CORNERSTONE PIC Bootcamp Demonstration Chip Guidelines

I. Photonic Chip overview

The PIC Bootcamp demonstration chips were fabricated on the CORNERSTONE 220 nm silicon-on-insulator (SOI) platform with a 120 nm Si etching depth, a 1 µm SiO_2 top cladding and a 2 µm buried oxide (BOX) layer. Metal heaters were integrated as thermo-optic phase shifters based on a metal stack consisting of 30 nm Ti + 200 nm Al. All devices are designed to work at a wavelength of 1550 nm.

The layout of this demonstration cell is shown in Fig. 1.

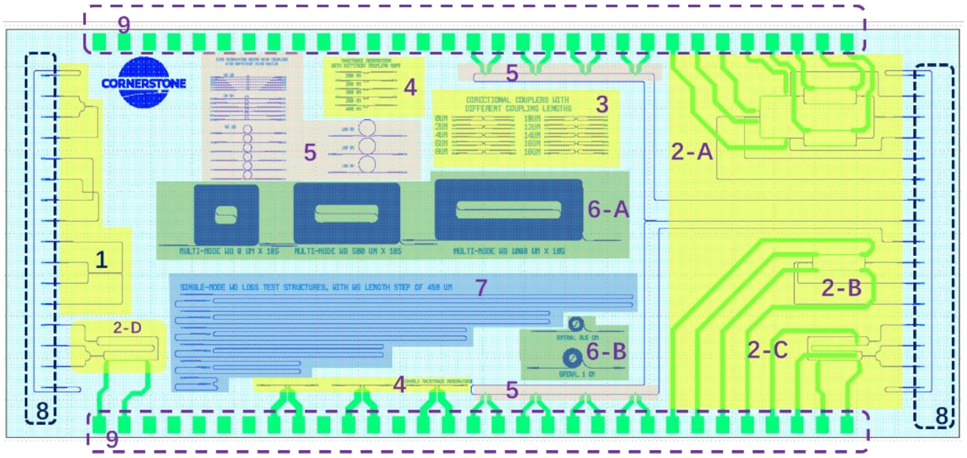

Figure 1. Layout overview.

There are six groups of devices/structures, and they are:

1. Photonic devices-Basic components
2. Photonic devices-Mach Zehnder Interferometers
3. Photonic devices-Directional Couplers
4. Photonic devices-Racetrack resonators
5. Photonic devices-Ring resonators
6. Photonic devices-Spiral waveguides
7. Photonic devices-Waveguide loss test structures
8. Optical packaging-optical fibre bonding
9. Electrical packaging-Wire bonding

Photonic devices are labelled physically on the chip, which is visible under a microscope.

For chip I/O configuration, refer to Section III.

II. Photonic Chip Details

1. Photonic devices-Basic components

The most basic components in a photonic integrated circuit (PIC) are straight waveguides, waveguide bends, waveguide crossings, and beam splitters/couplers.

As shown in Fig. 2, there are four devices, (1) a short straight waveguide in between two sets of grating couplers and a taper for light input and output, (2) a waveguide crossing with four input/output waveguides connected with grating couplers, (3) a 1x2 multi-mode interferometer (MMI) beam splitter/coupler with input/output grating couplers, and (4) a 2x2 MMI beam splitter/coupler with input/output grating couplers.

In Device (1), the optical loss of the short straight waveguide is negligible, and the transmission of this device reflects the transmission of the two grating couplers. A peak transmission of -11 to -15 dB is expected.

In Device (2), for example, when the light is launched into the device from Port 1, a peak transmission of -11 to -15 dB is expected from Port 4 because the optical loss due to the crossing is insignificant, whilst the transmission between Port 2 and Port 3 are possible and loss should be negligible.

In Device (3), assuming the light is launched into the device from the right port, similar spectra are expected from the two ports on the left, which means the 1x2 MMI can evenly split the optical power.

In Device (4), which is similar to (3), assuming the light is launched into the device from one of the two left ports, similar spectra are expected from the two ports on the right, which means the 2x2 MMI can also evenly split the optical power. Please note it is difficult to realize an exactly even splitting using a 2x2 MMI especially in a wide wavelength range. Also, there is pi/2 phase difference on the output ports.

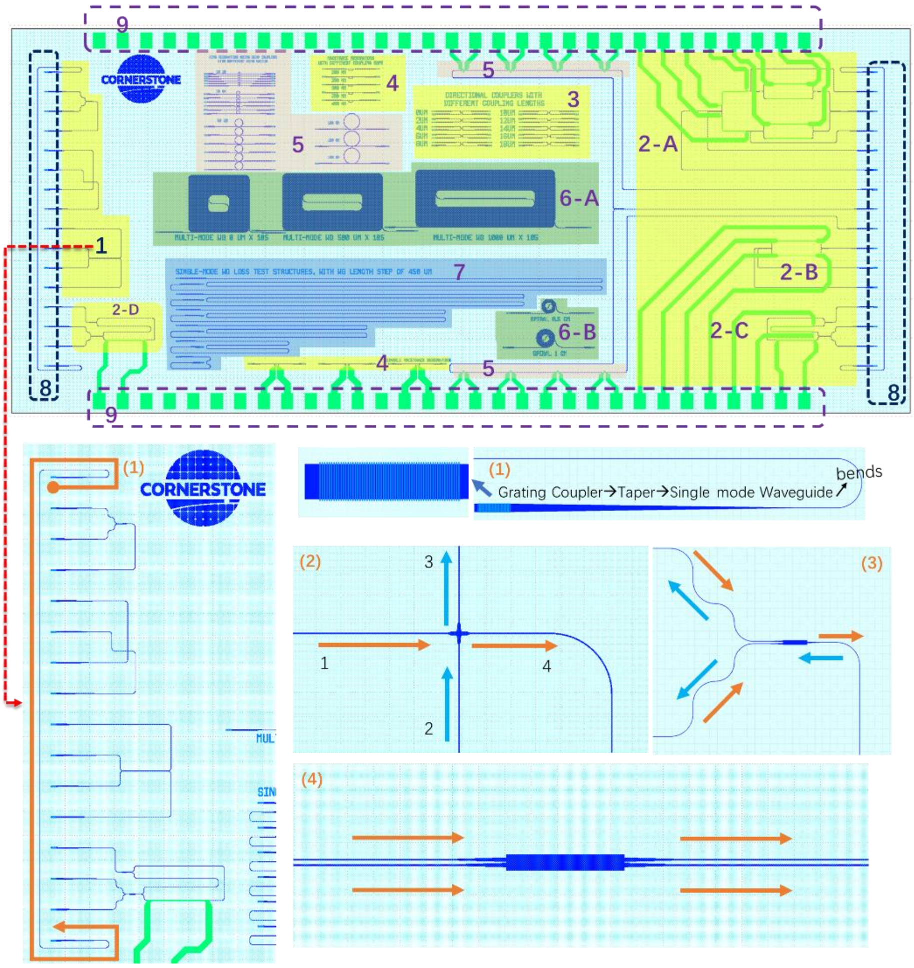

Figure 2. Basic components.

Please note that the straight waveguides in this section and following sections (if not specified) have a width of 450 nm and they are single mode (SM) transverse-electric (TE) waveguides. The waveguide bends also have a width of 450 nm. All the bends used on this demonstration chip are arc bends and thus they support single mode only.

2. Photonic devices-Mach Zehnder Interferometer

Using two MMIs, one can easily build a Mach–Zehnder interferometer (MZI). See the device in Fig. 3 as an example of a MZI, which is formed by a 1x2 MMI, 2x2 MMI, straight waveguides, waveguide bends and grating couplers. On the transmission spectrum, one should observe periodic constructive and destructive interference. The period is the so-called free-spectral-range (FSR), which is correlated with the optical path difference of the two MZI arms between the 1x2 MMI and 2x2 MMI.

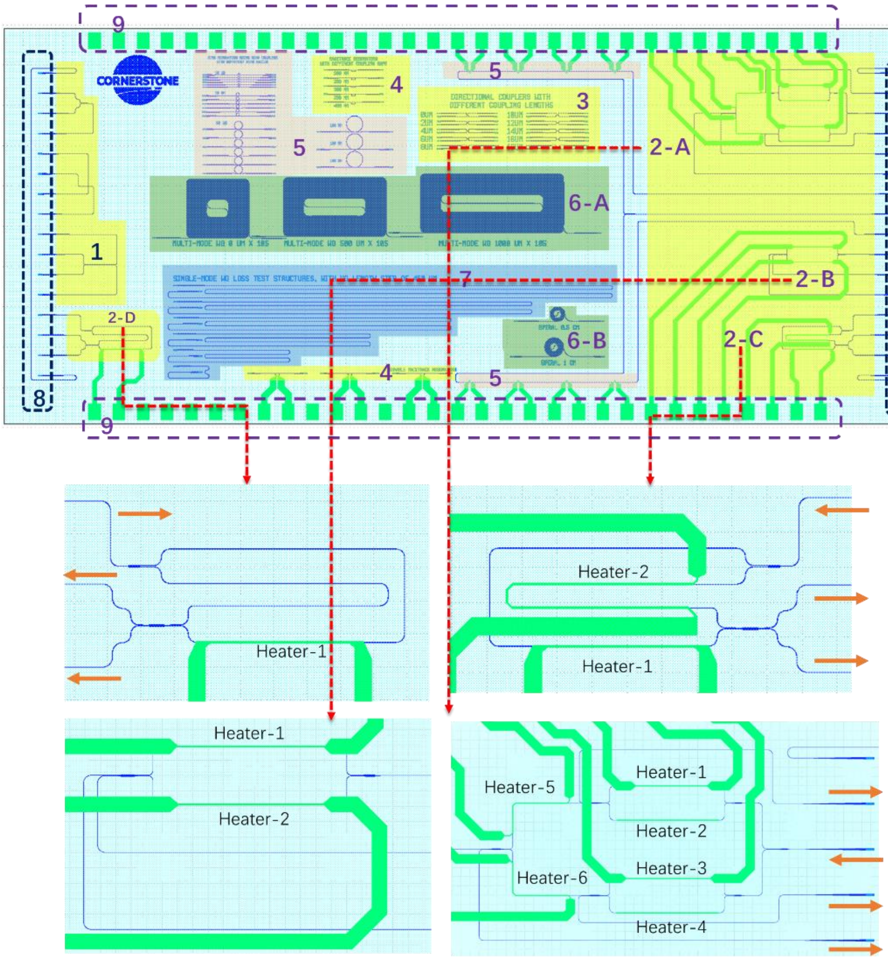

Figure 3. Tuneable MZI.

Please note that a thermo-optic phase shifter is integrated on one or two of the MZI arms. When a voltage difference is applied to the two contact pads, there will be a current flow through the filament to heat the MZI arm up, eventually resulting in the effective arm length difference change. Thus, when different voltages are applied, the constructive/destructive wavelength and the FSR can be tuned. Or, if the input wavelength is fixed and the output optical power is monitored, when the heating power is linearly increased, the optical power should vary as a sinusoidal curve. Please note these contact pads are designed for probes, whilst they can be bonded as well as explained in section 9. Device 2-D is an unbalanced MZI with one heater; Device 2-C is an unbalanced MZI with two heaters; Device 2-B is a balanced MZI with two heaters; Device 2-A is a balanced mother MZI with two Child MZI and each arm is integrated with a heater. Devices 2C&D show FSR over wavelength; Devices 2B&A are less dependent on wavelength and the optical output power is configured with applied current/voltage on the heaters. Device 2D can be programmed with different functionalities.

3. Photonic devices-Directional Couplers

As shown in Fig. 4, there are a series of directional couplers with various coupling lengths. When two waveguides are placed in parallel and close enough with each other, they are coupled evanescently, and the optical power will exchange between them. With a fixed coupling gap, the power exchange rate (power per unit distance) is fixed. By varying the coupling length, different amounts of optical power will be transferred from one waveguide to the other. So, if the light is launched into the device from one of the grating couplers, the transmission ratio at the grating couplers on the other side will be different with different coupling length.

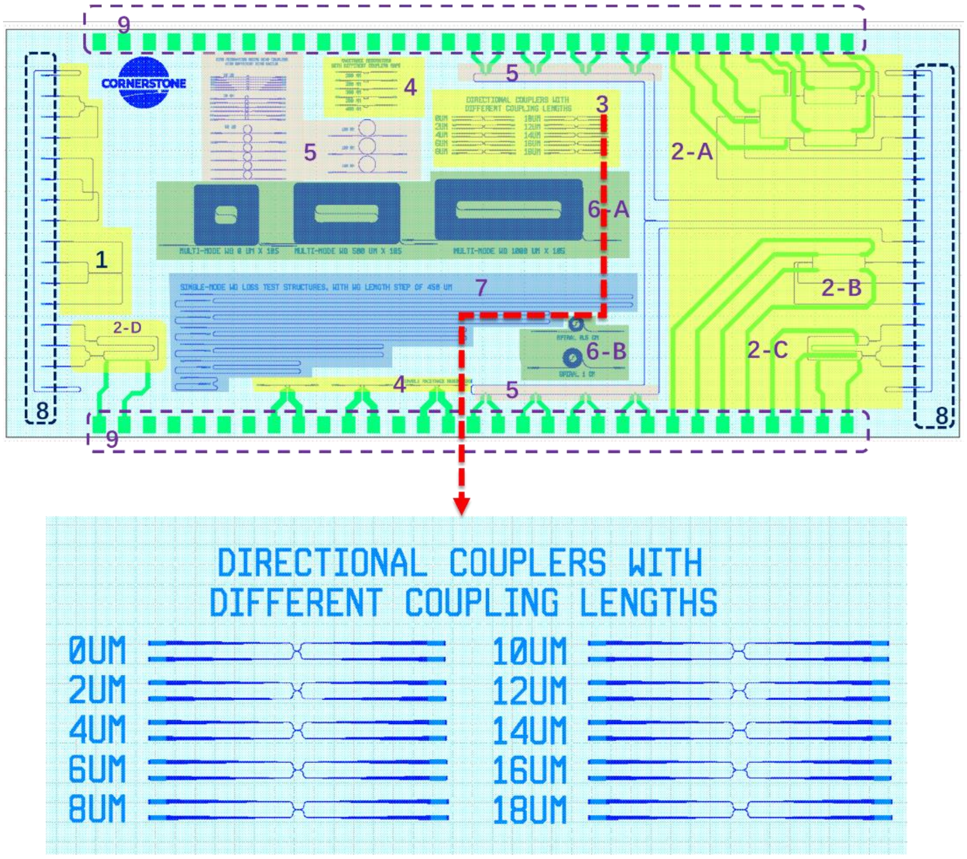

Figure 4. Directional couplers.

The directional coupler is also widely used in PICs. For example, it is the key part of a racetrack resonator.

4. Photonic devices- Racetrack resonators

Racetrack resonators are the most common resonant components used in PICs. Some examples of racetrack resonators are shown in Fig. 5. The top four racetrack resonators are fixed components, with different coupling gaps. Periodic resonance dips, which denote constructive interference in the resonator are expected in the transmission spectrum. The period, that is the FSR, is mainly determined by the circumference of the racetrack, whilst the coupling gap has a slight effect on the FSR. On the other hand, the coupling gap is a key factor in the design as it controls the *Q* factor and the coupling depth (extinction ratio) of the resonances.

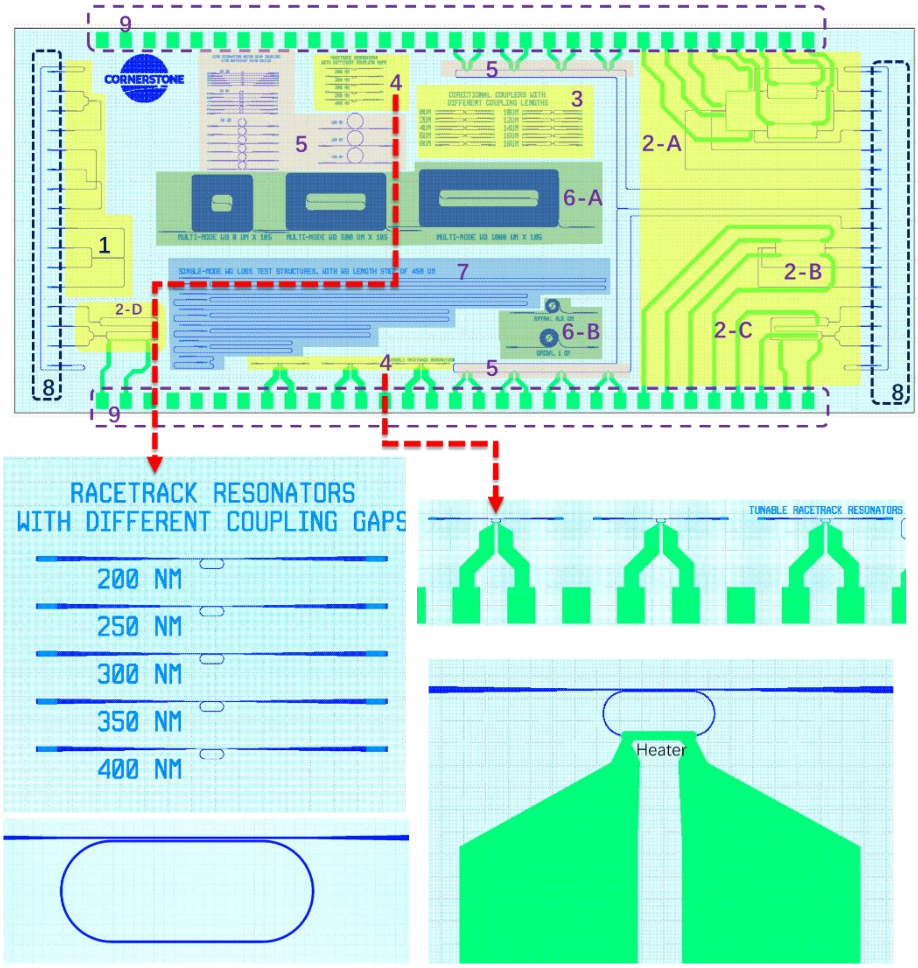

Figure 5. Racetrack resonators.

The bottom racetrack resonator is a tuneable design, in which a heater is built on the racetrack. When an electrical power is applied, the effective circumference of the racetrack will be increased, and one should observe that the resonance will shift to a longer wavelength.

5. Photonic devices- Ring resonators

Ring Resonators (RR), as shown in Fig. 6, are designed with different radii 10, 20, 50, 100 micrometres. The coupling gaps change from 200 – 325 nm for radii below 100 micrometres and 300-500nm for radii equal to 100 micrometres.

The bottom and top RR arrays are tuneable designs, in which a heater is built on each RR racetrack. When an electrical power is applied, the effective circumference of the RR will be increased, and one should observe that the resonance will shift to a longer wavelength. By doing so, each laser wavelength can be coupled into each RR by properly setting the heater power with minimal interactions between RRs.

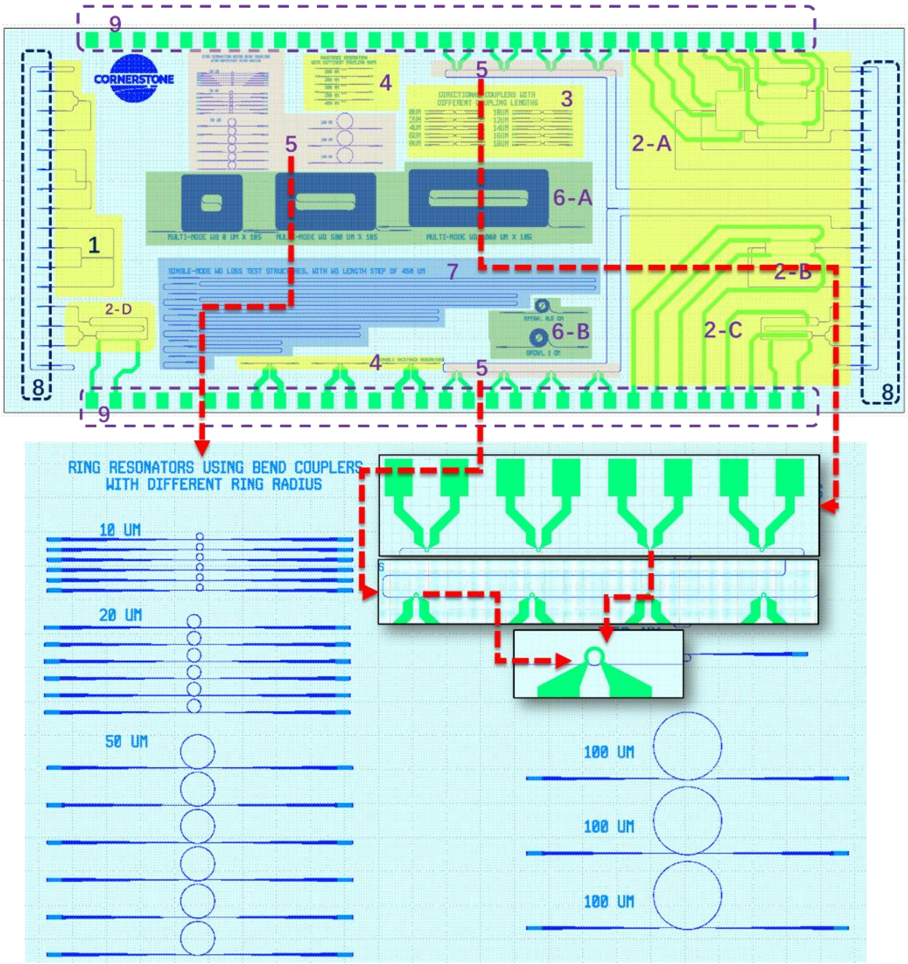

Figure 6. Ring resonators.

6. Photonic devices- Spiral waveguides

As shown in Fig. 7, there on two types of spiral waveguide.

In Design 6A, the straight part of the waveguides are multi-mode (MM) waveguides, with a width of 2 µm, whilst the waveguide bend must be SM to avoid mode crosstalk in the bend. They are connected using waveguide tapers as shown in the Fig. 7. There are three sets of spiral waveguides in Design 6A with stepped total waveguide length (optical path between the two gratings) and they can be used to measure the optical loss of the MM waveguide using the cutback method. Please note that the total waveguide length step is 500 x 105 µm as labelled on the chip.

In Design 6B, all the waveguides are arcs and thus SM waveguides. This is a popular design in sensing applications.

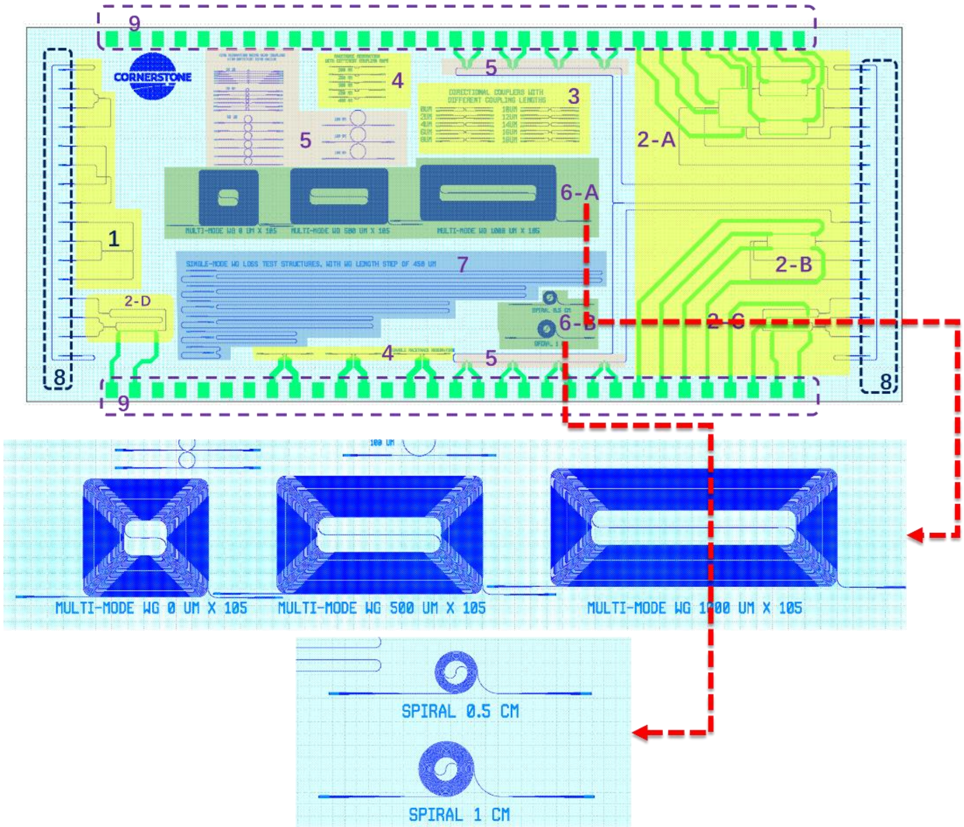

Figure 7. Spiral waveguides.

7. Photonic devices- Waveguide loss test structures

As marked in Fig. 8, there is one set of waveguide optical loss test structures for wavelengths of 1550 nm. In this set, there are 6 waveguides with a waveguide length step of 400 µm. If one measures the transmission in any set, and then plots and linearly fits the transmission in dB against the relative waveguide length, one can get the waveguide optical loss in dB per unit length. This is the so-called cutback measurement.

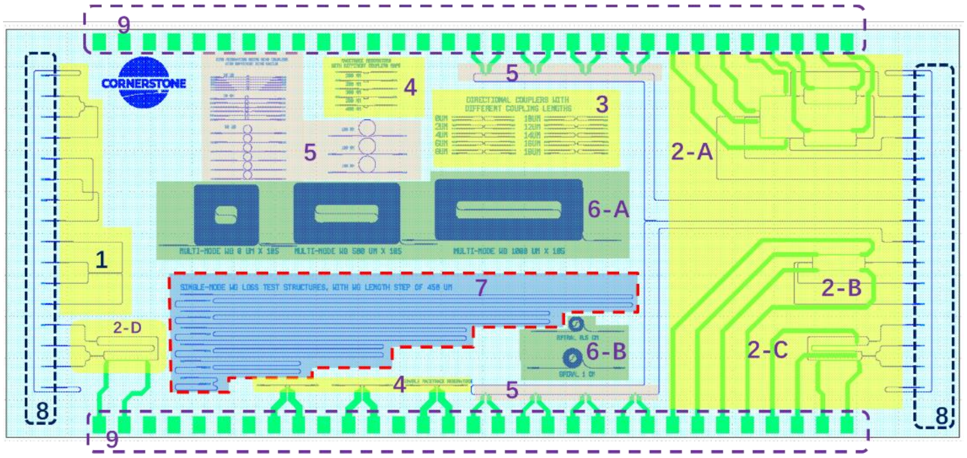

Figure 8. Waveguide loss test structures.

8. Optical packaging – optical fibre bonding

For high-level integration, a PIC chip can be optically packaged. This PIC offers an example of optical packing: optical fibre bonding. As marked in Fig. 9, there are grating coupler arrays on both the left and right sides of the chips.

On each side, there are 16 gratings couplers, and they all have a grating pitch of 250 µm. In all these grating arrays, the first grating and the last grating are always connected directly using a so-called ‘optical shunt’ to align the fibre array to the grating array during the fibre attach process, whilst the other gratings are functional gratings.

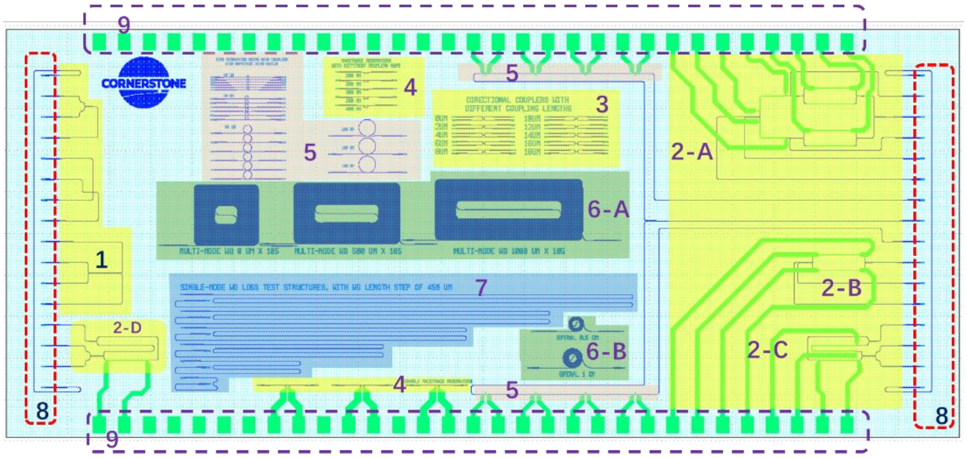

Figure 9. Grating coupler array for optical fibre attachments.

9. Electrical packaging- Wire bonding

As marked by the red circles in Fig. 10, there are two rows of metal contact pads on the top edge and bottom edge of the PIC, suitable for wire bonding, which match the pad layout on the PCBs provided for packaging.

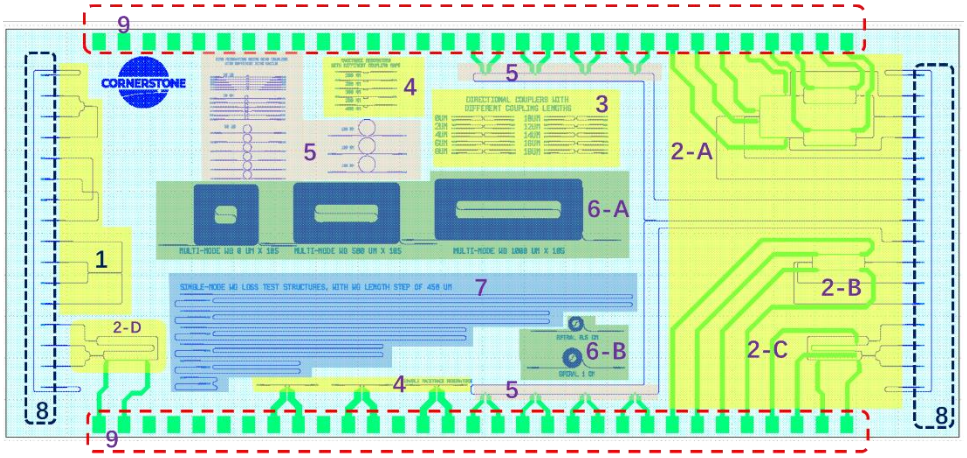

Figure 10. Metal contact pads template for wire bonding.

III. Photonic Chip I/O configuration

1. Optical packaging – optical fibre bonding

Figure 11 shows the grating coupler array labels on the west and east edges of the PIC. The connectivity of each grating coupler is summarised in Table 1.

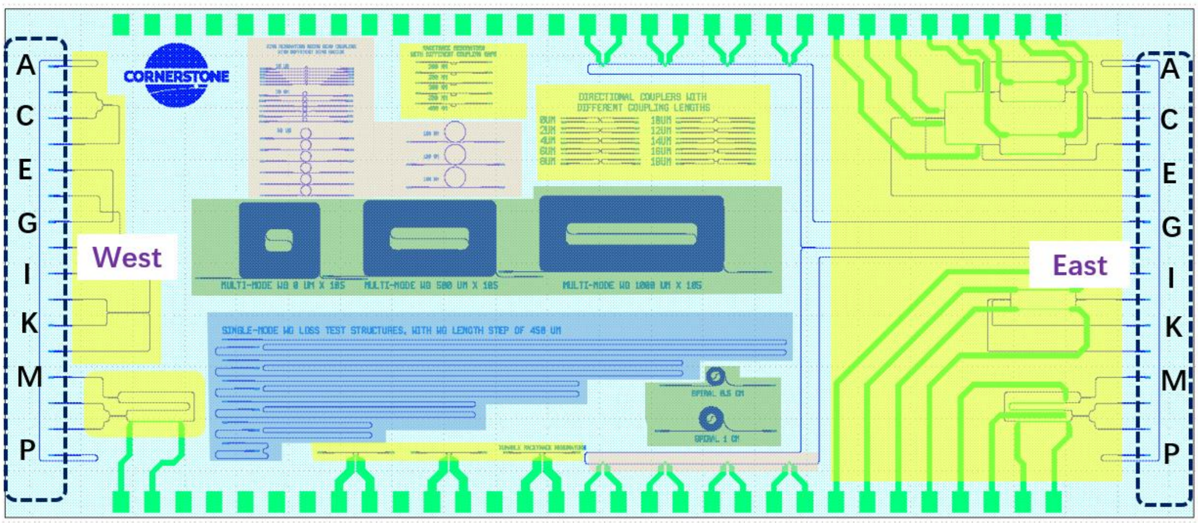

Figure 11. Grating coupler array labels.

Grating Coupler	Device Connectivity	Grating Coupler	Device Connectivity
West-A	Shunt waveguide input	East-A	Shunt waveguide input
West-B	1x2 MMI output 1	East-B	Mother-child tuneable MZI network – child output 1 (device 2A)
West-C	1x2 MMI output 2	East-C	Mother-child tuneable MZI network – input (device 2A)
West-D	1x2 MMI input	East-D	Mother-child tuneable MZI network – child output 2 (device 2A)
West-E	Waveguide crossing output 1	East-E	Mother-child tuneable MZI network – mother output 1 (device 2A)
West-F	Waveguide crossing output 2	East-F	Mother-child tuneable MZI network – mother output 2 (device 2A)
West-G	Waveguide crossing input 1	East-G	Cascaded tuneable RR network – output 1
West-H	Waveguide crossing input 2	East-H	Cascaded tuneable RR network – input
West-I	2x2 MMI output 1	East-I	Cascaded tuneable RR network – output 2
West-J	2x2 MMI input 1	East-J	Tuneable balanced MZI input (device 2B)
West-K	2x2 MMI input 1	East-K	Tuneable balanced MZI output 1 (device 2B)
West-L	2x2 MMI output 2	East-L	Tuneable balanced MZI output 2 (device 2B)
West-M	Tuneable imbalanced MZI input (device 2D)	East-M	Tuneable imbalanced MZI input (device 2C)
West-N	Tuneable imbalanced MZI output 1 (device 2D)	East-N	Tuneable imbalanced MZI output 1 (device 2C)
West-O	Tuneable imbalanced MZI output 2 (device 2D)	East-O	Tuneable imbalanced MZI output 2 (device 2C)
West-P	Shunt waveguide output	East-P	Shunt waveguide output

Table 1. Grating coupler connectivity.

2. Electrical packaging- Wire bonding

Figure 12 shows the electrical bond pad labels on the north and south edges of the PIC. The connectivity of each electrical bond pad is summarised in Table 2.

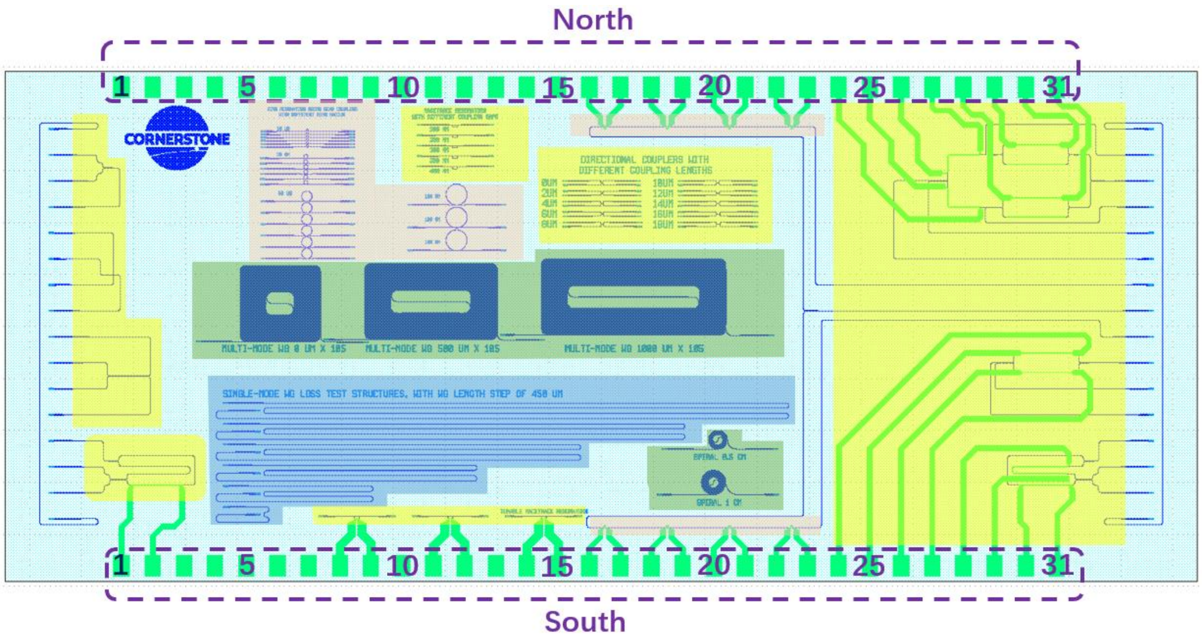

Figure 12. Metal contact pad labels.

Metal Pad	Device Connectivity	Metal Pad	Device Connectivity
North-1	Not connected	South-1	Tuneable imbalanced MZI port 1 (device 2D)
North-2	Not connected	South-2	Tuneable imbalanced MZI port 2 (device 2D)
North-3	Not connected	South-3	Not connected
North-4	Not connected	South-4	Not connected
North-5	Not connected	South-5	Not connected
North-6	Not connected	South-6	Not connected
North-7	Not connected	South-7	Not connected
North-8	Not connected	South-8	Tuneable racetrack resonator 1 port 1
North-9	Not connected	South-9	Tuneable racetrack resonator 1 port 2
North-10	Not connected	South-10	Not connected
North-11	Not connected	South-11	Tuneable racetrack resonator 2 port 1
North-12	Not connected	South-12	Tuneable racetrack resonator 2 port 2
North-13	Not connected	South-13	Not connected
North-14	Not connected	South-14	Tuneable racetrack resonator 3 port 1
North-15	Not connected	South-15	Tuneable racetrack resonator 3 port 2
North-16	Tuneable RR network – RR 1 port 1	South-16	Tuneable RR network – RR 5 port 1
North-17	Tuneable RR network – RR 1 port 2	South-17	Tuneable RR network – RR 5 port 2
North-18	Tuneable RR network – RR 2 port 1	South-18	Tuneable RR network – RR 6 port 1
North-19	Tuneable RR network – RR 2 port 2	South-19	Tuneable RR network – RR 6 port 2
North-20	Tuneable RR network – RR 3 port 1	South-20	Tuneable RR network – RR 7 port 1

North-21	Tuneable RR network – RR 3 port 2	South-21	Tuneable RR network – RR 7 port 2
North-22	Tuneable RR network – RR 4 port 1	South-22	Tuneable RR network – RR 8 port 1
North-23	Tuneable RR network – RR 4 port 2	South-23	Tuneable RR network – RR 8 port 2
North-24	Mother-child tuneable MZI network – Mother MZI arm 1 port 1 (device 2A)	South-24	Tuneable balanced MZI arm 1 port 1 (device 2B)
North-25	Mother-child tuneable MZI network – Mother MZI arm 1 port 2 (device 2A)	South-25	Tuneable balanced MZI arm 1 port 2 (device 2B)
North-26	Mother-child tuneable MZI network – Mother MZI arm 2 port 1 (device 2A)	South-26	Tuneable balanced MZI arm 2 port 1 (device 2B)
North-27	Mother-child tuneable MZI network – Mother MZI arm 2 port 2 (device 2A)	South-27	Tuneable balanced MZI arm 2 port 2 (device 2B)
North-28	Mother-child tuneable MZI network – Child MZI 1 arm 1 port 1 (device 2A)	South-28	Tuneable imbalanced MZI arm 1 port 1 (device 2C)
North-29	Mother-child tuneable MZI network – Child MZI 2 arm 1 port 1 (device 2A)	South-29	Tuneable imbalanced MZI arm 1 port 2 (device 2C)
North-30	Mother-child tuneable MZI network – Child MZI 2 arm 1 port 2 (device 2A)	South-30	Tuneable imbalanced MZI arm 2 port 1 (device 2C)
North-31	Mother-child tuneable MZI network – Child MZI 1 arm 1 port 2 (device 2A)	South-31	Tuneable imbalanced MZI arm 2 port 2 (device 2C)

Table 2. Electrical bond pad connectivity.