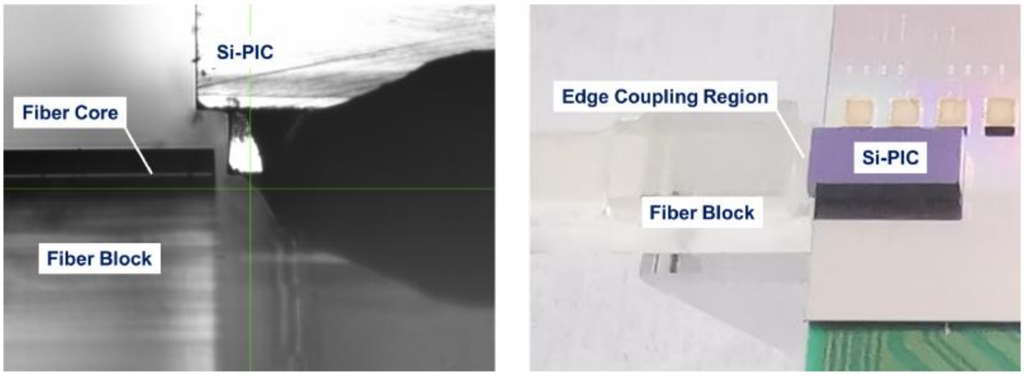

Figure 5. Coupling of a fibre array to the edge couplers on a Silicon PIC. Close up view of the fibre being aligned to the waveguides (left), expanded view of the fibre and PIC (right).

In fiber-array edge coupling, multiple fiber channels are aligned to multiple edge couplers on the PIC at the same time. We recommend using active alignment through a series of "optical shunts" to align the fiber to pairs of looped waveguides at each side of the optical interface. Given the high concentricity of the inner cores of the fibers in the array (<500*nm*), this approach ensures that all intermediate fiber channels are aligned to their corresponding edge-couplers. A typical implementation of such shunts on a PIC is shown in ***Figure 6***.

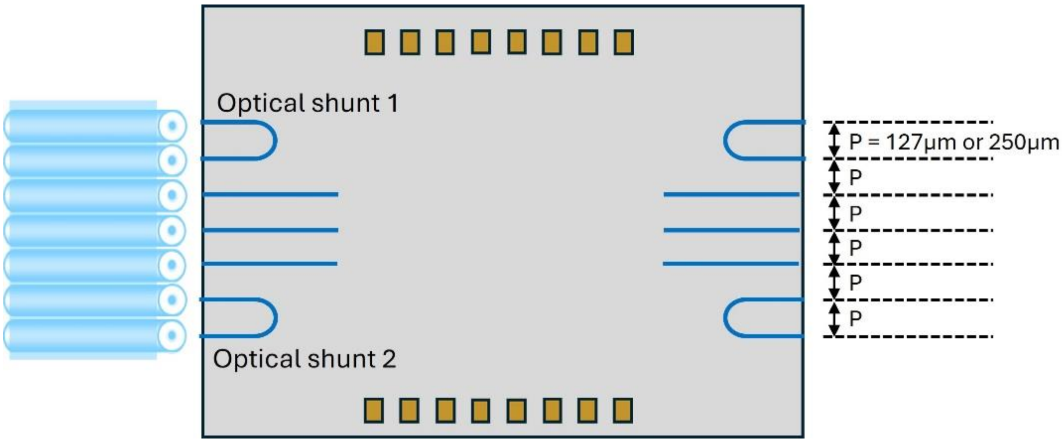

Figure 6. Overview of the "optical shunt" concept that is used to assist with fiber array alignment within a photonic package.

The pitch of the edge-coupler array on the PIC must be exactly $250\mu m$ or $127\mu m$, to match the edge-coupled fiber arrays offered by Tyndall - see ***Figure 6***. Since the first and last pairs of channels of the fibre-array and waveguide edge array are used for optical shunts, users requiring N channels for the operation of their PIC must choose a fibre-array with at least $N + 4$ channels. If two fiber-arrays are needed to package a PIC, they must be arranged on opposite sides of the PIC (e.g. West-side & East-side in some cases).

2.2.3. Grating Coupling

The alternative to edge-coupling, and a more widely adopted solution to coupling light to and from an Si-PIC, is grating coupling. Since it offers a lower profile, better mechanical stability, and has a smaller footprint on the PIC, Tyndall has standardised to quasi-planar-coupling (QPC) for Europractice packaging - see ***Figure 7***.

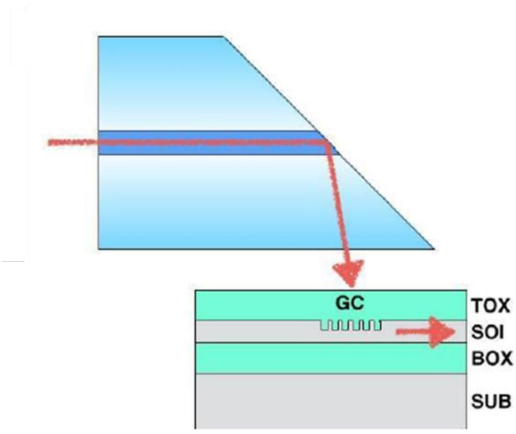

Figure 7. Schematic of fibre-to-grating coupling using quasi-planar-coupling (QPC).

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 the target-wavelength (usually 1550*nm*). The shift is typically of the order of 10*nm* per 1°(degree), and is therefore significant, given the typical 30*nm* 1dB bandwidth of the grating-coupler.

In wafer-scale testing, light is usually coupled from the fibre to the grating 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 8***.

For the QPC geometry used at Tyndall, adding the epoxy does not affect the AOI on the grating-coupler, because there are two compensating refractions 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.

Tyndall has standardised on a packaged-AOI of 7° as a compromise solution. Users are welcome to submit custom grating-coupler designs for packaging, but they must operate with a packaged-AOI =7°.

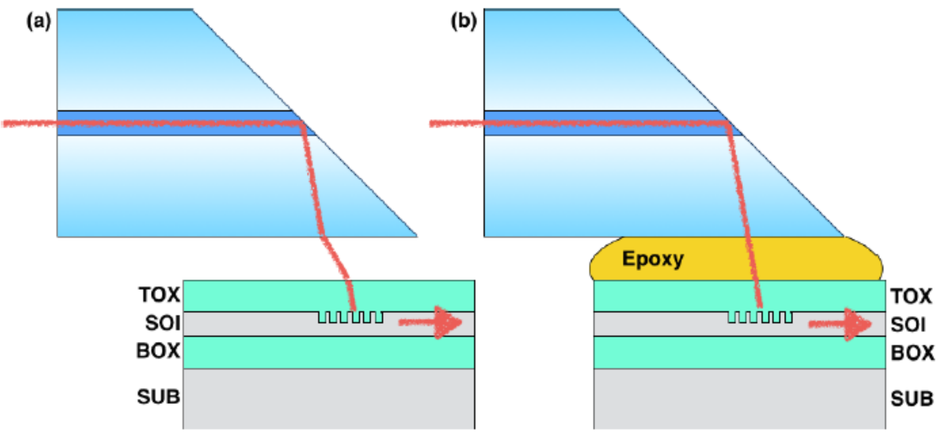

Figure 8. For QPC, adding index-matching epoxy does not change the AOI of light incident on the grating-coupler.

In fiber-array QPC, multiple fibre-channels are aligned to multiple grating couplers on the PIC at the same time. We recommend to use active alignment through an "optical-shunt" to align the first and last channels of the fibre-array with the first and last channels in grating array. Given the high concentricity of the inner cores of the fibers in the array (<500nm), this approach ensures that all intermediate fibre-channels are aligned to their corresponding grating-couplers. A typical implementation of such shunts on a PIC is shown in ***Figure 9***.

To facilitate shunt alignment and good mechanical bonding between the fibre-array and PIC, we require that grating-coupler array be located no closer than 750μm from the edge of the PIC, and that the array runs parallel to edge of the PIC. Additionally, we suggest to leave a 500μm exclusion zone around the 5mm footprint of the fibre-array, to allow for epoxy flow. These design rules are illustrated in ***Figure 9***.

The pitch of the edge-coupler array on the PIC must be exactly 250μm or 127μm, to match the QPC arrays offered by Tyndall - see ***Figure 6***. Since the first and last pairs of channels of the fibre-array and grating-array are used for optical-shunt, users requiring N channels for the operation of their PIC must choose a fibre-array with at least $N + 2$ channels. If two fiber-arrays are needed to package a PIC, they must be arranged on opposite sides of the PIC (e.g. West-side & East-side in some cases).

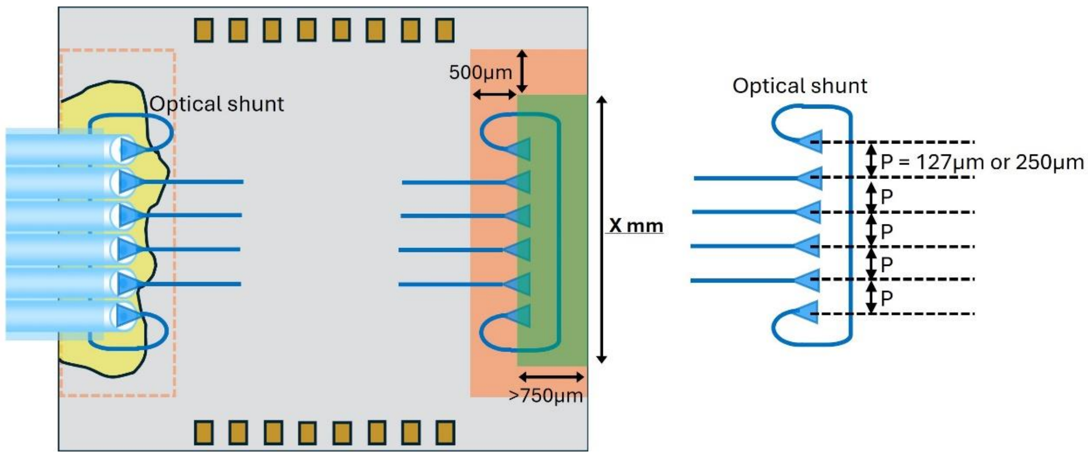

Figure 9. (left) Schematic showing the exclusion zone around the fibre array and grating-array needed for mechanical bonding of the fibre to the PIC. No phase-sensitive components should be located in this zone. (right) Schematic of the optical-shunt needed to align the fibre array onto the Si-PIC. The 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. Ideally, the dimensions of X indicated here will be about 5-6mm but will vary with optical channel and pitch of the fiber array, and needs to be reviewed.

Fiber alignment can only be made across opposite sides of the Si-PIC. *Tyndall* cannot provide fibre coupling 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 a PIC edge that also needs wire bonding (see ***Section 2.3***, and ***Figure 2*** for general layout). If wire bonds are needed, they must be made along an edge of the chip that runs parallel to the fibres.

2.2.4. Summary of Rules for Optical Packaging

A summary of some of the main design rules and specifications for optical photonic packaging are provided in ***Table 1***. Please note that these design rules are recommendations based on current standard processes that are offered under the Europractice program. If you require packaging outside the scope of these rules, please contact the Photonic Packaging Group at Tyndall for information on the current state-of-the-art and what custom options are available.

Table 1. Optical packaging design rules offered under Europractice

Optical Packaging Design Rules	
Platforms	SOI, SiN
Typical Coupler Mode Filed Diameters (MFD)	3.0μm, 6.0μm, 10.0μm
Coupler Types	Grating or Edge Couplers
Fiber Types	Fiber Arrays or Single Fiber (Edge Coupler only)
Fibre Options	SMF / PMF
Number of Channels	1-24
Channel Pitch	127μm, 250μm
Alignment Feedback	Optical Loopback (Shunt), Laser, PD

2.3. General Information and Rules for Electrical Packaging

Wire bonding is the most common method of providing an electrical connection from a PIC to a PCB within a package. To help users access integrated electrical components on their Si-PIC, *Tyndall* provides wire bonding as part of the *Europractice* packaging service.

For standard ball bonding, DC bond-pads on the Si-PIC must have a minimum pitch of 150µm and may not be staggered - see ***Figure 10***, as staggering bond pads on the PIC increasethe likelihood of shorting between adjacent wire bonds. *Tyndall* can make wire-bond connections to all standard bond-pads such as those defined as part of PDKs from the main European foundries (such as those offered by *IMEC* or *CEA-Leti*). If users opt for custom bond-pads, they must have a minimum footprint of 50µm x 70µm. All bond-pads for wire-bonding must have a Au-capping layer that is at least 100nm thick. *Tyndall* uses circular-section 18µm-diameter Au-wire for DC wire-bonds, and 50μm x 12μm gold ribbon wire-bonds.

It is recommended to keep bonds as close to the chip edge as possible. This ensures that the wire bond length is kept as short as possible when connecting the PIC to a PCB. Additionally, it is recommended that bond-pads for electronic-coupling should be located along the North- and South-sides of the PIC-die, and centered with respect to PIC-die, refer to ***Figure 1*** for optimum layout. It is also critical to ensure that bond pad metallisation on the PIC is compatible with the chosen assembly process.

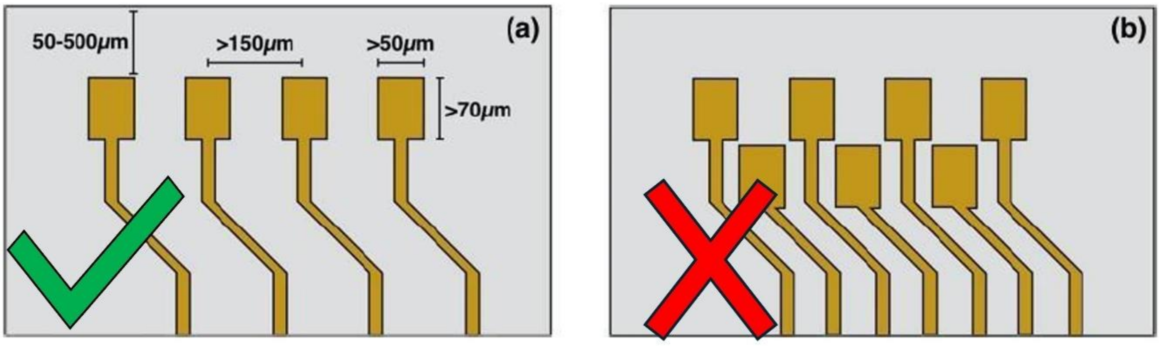

Figure 10. (a) Bond-pads must have a minimum pitch of 150µm, and be located between 50µm and 500µm from the edge of the PIC. If users opt for a custom bond-pad design, then the pad must have a minimum footprint of 50µm x 70µm. (b) Staggering of bond-pads is not acceptable for Europractice packaging.

Tyndall also offers flip chip bonding of chips onto a Tyndall-designed standard single layer Si-interposers as part of our "Chiplet Integration Service offering". Interested users should check the design rules for this service and should note that this service has different packaging options than those given in ***Section 3*** in this document.

Table 2 summarizes the acceptable metallisation and main design rules for electrical photonic packaging which are provided in Europractice. Please note that these design rules are recommendations based on our current standard processes in Europractice.

Table 2. Electrical packaging design rules offered under Europractice

Electrical Packaging Design Rules for PICs		
Connection method	Wire bonding (DC)	
Bond pad size	$50\mu m \times 50\mu m$ (minimum)	
Bond pad distance from edge	50-500μm	
Bond pad location on PIC	North- and South-sides of, and centered with respect to PIC-die	
Bond Pad pitch	$150\mu m$ (minimum)	
Max no of DC bond pads	120	
Metallisation	Preferred Metal	Acceptable Metal
	Au	Al

3. Standard Package Options in Europractice

This section describes the two different standard 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.

Users can find details about our solutions for thermal management and Tyndall designed generic PCBs that allows Europractice users to access a low-cost fully packaged standard module with optical and electrical coupling and thermal management.

3.1. Generic Package for Fiber Array Optical Coupling

The advantage of this package design is not only for its suitability for both edge and grating optical coupling of fiber arrays in a single package design, but also features an adjustable split PCB design to allow PICs of various sizes to be connected to the PCB bond pads via wire bonding.

This package allows flexibility to have one- or two pieces of PCB(s) depending on the required number of electrical connections and has one or two electrical connectors with 30 DC wire-bond connections in each PCB split. The package offers one or two optical fibre array connections (edge or grating coupling), and users can choose between a pair of fibre arrays offering 2 x 12 or 2 x 24 channels on the PIC (please consider the required optical shunt channels which are included in these total channels - refer to ***Edge Coupling*** and ***Grating Coupling*** Sections for optical shunt rules). Users may also choose between a fiber-array pitch of 250μm or 127μm, and SMF or PMF fibres. Both the SMF and PMF fibre-arrays are in FC/APC connectors. Thermal management is provided by the integrated thermistors and the 8W TEC, which couples heat from the PIC into the mechanical body of the module, for heat sinking to the ambient. The transparent lid is included in the package to secure the fiber attachment and wire bonding. The heat spread has minor changes depending on the optical coupling type (edge or grating coupling).

See ***Figure 11*** for overall package and

Table 3 for detailed specifications of this package.

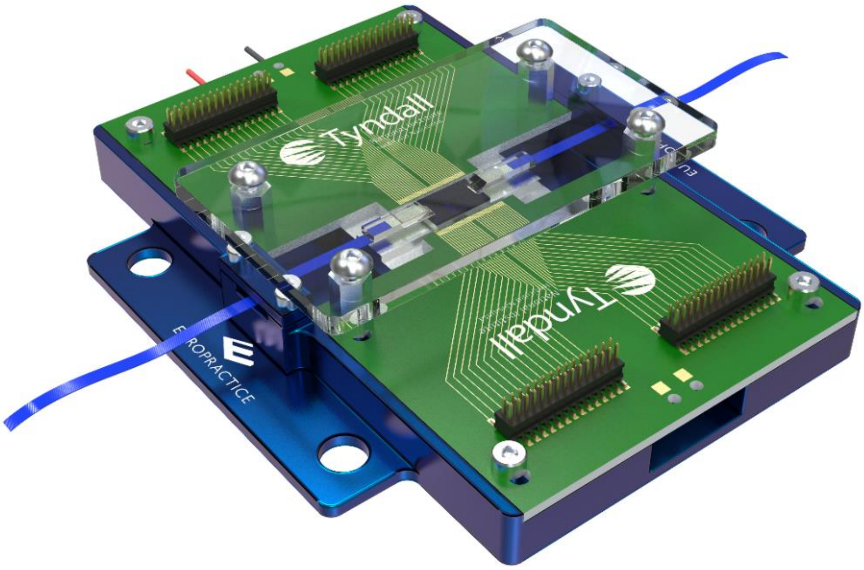

Figure 11. Standard package for edge and grating optical coupling offered in Europractice.

Table 3. Specifications of generic package compatible with two optical couplings offered in Europractice.

Grating & Edge Coupling Generic Package	
Mechanical base dimensions	104mm × 90mm × 9mm
Compatible PIC dimensions	From 3 × 3 mm to 10 × 10 mm
PCB dimensions	60mm × 48mm on each side
Electrical Packaging	Wire bonding (from either side of PIC)
DC connections	Up to 120 DC connections 2 × 60 DC connections in each PCB split
PCB bond pad dimensions and pitch	125μm × 1000μm, and a 250μm pitch
Thermal solutions	Yes – Thermistors (10kOhm) and TEC (8W)
Waveguide Pitch	127μm or 250μm
Optical Channel Count	12, 24
Optical shunts – no. of channels	4 for edge coupling and 2 for grating coupling
Fiber Type	SMF & PMF
Optical Interface	2 × Fiber Arrays (from either side of PIC)

3.2. Generic Package for Single-lensed Fiber Optical Coupling

This package allows for two optical single-fibre connections (edge coupling) and users may choose SMF or PMF fibres. Both the SMF and PMF fibres are in FC/APC connectors. Fibre attachment to the PIC is via laser welding. Thermal management is provided by the integrated thermistor in the Tyndall-generic PCB and the 8W TEC, which couples heat from the PIC into the mechanical body of the module through an aluminium heat spreader, for heat sinking to the ambient. This package has 10 DC electrical connections. The transparent lid is included in the package to secure the fiber attachment and wire bonds.

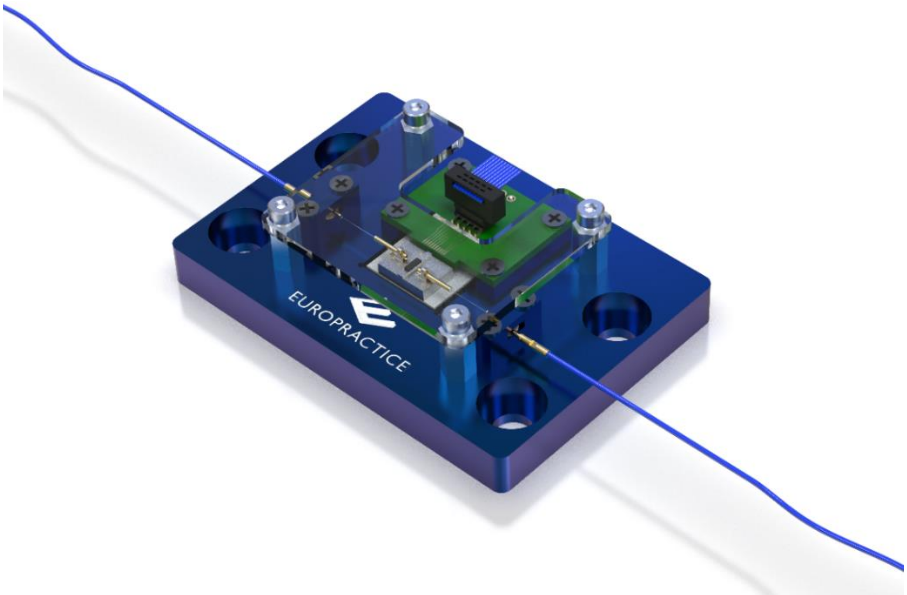

Figure 12. Standard package for single-lensed fiber offered in Europractice.

Table 4. Specifications of a standard single-lensed fiber package offered in Europractice

Single Lensed Fiber Generic Package	
Mechanical base dimensions	74mm × 51.5mm × 8mm
Compatible PIC dimensions	Up to 5 × 5 mm
PCB dimensions	25mm × 20mm × 1.6mm
DC connections	10
Thermal solutions	Yes - Thermistors (10kOhm) and TEC (8W)
Waveguide Pitch	NA
Optical Channel Count	1
Fiber Type	SMF & PMF
Optical Interface	2 × Single Fibers (from either side of PIC)

Thermal management

Si-PICs are much more temperature sensitive than electric-ICs. A temperature increase of 10°C 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 thermo-electric 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 or the base of the package. 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 +/- 0.01°C after a few minutes of cooling.

Tyndall-generic PCBs

Tyndall has developed two standard PCB modules. A split PCB configuration for the fiber array standard package and a single PCB for the single fiber packages:

(i) A split-PCB module: Compatible with edge and grating coupling (QPC) of fiber-arrays and offers max 120 DC wire-bonds (2 for TEC and 2 for thermistor) on either side of the PIC through 4 connectors. This split-PCB consists of two identical PCBs, positioned on either side of the die and allows PICs of various sizes to be packaged via its adjustability - see both ***Figure 13*** and the fully-packaged described in ***Section 3.1*** for technical rules.

For wire bonding, the PCB bond pads are rectangular, measuring $125\mu m \times 1000\mu m$, and have a $250\mu m$ pitch. These bond pads are aligned to bond pads on the PIC, which have a pitch ranging from $100\mu m$ to $300\mu m$, provided that the bond-pads on the PIC are centered or edge. For thermal management, a 10kOhm thermistor is placed close to the chip,for measuring its temperature. An 8W TEC is arranged below and controls the temperature through the aluminium heat-spreader (located between the PIC and TEC). 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).

This split-PCB is designed to accept single-block and mini-blocks from the MPW runs offered at Europractice and others such as, *CEA-Leti*.

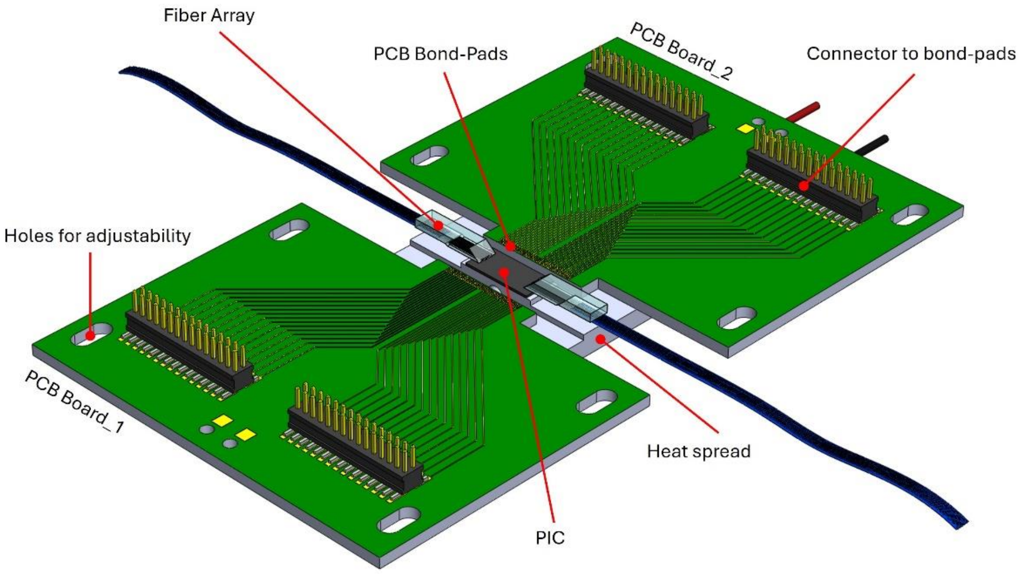

Figure 13. Schematic of the Tyndall split-generic PCB module showing how optical and electrical coupling is made to the Si-PIC, and where the integrated thermistor and heat-spreader is located. The PCB can be integrated into a low-cost fully-packaged module (see Section 3.1) with a TEC and a mechanical base-plate.

(ii) A PCB module allows for single-lensed fiber attachment and offers up to 10 DC connections to the Si-PIC fibre. For wire bonding, the PCB bond pads are $200\mu m \times 600\mu m$, and the pitch of the bond pads are $500\mu m$, and can be matched to bond pads on a PIC provided the PIC-side bond-pads are centred. For thermal management, a 10kOhm thermistor is placed next to the chip for measuring its temperature and an 8W TEC placed underneath and controls the temperature through the aluminium heat-spread (locateed between the PIC and TEC).. See both ***Figure 14*** and the fully-packaged described in ***Section 3.2***.

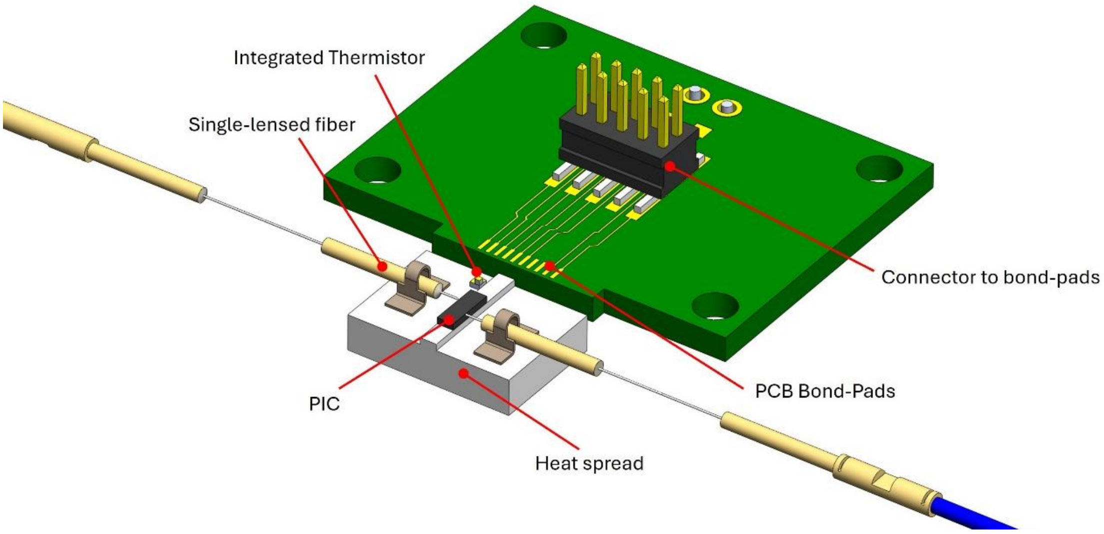

Figure 14. Schematic of the Tyndall generic PCB showing how optical and electrical coupling is made to the Si-PIC, and where the integrated thermistor and heat-spreader is located. The PCB can be integrated into a low-cost fully-packaged module (see Section 3.2) with a TEC and a mechanical base-plate.

4. Europractice Packaging Service

Tyndall offers packaging service of given standard packages at ***Section 3*** under a RUN-based service for Europractice users, which is called, *Multi-Project Packaging Run* (MPP-Run). Briefly, annual MPP-Run schedules will be announced on the Europractice website and interested users should reach out to Tyndall via the user interest form (Europractice website). During the technical evaluations between users and technical experts in Tyndall, the user design is reviewed by Tyndall and once its compatibility with our standard packages is approved, users can proceed with pre-scheduled run registration in order to initiate the packaging service – see workflow at ***Figure 15***. Please consider registering appropriate run according to fabrication of your chips as this may cause delays and effect other users packaging activities in a scheduled run. If your chips have not been fabricated at the time of registration, please consider registering for a following run.

We strongly recommend Europractice users interested in packaging their devices to review their PIC design with Tyndall before submission to a foundry, to avoid any issues at the packaging phase and to leverage our packaging services.

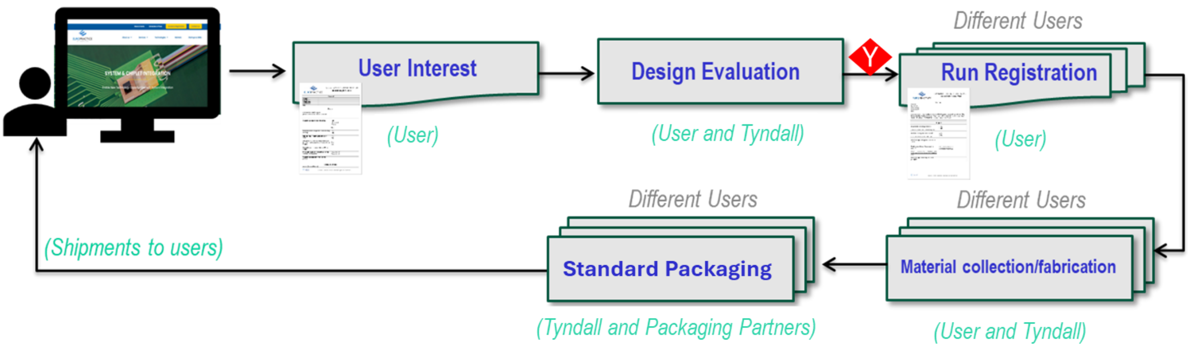

Figure 15. High level MPP-Run workflow. Please note that only users with approved designs will be accepted for the offered standard packaging service.

This MPP-Run service is organized in order to reduce the packaging cost-barrier to academic researchers and provide rapid turn-around time. We currently only offer the standard packaging solutions provided in this document within Europractice, but we are continuing to develop our capabilities and grow the service, so check back soon for further updates to the packaging services we offer. Please note that our “Chiplet Integration Service” offers are different than those given in this document, so interested users should refer to the “Chiplet Integration Design Rules”.

5. 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 the packaging service RUN should be addressed directly to (marc.rensing@tyndall.ie and ece.senel@tyndall.ie) who are part of the Photonics Packaging & System Integration Group at Tyndall, a Europractice partner.