Advanced Photonics Packaging and System Integration Services within EUROPRACTICE

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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 & System Integration Group* to enable users to realise a low-cost fully- packaged module (optical, electrical, and thermal) for their Si-PICs. The three 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:

AOI	Angle of Incidence (defined with respect to the surface-normal of the Si-PIC)
MPW	Multi-Project Wafer
PCB	Printed Circuit Board
PIC	Photonic Integrated Circuit
PLC	Planar Lightwave Circuit
PMF	Polarisation Maintaining Fibre (assumed to also be single-mode)
SOI	Silicon on Insulator
SMF	Single Mode Fibre
TEC	Thermoelectric cooler
TOX	Top Oxide
QPC	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 packaged photonic module that offers easy optical and electrical access to their Si-PIC, without the need for 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 an 8.4µm-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 1*.

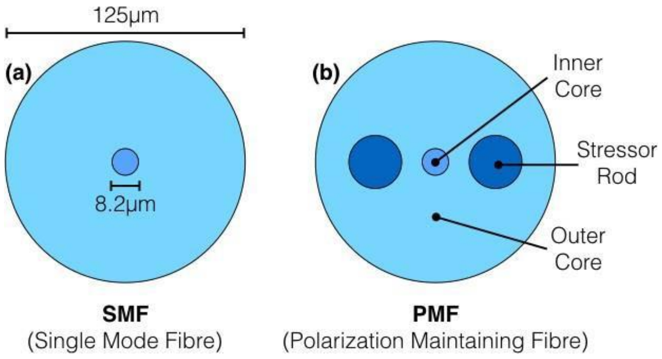


Figure 1 *- Cross-sections of* ***(a)*** *single-mode fibre (SMF) and* ***(b)*** *polarization-maintaining fibre (PMF)*

For both PMFs and SMFs, the mode-field diameter (MFD) of the light exiting the fibre is 10.4µm 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 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 *EUROPRACTICE*, 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 EUROPRACTICE 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 the target-wavelength (usually 1550nm). The shift is typically of the order of 10nm per 1deg, and is therefore significant, given the typical 30nm 1dB bandwidth of the grating-coupler.

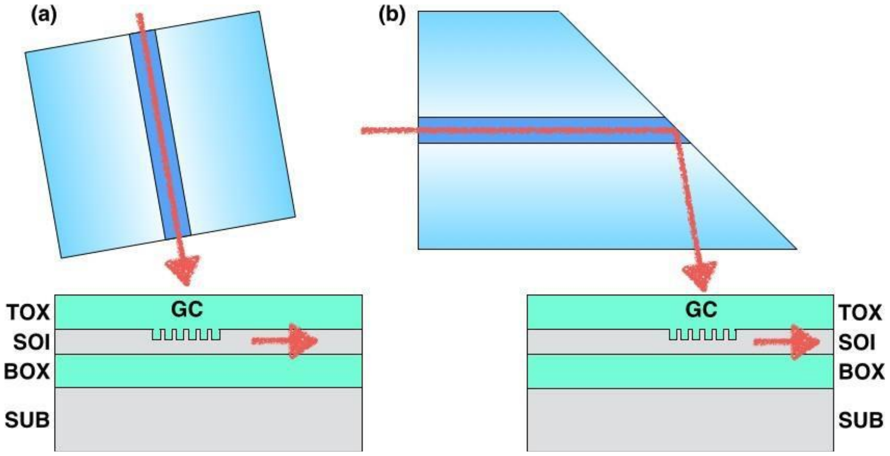


Figure 2 *- Schematic of fibre-to-grating coupling using* ***(a)*** *vertical/butt-coupling, and* ***(b)*** *quasi-planar-coupling (QPC).*

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 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 operate with a packaged-AOI =7deg.

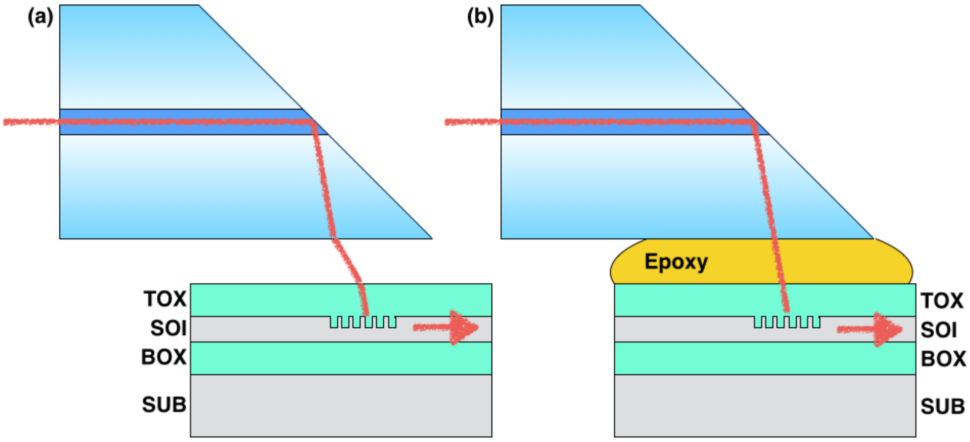


Figure 3 *For QPC, adding index-matching epoxy does* *<u>not</u>* *change the AOI of light incident on the grating-coupler.*

2.3 Fibre Arrays

Tyndall offers QPC fibre arrays. The fibre arrays 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 fibres and PIC, and (ii) no phase-sensitive components close to the grating-couplers that would be negatively impacted by the inevitable flow of epoxy 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.

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 (<500nm), 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 750µm from the edge of the PIC, and that the array runs parallel to edge of the PIC. We recommend users to leave a 500µm exclusion zone around the 5mm footprint of the fibre-array, to allow for epoxy flow - see *Figure 4(a)*. The pitch of the grating-coupler array on the PIC must be exactly 250um or 127um, to match the QPC arrays offered by *Tyndall* - see *Figure 4(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.

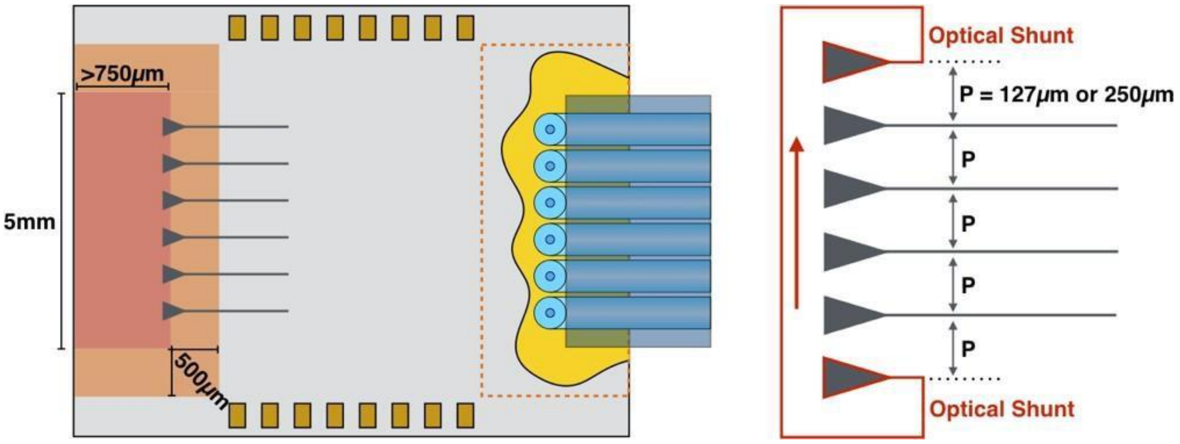


Figure 4 **- *(a)*** *Schematic showing the exclusion zone around the fibre array and grating-array needed for mechanical bonding of the fibre to the PIC. No phase-sensitive components should be located in this zone.* ***(b)*** *Schematic of the optical-shunt needed to align the fibre array onto the 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*

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 2.4). If wire bonds are needed, they must be made along an edge of the chip that runs parallel to the fibres.

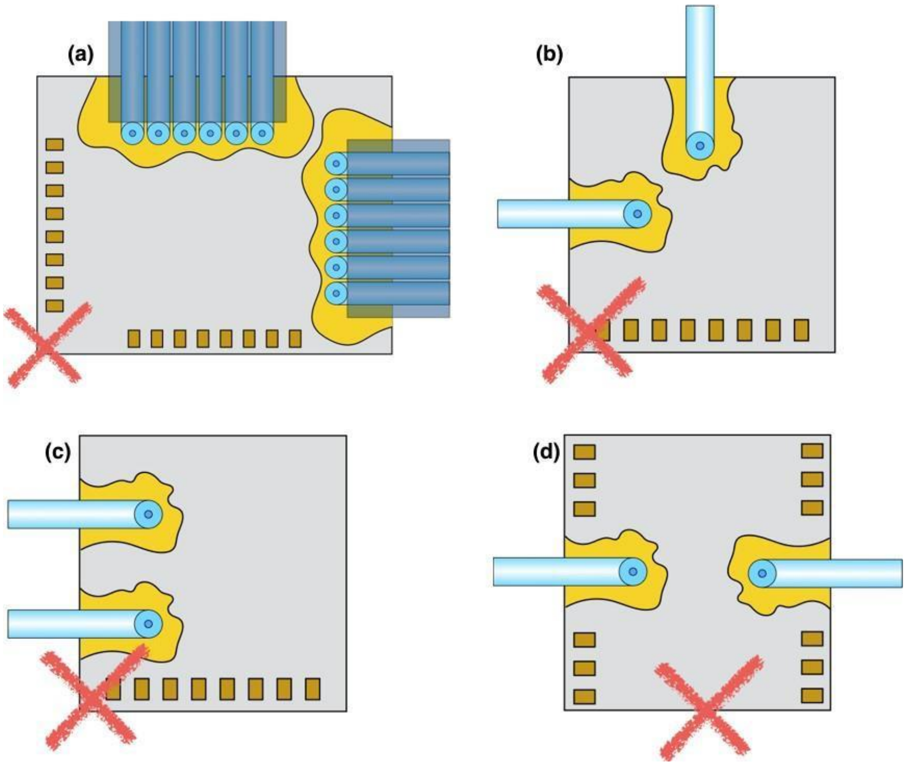


Figure 5 *- Schematic showing four PIC designs that are <u>not</u> compatible with the EUROPRACTICE packaging offered by Tyndall. Orthogonally orientated fiber alignment is not permitted, and fibre coupling cannot be made from a PIC edge that also needs wire bonding. We do not offer multiple single fibre coupling to the same side of the PIC.*

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 150µm, and may not be staggered - see *Figure 6*. *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 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 tape-section Au-wire or RF wire-bonds. Si-PICs operating with RF signals (in the 10-25GHz 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*).

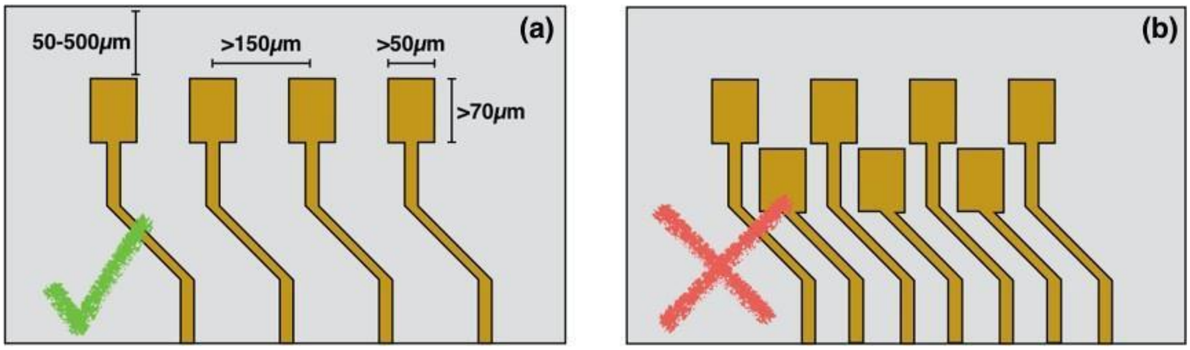


Figure 6* - *(a) *Bond-pads must have a minimum pitch of 150µm, and be located between 50µm and 500µm from the edge of the PIC. If users opt for a custom bond-pad design, then the pad must have a minimum footprint of 50µm x 70µm.*
(b) *Staggering of bond-pads is not acceptable for EUROPRACTICE packaging.*

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 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 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 +/- 0.01deg 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 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 7* 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 centered 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 <u>not</u> 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*.

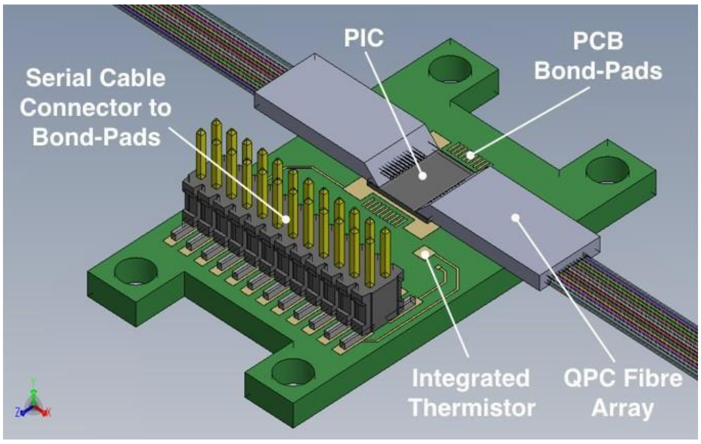


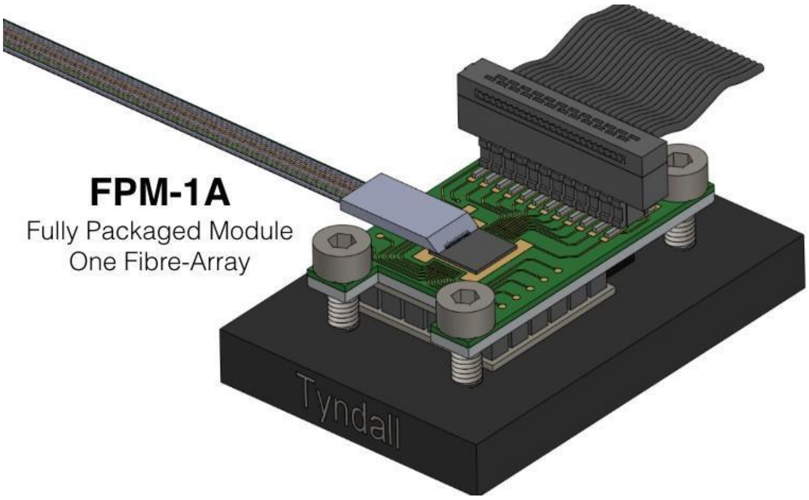
Figure 7 *- Schematic of the Tyndall-PCB showing how optical and electrical coupling is made to the Si-PIC, and where the integrated thermistor is located. The PCB can be integrated into a low-cost fully-packaged module (see Section 3.2) with a TEC and a mechanical base-plate.*

3 PACKAGING OPTIONS

This section describes the two 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.

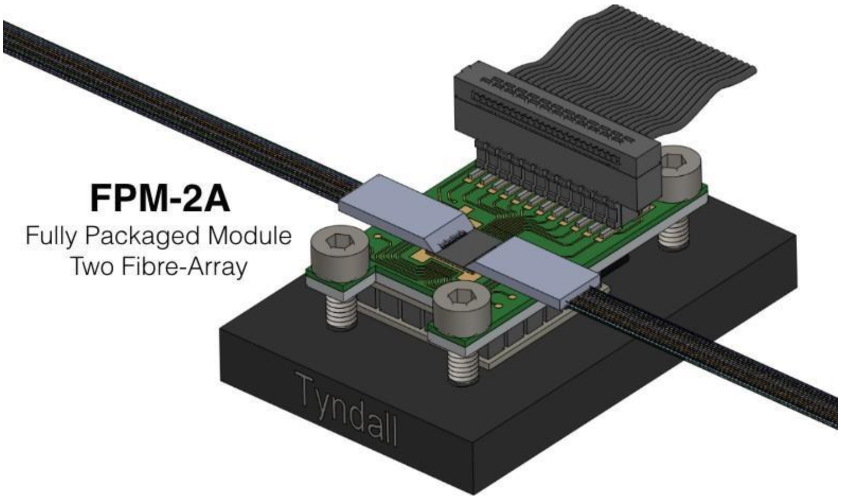
3.1 Fully Packaged Modules

Fully packaged modules (FPMs) offer optical and electrical 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 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).



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

The one-fibre-array FPM option allows multiple 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 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 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.



3.1.2 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 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 250µm or 127µm, and SMF or PMF fibres. Both the SMF and PMF fibre-arrays are in FC/APC connectors.

3.3.0 Other Packaging and System Integration Services

We are continuing to develop our capabilities and grow the service, so check 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* (marc.rensing@tyndall.ie) who is part of the Photonics Packaging & System Integration Group at Tyndall, a EUROPRACTICE partner.