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E. Kehayas

L. Stampoulidis

P. Henderson

Andrew Robertson

et al.

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THE EUROPEAN PROJECT HIPPO HIGH-POWER PHOTONICS FOR SATELLITE LASER COMMUNICATIONS AND ON-BOARD OPTICAL PROCESSING

E. Kehayas, L. Stampoulidis, P. Henderson, A. Robertson
Gooch and Housego
Broomhill Way, Torquay, Devon, TQ2 7QL, United Kingdom

F. Van Dijk, M. Achouche
III-V Lab
1 Avenue Augustin Fresnel, Palaiseau, 91767, France

A. Le Kernec, M. Sotom
Thales Alenia Space
26 Avenue Jean François Champollion, Toulouse, 31100, France

F. Schuberts, T. Brabant
Fiberware
4 Bornheimer Street, Mittweida, 09648, Germany

I. INTRODUCTION

Photonics is progressively transforming from a highly- focused technology applicable to digital communication networks into a pervasive “enabling” technology with diverse non-telecom applications. However, the centre of mass on the R&D level is still mostly driven by, and invested in, by stakeholders active in the telecoms domain. This is due to the high level of investments necessary that in turn require a large and established market for reaching break-even and generation of revenues. Photonics technology and more specifically, fibre-optic technology is moving into non-telecom business areas with great success in terms of markets captured and penetration rates. One example that cannot be overlooked is the application of fibre-optics to industrial applications, where double-digit growth rates are recorded with fibre lasers and amplifiers constantly gaining momentum. In this example, several years of R&D efforts in creating high-power amplification solutions and fibre-laser sources by the telecom sector, were piggy-backed into industrial applications and laser cutting/welding equipment that is now a strong R&D sector on its own and commercially now displacing some conventional free space laser cutting/welding.

The space sector and associated market characteristics pose significant constraints on the levels of investment justifiable due to factors relating to expected revenues, high development costs due to “zero-failure” requirements and extensive testing and qualification required. Hence, technology development from TRL 1 within the space domain takes longer to mature and is harder to justify in terms of investments. The “rules of engagement” change radically when lower TRL technologies are piggy-backed into the space domain, hence exploiting investments already allocated and applying novel designs and required advancements starting from a higher TRL. Research and development is now required focusing on satellite communications that make use of high-power photonics technologies, exploiting the advances from telecommunications and fibre-optics in laser industrial applications.

Table 1. Photonic technologies and market drivers

Photonic technology	Today’s market driver	Space driver
Indium-Phosphide monolithic fabrication processes and chips	Telecom transmitters	Laser sources in satellite laser communication terminals and photonic telecom payloads
Fused fibre technology	telecom transceiver, amplification and switching modules, industrial lasers	telecom/remote sensing satellite building blocks
Micro-structured Large-Mode-Area fibres	high-power fibre lasers for industrial and sensing applications	High-power lasers and amplifier building blocks
Erbium/Ytterbium-doped fibre amplifiers	CATV and Passive Optical Networks	Laser communication terminals and on-board photonic processing

II. R&D ACTIVITIES AND WORKPLAN

HIPPO [1] is a 3-year research & development collaborative project co-funded by the European Union. The project aims to design and develop a new generation of robust and reliable high-power photonic components and modules, demonstrate applicability to space applications and prove that the technology can operate in the stringent requirements set by the space environment. HIPPO development plan includes active photonic components that rely on advanced semiconductor fabrication and packaging approaches developed by III-V LAB and G&H respectively. On the fibre side, development of new micro-structured optical fibres by FIBERWARE and passive fibre components by G&H are scheduled. Using the components developed, high-power amplifier modules are developed and tested by G&H. All HIPPO components and modules are then evaluated by the space vendor (Thales Alenia Space), exploiting its unique expertise and infrastructure on space systems. Table 2 shows the technology development activities foreseen within the program. HIPPO focuses on creating a powerful "made in Europe" technology base covering the complete spectrum of "high-power photonics". In so doing, it will create a strong potential to capture significant market segments due to the vertically-integrated consortium. The HIPPO development phase starts with the system vendor and prime space contractor (Thales Alenia Space) for providing initial inputs on the space-born systems where HIPPO components would offer unique advantages not possible with competing technologies. According to these high-level set of performance metrics, the component manufacturers (III-V LAB, G&H TQY, FIBERWARE) and module vendor (G&H STG) provide the necessary design methodologies and device designs for realizing the specifications.

Table 2. Photonic technologies developed

Component technology	**Description**
High-power semiconductor components for space	o Narrow-linewidth and high-power seed lasers at 1550nm o High-efficiency photodetectors at 1550nm o High-power multimode pumps
Photonic Crystal fibres	o Erbium and Erbium/Ytterbium co-doped rad-hard micro-structured fibres
High-power handling passive components for space	o Signal/pump combiners and fused couplers o Fibre-pigtailed passive components involving free-space elements o PCF fusion splicing technology
High-power optical fibre amplifiers	o 500mW – 1W rad-hard amplifiers (GEN-1) o 1-10Watt rad-hard amplifiers using PCF Er/Yb fibres (GEN-2)

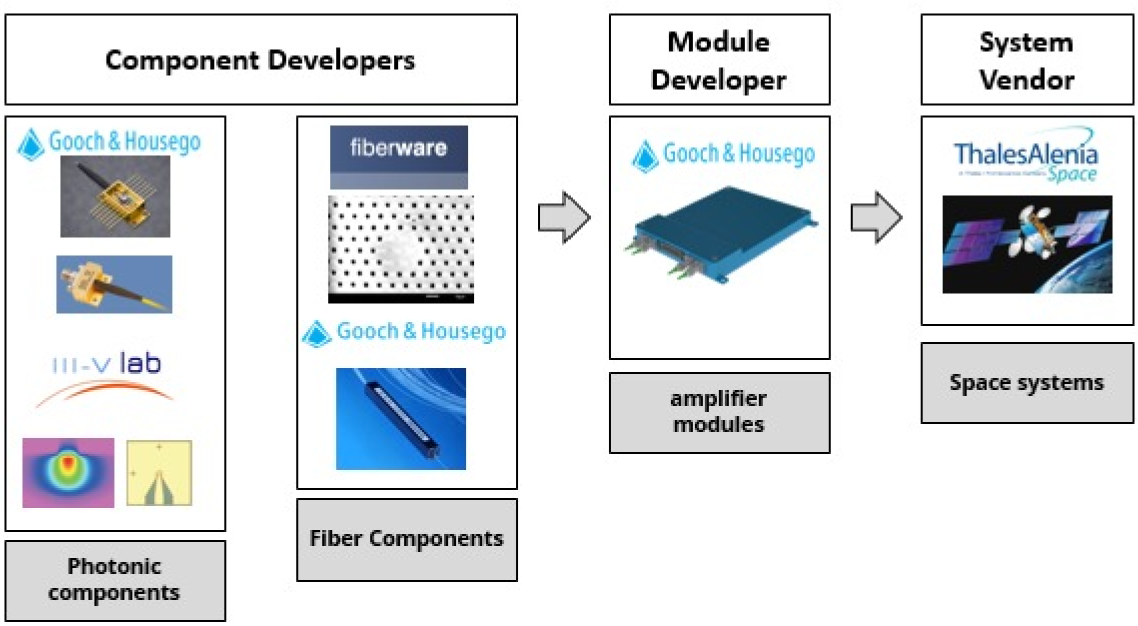

Fig. 1. HIPPO project value chain

III. APPLICATION SCENARIOS

The satellite communication field is facing new challenges: whilst future broadband communication satellites ask for higher throughput, extended coverage and flexibility, observation and scientific missions will need for larger data transfer capacity. In this context, photonic technologies are perceived as a credible alternative to traditional electronic counterparts and are expected to bridge the gap addressing different applications including on-board photonic signal handling and processing as well as free-space optical communications for near-Earth and deep space applications. HIPPO components are specifically designed for application in the following two future space markets:

- **Free-space laser communications:** The growing demand for high transmission data rates in space observation applications is reaching the limits of actual RF systems. LEO satellite missions clearly show a large data rate increase trend, rising toward 10 Gbits/s and beyond at short-/medium-term while optical technologies are investigated as a potential candidate to implement high capacity feeder links, exceeding the capacity of traditional RF systems [2]-[4]. In this context, free space optical communications at 1550 nm are perceived as a promising option to cope with these huge data transmission needs. Going beyond near-Earth Observation missions, future requirements in data capacity requirements from deep space exploration suggest a data bottleneck when considering current conventional technologies. Deep space probes equipped with laser-comm terminals can enable reliable and high capacity laser links to Earth [5].
- **Flexible photonic microwave repeaters:** Future high-capacity, flexible satellite payloads will require breakthrough technologies such as multi-beam active antennas in Ka-band or advanced on-board processing. Microwave photonics is emerging as a key technology in future satellite sub-systems, not only for improving critical figures such as mass or size, but for enabling advanced payload concepts with enhanced functionality.

IV. COMPONENT SPECIFICATIONS

HIPPO will develop a complete family of high power components including DFB lasers, high power-handling photodiodes, pump lasers, passive fibre optic components and photonic crystal fibres. High-power optical fibre amplifier modules will be designed and developed through functional integration of HIPPO fibre-optic and optoelectronic components.

A. Optoelectronic components

In the case of semiconductor lasers, the main way to increase optical power and efficiency is to reduce optical losses inside the optical cavity. In 1.55µm semiconductor lasers on InP, the two main sources of optical losses inside the cavity are re-absorption in quantum wells and intra-valence-band absorption (IVBA) in P-type doped layers.

Reduction of internal losses can be achieved by either a reduction of the optical mode overlap with quantum wells or the reduction of the optical mode overlap with p-type doped layers, which is the main path selected within HIPPO for increasing optical laser power.

Table 3. Laser specifications

Specification	**Value**	**Unit**
Optical power	100-200	mW
Relative Intensity Noise (RIN)	<-160	dB/Hz
Linewidth	100	kHz
Efficiency	> 0.3	W/A

Table 4. Detector specifications

Specification	**Value**	**Unit**
Sensitivity	>0.9	A/W
Power handling	>10	dBm
Bandwidth	>20	GHz
Linearity (OIP3)	>20	dBm

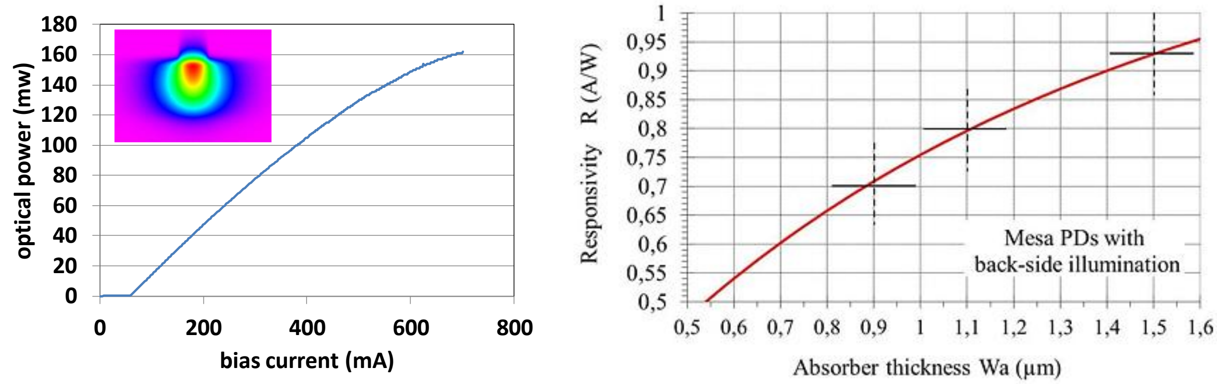

Fig. 2. (left) DFB experimental results from various devices within the 1st fabrication run and (right) simulation of the back-side illuminated UTC photodiode versus absorber thickness (Wa)

The main challenge on HIPPO photodetectors relate to detecting high optical input power at microwave frequencies which sets challenges on bandwidth/saturation limitation, thermal dissipation and linearity. To fulfil such requirements one has to design an appropriate photodiode vertical structure by optimizing the active layer which should take into account the illumination scheme of the detection area. For such requirements, the candidate of choice is the UTC-type (Uni-Traveling-Carrier) vertical photodiode structure and more specifically, MUTC (for Modified UTC), which was recently introduced by III-V Lab to improve detector responsivity.

B. High-power optical fiber amplifiers

High-power optical fibre amplifiers suitable for space flight environment will be designed and developed, exploiting the expertise available within the team. The R&D activity scheduled for the project aims at creating a new family of optoelectronic and fibre-optic components, supporting the requirements set by high-power amplifier modules. Within the HIPPO project, different generation of amplifier modules will be designed and developed using a variety of co-doped fibres employing micro-structured active fibres.

Table 5. Amplifier specifications

Specification	**Value**	**Unit**
Output power	+30 to +40	dBm
Gain	>30	dB
Noise Figure	<7	dB
Input power range	0 – 10	dBm
Fibre gain medium	Er and Er/Yb photonic crystal fibre	-
Wavelength Range	1540 – 1565	nm

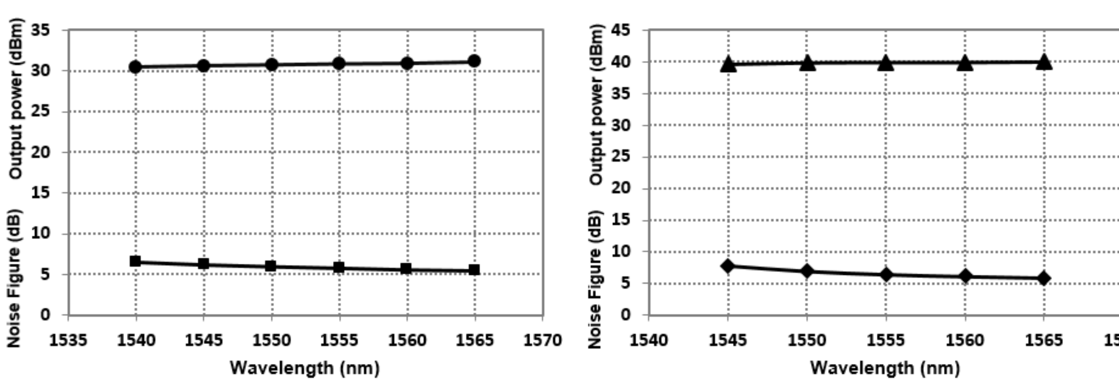

Fig. 3. Preliminary modelling results using conventional silica Er/Yb co-doped fibre for the two amplifier models foreseen within the project.

The first phase of the workplan involves the investigation of the performance of the amplifiers using non micro-structured fibre and specifically Erbium/Ytterbium co-doped active fibres. The modeling and experimental results are to be used as a benchmark against the performance obtained from the new micro-structured active fibres drawn within the project. The simulation results provide insight on the saturated output power achievable, the noise performance and the overall optical to optical conversion of the amplifier sub-assemblies.

V. ACKNOWLEDGMENT

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VI. REFERENCES

[1] Online: http://www.fp7-hippo.eu
[2] M. Toyoshima, "Free-Space Laser Communications: The Japanese Experience", *European Conference on Optical Communication*, Vienna, Austria, Sept. 2009
[3] M. Toyoshima, "Research and development of free-space laser communications and quantum key distribution technologies at NICT*", International Conference on Space Optical Systems and Applications (ICSOS),* Santa Monica, California, USA, May 2011
[4] N. Perlot, "Optical GEO Feeder Link Design", Future Network Mobile Summit, 2012
[5] B. L. Edwards, et al, "The Laser Communications Relay Demonstration," *Proc. International Conference on Space Optical Systems and Applications (ICSOS) 2012*, 1-1, Ajaccio, Corsica, France, October 9-12 (2012)