IEC TR 63072-1

Edition 1.0 2017-05

TECHNICAL REPORT

colour inside

Photonic integrated circuits –
Part 1: Introduction and roadmap for standardization

iTeh STANDARD PREVIEW
(standards.iteh.ai)
IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standards/sist/479f9108-b9ae-49ba-9dc0-4fd0ec169791/iec-tr-63072-1-2017

IEC TR 63072-1:2017-05(en)

THIS PUBLICATION IS COPYRIGHT PROTECTED
Copyright © 2017 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue
The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - www.iec.ch/searchpub
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

Electropedia - www.electropedia.org
The world's leading online dictionary of electronic and electrical terms containing 20 000 terms and definitions in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary
65 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

iTeh STANDARD PREVIEW
(standards.iteh.ai)
IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standar...
4fd0ec169791/iec-tr-63072-1-2017

IEC TR 63072-1

Edition 1.0 2017-05

TECHNICAL REPORT

colour inside

Photonic integrated circuits –
Part 1: Introduction and roadmap for standardization

iTeh STANDARD PREVIEW
(standards.iteh.ai)
IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standards/sist/479f9108-b9ae-49ba-9dc0-4fd0ec169791/iec-tr-63072-1-2017

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.180.99 ISBN 978-2-8322-4279-7

Warning! Make sure that you obtained this publication from an authorized distributor.

® Registered trademark of the International Electrotechnical Commission

CONTENTS

iTeh STANDARD PREVIEW
(standards.iteh.ai)
IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standards/sist/479f9108-b9ae-49ba-9dc0-4fd0ec169791/iec-tr-63072-1-2017

iTeh STANDARD PREVIEW
(standards.iteh.ai)
IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standards/sist/479f9108-b9ae-49ba-9dc0-4fd0ec169791/iec-tr-63072-1-2017

iTeh STANDARD PREVIEW
(standards.iteh.ai)
IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standards/sist/479f9108-b9ae-49ba-9dc0-4fd0ec169791/iec-tr-63072-1-2017

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

PHOTONIC INTEGRATED CIRCUITS –

Part 1: Introduction and roadmap for standardization

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

iTeh STANDARD PREVIEW
(standards.iteh.ai)
IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standards/sist/047919108-b9ae-490a-9dc0-4fd0ec169791/iec-tr-63072-1-2017

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 62072-1, which is a Technical Report, has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
86C/1428/DTR	86C/1441/RVDTR

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 63072-1 series, published under the general title *Photonic integrated circuits*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

iTeh STANDARD PREVIEW
(standards.iteh.ai)
IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standards/sist/479f9108-b9ae-49ba-9dc0-4fd0ec169791/iec-tr-63072-1-2017

PHOTONIC INTEGRATED CIRCUITS –

Part 1: Introduction and roadmap for standardization

1 Scope

This part of IEC 63072, which is a Technical Report, provides an introduction to photonic integrated circuits (PICs) and describes a roadmap for the standardization of PIC technology over the next decade.

NOTE The trademarks and trade names mentioned in this document are given for the convenience of users of this document; this does not constitute an endorsement by IEC of these companies.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

iTeh STANDARD PREVIEW
(standards.iteh.ai)

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standards/sist/479D108-b9ae-49ba-9dc0-4fd0ec169791/iec-tr-63072-1-2017

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
photonic integrated circuit
PIC
integrated circuit that contains optical structures to guide and process optical signals

3.2
III-V
three-five
compound semiconductor formed of materials from the third and fifth column of the periodic table

EXAMPLE 1 Indium phosphide

EXAMPLE 2 Gallium arsenide

3.3
through-silicon-via
TSV
metallised hole (via) through a silicon wafer enabling electrical conductivity from one surface of the silicon to the other

3.4
silicon photonics
structure or system of structures fabricated into a silicon wafer to guide light and enable passive and active optical processes to be carried out at the integrated circuit level

3.5
silicon-on-insulator
SOI
structure or system of structures fabricated into a silicon wafer to guide light and enable passive and active optical processes to be carried out at the integrated circuit level

3.6
vertical cavity surface emitting laser
VCSEL
semiconductor laser diode with direction of laser emission perpendicular to top surface

3.7
Mach-Zehnder interferometer
MZI
waveguide structure whereby an incident optical signal is split into two paths and allowed to recombine into an output signal and on which the phase variance between the two recombined signals can be manipulated to allow modulation of the output signal or switching between two or more input and output signals

3.8
ring resonator
closed optical path in which the optical radiation circulates in an optical loop in the same direction

Note 1 to entry: Standing waves are possible to exist at particular wavelengths.

iTeh STANDARD PREVIEW
(standards.iteh.ai)

3.9
micro-ring resonator
MRR
closed ring resonator waveguide structure on a PIC

IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standards/sist/479f9108-b9ae-49ba-9dc0-4fd0ec169791/iec-tr-63072-1-2017

Note 1 to entry: When located near a waveguide, the MRR will selectively couple out of the waveguide optical radiation only at the wavelengths λ_m, which satisfy the following resonance condition: MRR optical path length = $2\pi n_{eff} = m\ \lambda_m$, where n_{eff} is the effective refractive index of the MRR waveguide and m is a positive integer.

3.10
resonator finesse
F
quantity describing the sharpness of a resonant peak relative to the free spectral range of the resonator, obtained by dividing free spectral range (FSR) of a resonator by full width half maximum (FWHM) of a resonant peak

3.11
quality factor of a ring resonator
resonator finesse multiplied by the mode number m, where $m = 2\pi n_{eff}/\ \lambda_m$ and where n_{eff} is the effective refractive index of the ring resonator and λ_m is the resonant wavelength

3.12
large-scale integration
LSI
process of integrating thousands of transistors onto a single semiconductor chip

3.13
buried oxide
BOX
silicon dioxide (SiO_2) layer buried in silicon wafers to form silicon-on-insulator assemblies

Note 1 to entry: BOX layer is typically buried at less than 100 nm to several micrometers beneath the wafer surface depending on application. BOX layer thickness typically ranges from 40 nm to 100 nm.

3.14
grating coupler
GC
periodic grating structure on the surface of a PIC, which redirects light propagating in a waveguide in the PIC out through the surface of the PIC, typically at a small angle normal to the PIC surface

Note 1 to entry: This is the preferred method of coupling light into and from a PIC and typically uses a single-mode fibre or single-mode fibre array with an 8° angled interface. Therefore grating couplers are usually designed to redirect light into and out of the PIC at an angle of 8° normal to the PIC surface.

3.15
single polarization grating coupler
SPGC
grating coupler designed to couple light of one linear polarization to and from a waveguide in the PIC

3.16
polarization splitting grating coupler
PSGC
grating coupler designed to split the light incident on the PIC into two orthogonal linear polarizations, which are conveyed along two separate corresponding waveguides in the PIC

3.17
laser induced forward transfer
LIFT
direct-writing technique allowing the deposition of tiny amounts of material from a donor thin film through the action of a pulsed laser beam

iTeh STANDARD PREVIEW
(standards.iteh.ai)
IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standards/sist/479f9108-b9ae-49ba-9dc0-4fd0ec169791/iec-tr-63072-1-2017

3.18
complementary metal oxide semiconductor
CMOS
technology for constructing low power integrated circuits typically used in microprocessors, microcontrollers, static RAM, and other digital logic circuits

3.19
high speed phase modulator
HSPM
device allowing the phase of an optical signal to be rapidly varied

Note 1 to entry: One example of a HSPM is a PN junction on one of the waveguide branches of a MZI in a PIC, which causes a change in refractive index in response to the density in charge carriers passed through it.

4 Photonic integrated circuit (PIC)

4.1 Overview

A PIC is an integrated circuit on which operations can be carried out on light conveyed through it. One could think of a PIC as a miniature optical train, i.e. a sequence or collection of elements or structures, which perform an operation on one or more incident light beams. These operations may include modulation, wavelength dependent and independent switching, wavelength multiplexing/demultiplexing, power splitting, filtering, amplification, light generation (lasers) and light detection (detectors). Depending on the available chip size, element size and layout efficiency of optical elements and structures, a PIC can incorporate functions of varying complexity.

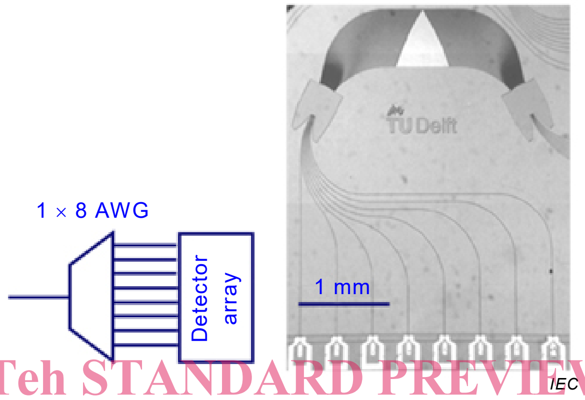
PICs operate on information signals imposed on optical wavelengths typically within the infrared 850 nm to 1 650 nm portions of the electro-magnetic spectrum reserved for fibre optic communication.

PICs can accommodate huge bandwidth densities, for example high data rates of information conveyed along tiny channels, which can be very densely arranged at the chip level. For this reason, PIC products are primarily deployed in the optical fibre communications market.

Optical sensors, however, represent a promising emerging application field for PICs, in which they can be used in the medical, aerospace, energy, automotive and defence sectors.

PICs are also widely anticipated to play a key role in the future commercialisation of quantum computers.

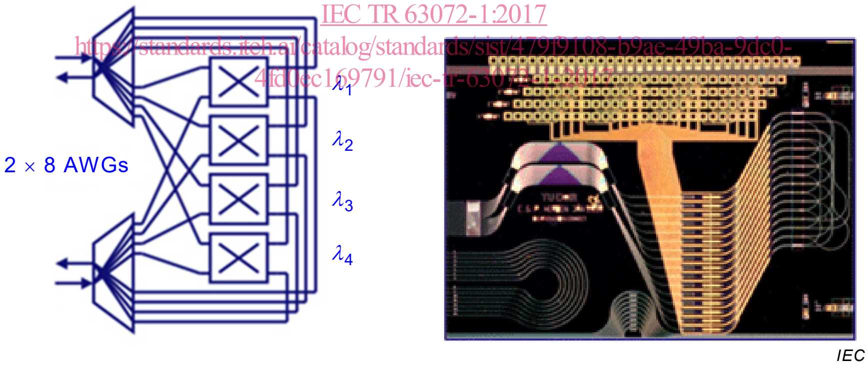
Figure 1 shows some examples of PICs of varying complexity and functionality.



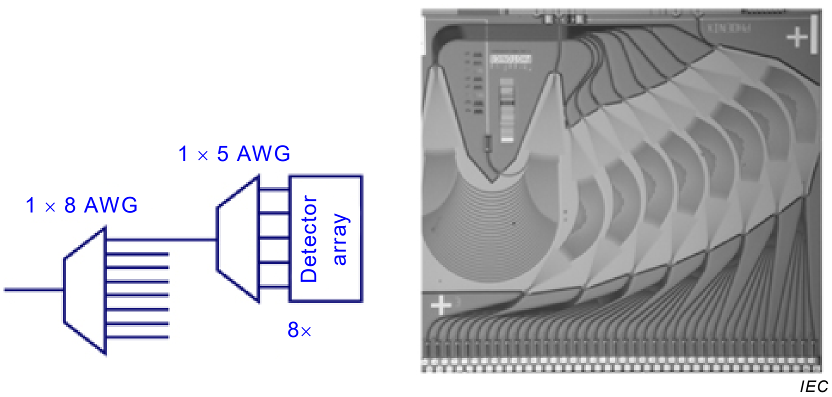
iTeh STANDARD PREVIEW
(standards.iteh.ai)

a) Wavelength-division multiplexing (WDM) receiver consisting of an array waveguide (AWG) integrated with an 8 detector diode

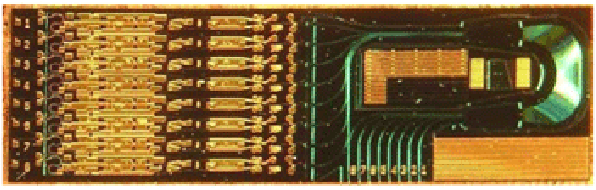
IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standards/sist/479f9108-b9ae-49ba-9dc0-4fd0ec169791/iec-tr-63072-1-2017



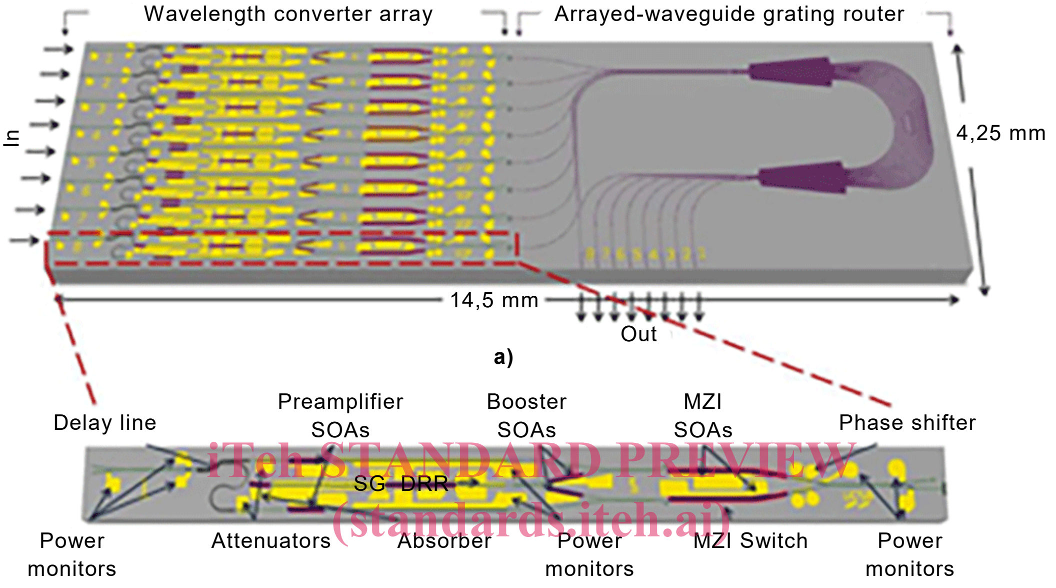
b) 4-channel 2 × 2 WDM cross-connect integrating 2 AWGs with 16 Mach-Zehnder interferometer switches in dilated configuration (66 components in total)



c) 40-channel WDM monitor chip integrating 9 AWGs and 40 detector diodes



d) 8 × 8 channel wavelength router, integrating 8 wavelength converter circuits with an 8 × 8 AWG, with over 175 components



iTeh STANDARD PREVIEW
(standards.iteh.ai)
IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standards/sist/479f9108-b9ae-49ba-9dc0-4fd0ec169791/iec-tr-63072-1-2017

e) Detail of wavelength converter section

SOURCE Institute of Physics

Figure 1 – Examples of PICs [1][1]

4.2 PIC families

4.2.1 General

The fabrication techniques for PICs are similar to those used in electronic integrated circuits, in which photolithography is used to pattern semiconductor wafers for etching and material deposition.

Unlike electronic integration where silicon is the dominant material, PICs can be fabricated from a variety of semiconductor materials including silicon, indium phosphide (InP) and gallium arsenide (GaAs), and different material systems, including electro-optic crystals such as lithium niobate, silica-on-silicon and silicon-on-insulator (SOI).

Different materials provide different advantages and limitations depending on the functions to be carried out.

[1] Figures in square brackets refer to the Bibliography.

4.2.2 Silicon photonics

Silicon PICs enable direct co-integration of the photonics with transistor based electronics; however, as an indirect bandgap material, silicon PICs will typically require separate elements for light generation and detection. Although it was shown in 2005 that silicon can be used to generate laser light via the Raman effect, such lasers would need to be optically driven rather than electrically driven, which would require an additional optical pump laser source [2].

4.2.3 III-V photonics

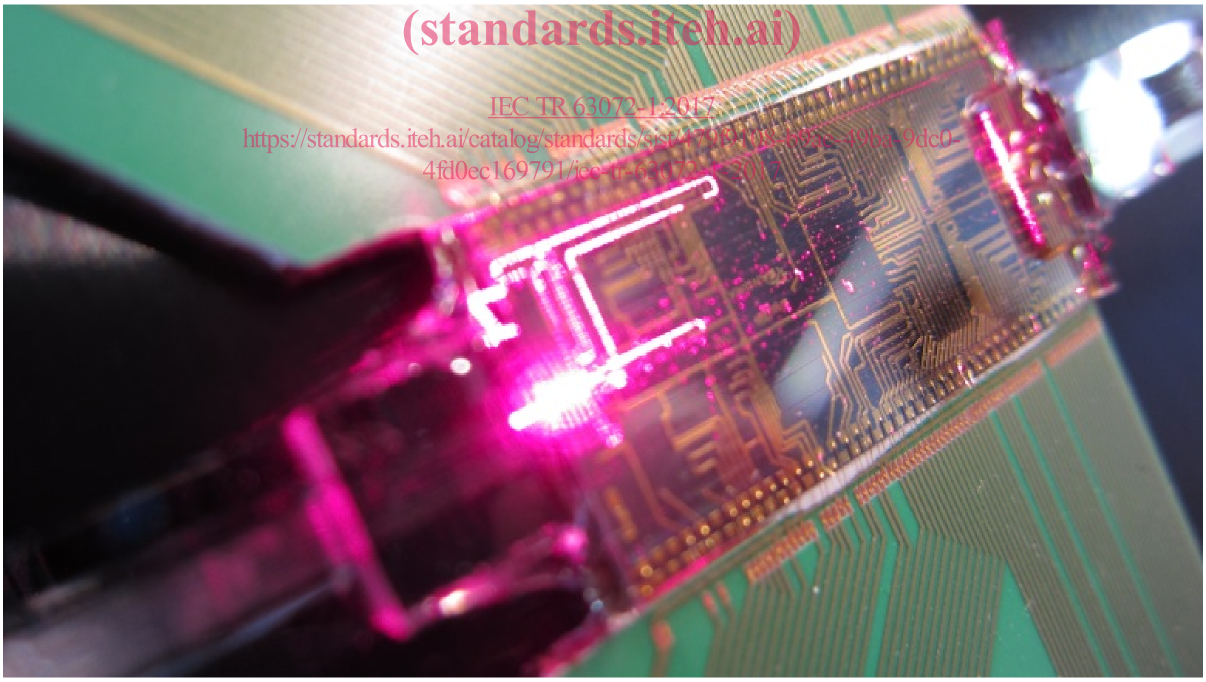
PICs based on so called direct bandgap materials, such as indium phosphide or gallium arsenide, do allow the direct integration of light sources and detectors on the same integrated circuit; however, the foundry infrastructure is much more limited when compared to silicon wafers, leading to III-V PICs being typically restricted to low volume, high cost applications.

4.2.4 Silica and silicon nitride PICs

Silica (silicon dioxide) based PICs have very desirable properties for passive photonic circuits such as arrayed waveguide gratings (AWGs) due to their comparatively low losses and low thermal sensitivity.

Silicon nitride (Si_3N_4) based PICs are also becoming a leading material candidate for PICs in the datacom space, mainly due to the lower optical losses introduced and the inherent complementary metal oxide semiconductor (CMOS) compatibility with the electronics fabrication processes (see Figure 2).

iTeh STANDARD PREVIEW
(standards.iteh.ai)
IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standards/sist/4709f098-6b2c-49ba-9dc0-4fd0ec169791/iec-tr-63072-1-2017



IEC

SOURCE Photo courtesy of SATRAX B.V., www.satrax.nl

Figure 2 – Optical beam forming network fabricated in TriPleX (silicon nitride)

Currently, the two most commercially utilised material platforms for PICs are based on silicon and indium phosphide.

4.3 Manufacturing capabilities

As of 2016, there were only a handful of organisations that could directly manufacture PICs. These included STMicroelectronics (France-Italy), Intel (US), and AMS (Austria).

Given the long turn-around for PIC wafer fabrication, the concept of multi project wafers was introduced by which a variety of different PIC designs from different organisations (usually small to medium enterprises) could be incorporated onto a single wafer, allowing a variety of different designs to be fabricated at once. Access to PIC fabrication by small to medium enterprises has been made possible through so-called multi-project wafer platforms, including JEPPIX (http://www.jeppix.eu/) for III-V photonics, EPIXFAB (http://www.epixfab.eu/) for silicon photonics, and TRIPLEX ("http://www.lionixbv.nl/triplex-integrated-optics) for silicon nitride photonics.

4.4 Global market

As of 2013, North America was the leader in the PIC market with 49 % market share; however, it is estimated that Asia-Pacific (APAC) will emerge as the market leader by 2022, growing at a compound annual growth rate (CAGR) of 35,9 % from 2012 to 2022.

The PIC market is expected to yield revenue growth from $150,4 million in 2012 to $1 547,6 million by 2022, at an estimated CAGR of 26,3 % from 2012 to 2022 [3].

As of 2015, some of the leading global organisations selling PIC products are Infinera Corporation (USA), NeoPhotonics Corporation (USA), Luxtera (USA), Mellanox (Israel) and OneChip Photonics (Canada).

iTeh STANDARD PREVIEW
(standards.iteh.ai)

4.5 Global government investment in PIC research and development

IEC TR 63072-1:2017
https://standards.iteh.ai/catalog/standards/sist/479f9108-b9ae-49ba-9dc0-4f10ec169791/iec-tr-63072-1-2017

4.5.1 General

In addition to large scale research and development on PIC technologies, as of 2016, there has been renewed global government level investment into PIC development, which is seen as a key enabling technology.

4.5.2 United States of America

The importance of developing an integrated photonic eco-system was underscored by the launch in 2016 of the American Institute of Manufacturing Integrated Photonics (AIM), a public-private partnership providing over $610m worth of funding (http://www.aimphotonics.com/).

4.5.3 Europe

As of 2016, the European Commission Horizon2020 framework programme has provided and was expected to continue to provide substantial funding towards integrated photonics technologies between 2014 and 2020 of a similar order to that of the United States AIM initiative.

4.5.4 Japan

Photonics Electronics Technology Research Association (PETRA) is an incorporated technology research association, established on August 24, 2009. The organization is approved by METI (Ministry of Economy, Trade and Industry) under the Japanese Act on an Incorporated Research and Development Partnership. PETRA carries on national research and developments projects on leading-edge photonics and electronics converged devices and systems in the information and communication technology area, where photonics technology and electronics technology are mutually incorporated.