PARADIGM Publishable summary

PARADIGM: Photonic Advanced Research And Development for Integrated Generic Manufacturing

***The PARADIGM project* aims to establish, and facilitate access to, cost-effective Photonic Integrated Circuit (PIC) manufacture in Europe**

Background: PARADIGM is an *integrating project* focusing on platform technology. It aims to create a paradigm shift in the development and manufacturing of photonics. It is developing an open-access industrial generic foundry production capability for integrated circuits based on Indium Phosphide (InP), building on the foundations laid by the EU-NMP project EuroPIC[1]. PARADIGM has brought together a strong cross-European consortium of experts, consisting of a mix of SMEs, industry and academic partners in the fields of component manufacturing, PIC design and applications, photonic CAD, and packaging. It has a total budget of ~13M€, with €8.75 million funding from the EU Seventh Framework Programme to effect a fundamental change in the way applications based on InP-based photonic integrated circuits are designed and manufactured in Europe.

PARADIGM is making good progress, creating the foundations for a powerful, cost effective and versatile foundry platform in Europe. This is expected to lead to a dramatic reduction of fabrication, packaging and testing costs as well as the development time of Application Specific Photonic ICs (ASPICs) and thereby pave the way for the breakthrough of the large-scale application of photonics in our daily lives. The PARADIGM project has integrated the various elements of the required foundry processes at different locations, created design rules, libraries, building blocks, packaging, test and validation mechanisms and promoted the adoption of the developed standards. PARADIGM targets the following objectives:

- **Technology convergence and roadmapping:** Two highly capable, stable and convergent technology platforms are being created, covering the major part of today's and future application areas. Platforms I and II address a wide range of applications operating ~1.55µm wavelength range, including fibre optic sensors, medical applications and signal processing as well as telecommunications and data communications systems. A platform-level extension to longer wavelengths (Platform III) focuses on sensing and medical applications requiring longer wavelengths (out to 2.1µm).
- **Create methods and tools:** New working methods and tools are being developed to decouple the design work from the fabrication technology and to bring the design of photonic integrated components to a higher (circuit) level of abstraction.
- **Set up generic packaging and test:** A generic packaging approach are being created by standardizing the positions of optical and electrical ports, which allows packaging of a variety of different chips in a single standardized package. Standardized in-line test methods to control the quality of the fabrication platforms and on-wafer test methods to characterize and prove the performance of the products are being developed.
- **Platform exploitation:** The project provides access to the created generic platforms for the project's Applications Group by offering several multi project fabrication runs. Interaction with external users of the technology helps to bring PARADIGM into the public domain, expanding awareness of the potential of ASPICs and enlarging the potential application areas of photonics.

[1] EuroPIC is a European (FP7-NMP) SME project, in which 17 partners cooperated to move the foundry concept, which had been pioneered in ePIXnet, to an industrial environment and make it accessible for SMEs

Roadmap

A timeline for platform introduction to the marketplace has been elaborated in the form of the JePPIX roadmap recently updated. Members of the consortium are working hard to make semi-commercial multi-project wafer runs based on first release technology a reality in the near future, and expect to make a formal announcement before the end of this year. (http://www.jeppix.eu/document_store/JePPIXRoadmap2013.pdf).

Expected Results

PARADIGM is working towards development, characterization and validation of a second generation generic platform capability embracing:

- 40GHz TxRx platform with extended functionality (polarization handling, modular gain blocks, SSC-array for I/O).
- Extension of platform capability to new wavelength ranges (out to 2.1µm)
- Use of high electrical isolation processes (e.g. SI substrates and ion implantation processes) for low parasitics and high integration levels.
- Extension to selective area growth (SAG) techniques for multi-wavelength circuits, and investigation of mixed BH and surface ridge technology.

This involves the development of supporting technology in many areas

- Development of a full photonic circuit simulator including layout tools.
- Development of a design library at the component level, as well as the full range of building blocks provided by the new extended platforms
- Attention to RF-design aspects
- Attention to cross-talk issues
- Design rule checking
- Development of a generic packaging approach and prototype generic package(s) for a) low (optical) port count, b) close packed array I/O.
- Development of Generic Test algorithms and experimental setups for rapid testing and wafer validation. Standardised I/O and test layout (see generic testing)

More generally, PARADIGM fully involves the university sector in spinning out design expertise through its applications group, and the move to create local design centres. The design hub at Warsaw University of Technology servicing the new EU member states is one example, TU/e and University of Cambridge are others. This involves setting up photonic IC design and technology courses and educating users about application opportunities. The brokering organization (JePPIX[2]) also needs to be expanded for facilitating user access, for example by setting up an organization with national contact points, for informing and supporting users and organizing training.

Achievements so far

PARADIGM has already made great strides in putting in place both the infrastructure for platform access and new technology. ASPICs from the first PARADIGM Multi-project wafer cycle are now in test and designs accepted onto a second MPW cycle are in process at the fabs of Oclaro and HHI. Third cycle designs are in the final stages of design and mask realisation; many of these designs are state of-the-art on InP in terms of their complexity. To support these MPW cycles software tools have further developed. Software tools for circuit design and simulation such as PICWave and Aspic have become well established and now contain a full complement of ready to use building blocks calibrated to each of the platforms and the MaskEngineer layout tool from PhoeniX Software contains automatic design rule checking – all to assist the user in making a correct design quickly.
In a fundamental advance the consortium has demonstrated the use of library modules for complex composite building blocks such as Arrayed Waveguide Grating devices and Multimode interference

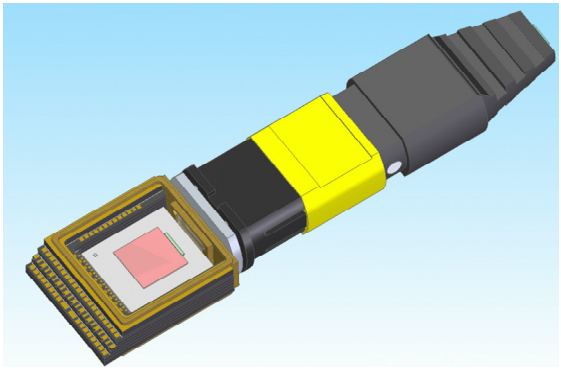
[2] Joint European Platform for InP-based Photonic Integrated Components and Circuits (www.jeppix.eu)

filters (AWGs and MMIs). Circuit libraries can now be accessed simply from a tool such as Aspic using the PDAFlow API (Applications Programmers Interface – maintained and controlled by non-profit PDAFlow Foundation) which glues together the complete toolset. Any design house can now use the power of the API to develop its own intellectual property on the platforms and make it available to other designers

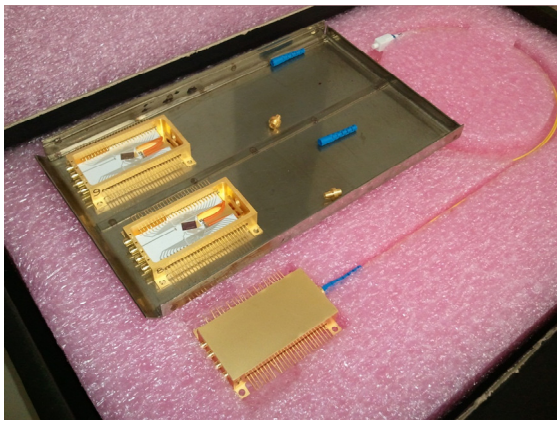
PARADIGM has entered a particularly exciting phase of the project; in cycle three HHI has introduced a new gain block and Bragg grating capability bringing transmitter performance to its high frequency platform. In cycle 4 scheduled for early 2014 we expect further major technological advances as HHI consolidates its new high speed TxRx platform, Oclaro trials its own new high speed TxRx technology in platform format for the first time and COBRA proves its long wavelength capability. High frequency detectors and phase modulators capable of 40Gbit/s operation have already been demonstrated at Oclaro and lasers out to 2.1µm in the COBRA fab.

The RF performance is one of the focus points of PARADIGM and within the design environment a progress has been made with the design and simulation of RF building blocks for both chip platforms, to support designers in the later MPWs with well defined building blocks with RF capability, and a choice of micro-strip and coplanar lines. Generic packaging solutions for photonic integrated circuits were simply unavailable at the start of PARADIGM and bespoke packaging concepts are always high cost. PICs are relatively large chips, from a few mm^2 up to 6x6 mm^2 in PARADIGM, they often require a combination of multiple optical I/O, many tens of dc drive channels and several RF ports so even initial testing has up until now been a challenge

PARADIGM has pursued three different generic packaging concepts capable of housing most if not all ASPICs. The project can now offer a 'gold box' solution at LINKRA/TEO, and is in the final stages of building a completely new generic package, designed to current standards and with the potential for IEC adoption. This new PICOSA (PIC Optical Sub Assembly), measuring just 15.5x18x5mm^3, with an internal active device cavity ~9.5mm square will support up to 12 optical interfaces with 10x10Gbit/s RF lines and at least 48 DC connections and a high current TEC connection. The package has been designed in conjunction with one of the largest manufacturers of this style of package to ensure the highest performance, best price and manufacturability. All of these factors should help minimise cycle times for new products with the best cost.



PICOSA package with PIC and optical connector (optical sub assembly)



ASPICs in a generic package developed by partner LINKRA/TEO.

Finally, PARADIGM is pursuing passive assembly approaches capable of high fibre I/O counts which it hopes to demonstrate in the final period of the project

Potential Impact of PARADIGM

PARADIGM is already having a significant impact in Europe and indeed worldwide as is evidenced by the more than fifty ASPIC designs fabricated or in process on its platforms to date and the large number of invited presentations at almost all relevant conferences in Europe, Asia and North America. Through its training activities and extensive mentor led user support, PARADIGM has already helped a large number of groups to gain expertise in this area of photonics at the same time as developing new technology and new platforms with greatly enhanced performance.

PARADIGM is:

- **Reinforcing European leadership and industrial competitiveness:** As a result of the pioneering work within the EU ePIXnet[3] Network of Excellence and the EU SME project EuroPIC[4], Europe has maintained a lead in the elaboration of the new generic platform paradigm for InP Photonics.
- **Providing opportunity for new applications and new products:** By reducing the production costs by more than an order of magnitude, PICs will get a competitive advantage over hybrid or micro-optic solutions, or solutions based on discrete components. Superior cost-effectiveness will create a business case for a wide range of products where the production costs are presently too high to address a sufficiently large market.
- **Establishing an integrated production path from design to volume manufacturing:** The key to a generic process is the availability of design tools for circuit design and layout which are fully integrated with mask layout tools and fab processing technology. By adding a generic packaging capability (with compatibility ensured by standardised design rules) integrated with the chip process, PARADIGM is putting together for the first time a truly integrated end-to end process methodology for ASPIC production.
- **Providing cost-effective access:** Users will be able to develop circuits in a "frozen" technology release, and those willing to make the shift will experience the new freedom that it brings; designing complex circuits with sophisticated design tools and a powerful component library in a high performance technology. These developments make it possible for the first time to provide cost-effective access for fabless companies and through the mechanism of shared MPW runs, entry costs per user can be driven even lower.

General facts and figures

The website address for the project is www.PARADIGM.jeppix.eu

Partners in the PARADIGM consortium are:

Technical University of Eindhoven (Coordinator, Netherlands,);Willow Photonics Ltd (UK), CIP Technologies (UK), Oclaro Technology, Ltd. (UK), FhG-HHI (Germany), FhG-IZM (Germany), Chalmers Tekniska Hogskola AB, (Sweden), Filarete, Italy, PhoeniX Software (Netherlands), Gooch and Housego (Torquay) Ltd (UK), Photon Design Ltd (UK), III-V Lab (France), University of Cambridge (UK), Linkra srl. (Italy), Politecnico di Milano (Italy), Politechnika Warszawska (Poland), and Bright Photonics (Netherlands).

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[3] The "*European Network of Excellence on Photonic Integrated Components and Circuits*" is an European FP6 research project, in which more than 60 R&D groups from industry, universities and research institutes cooperated on development of open access to expensive technological infrastructures.