Terabit Per Second

Science Leader:
Arthur Lowery, +61 3 9905 3223,
arthur.lowery@monash.edu

Project Leader:
Mark Pelusi, +61 2 9351 7697,
m.pelusi@physics.usyd.edu.au

Researchers:
Douglas Bulla, ANU
Duk-Yong Choi, ANU
Benjamin Eggleton, USyd
Chad Husko, USyd
Arthur Lowery, Monash
Barry Luther-Davies, ANU
Steve Madden, ANU
Arnan Mitchell, RMIT
Mark Pelusi, USyd
Jochen Schröder, USyd

Partner Investigators:
Trevor Anderson, NICTA
Roel Baets, University of Ghent
Steven Frisken, Finisar
Franz Kärtner, MIT
Thomas Krauss, University of St. Andrews
Juerg Leuthold, University of Karlsruhe
Shu Namiki, AIST
Leif Oxenløwe, DTU

HDR Students:
Owen Brasier, USyd
William Corcoran, USyd
Liang Du, Monash
Martin Firus, Monash
Mohammad Morshed, Monash
Yvan Paquot, USyd
Trung Vo, USyd

This project aims to push the frontiers of high-speed optical systems through device breakthroughs in nanophotonics, slow light, nanowires, ring resonators, meta-materials and plasmonics, in order to surpass the speed of electronics with less power. It also aims to develop signal processors with multi-Tb/s bandwidth that extend the capacity of next generation optical networks and mitigate the nonlinear barriers to approaching the fundamental Shannon limit in optical communications. These objectives will draw on the outcomes from the Hybrid Integration Project in developing advanced highly nonlinear waveguides in silicon, chalcogenide, tellurite and other advanced materials.

Fig. 1 shows an image of the chalcogenide waveguide fabricated at ANU that underpins current research in signal processing applications. We aim to develop new materials and processes, enabling more sophisticated structures in lower loss devices. These will integrate both linear and nonlinear functionality with on-chip gain, demultiplexers and optical filters. The project will also build on photonic crystals (slow light) and metamaterials to enable more energy-efficient signal processing. The device science challenges for realizing lower loss waveguides with broadband low dispersion will be common to the other Centre projects of Quantum Photonics, Mid IR, and in principle, metamaterials. We will use these novel devices for advanced signal processing demonstrations using the optical communication test bed facilities at both Monash and USyd. We will also collaborate closely with local industry partners (Finisar) in applying their innovative Waveshaper technology to novel applications.

CUDOS has unique skills and facilities to undertake this work. ANU combines expertise and world-class facilities for the fabrication of novel glasses, studies of their basic physical and optical properties, film production and characterization, and film processing to create world leading low loss optical waveguides with ultra-high nonlinearity (Fig. 1).

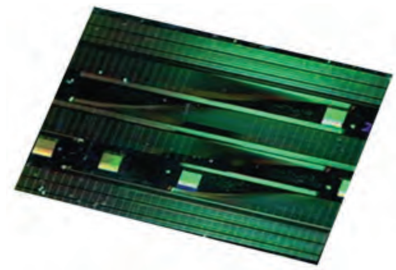

Fig. 1. The photonic chip fabricated from chalcogenide glass for enabling high-speed signal processing in a compact platform. This compact, dispersion engineered device with high nonlinearity has enabled advanced signal processing of 1.28 Tb/s signals.

At USyd and Monash, we investigate higher-speed and broader bandwidth nonlinear optical signal processing using devices based on the ANU platform, and others including highly nonlinear optical fibres. We will draw on extensive expertise at USyd to write strong optical Bragg grating filters into chip-based waveguides by exploiting the photosensitivity of the refractive index to irradiation by a custom laser system.

We will evaluate the performance of the integrated devices for advanced all-optical signal processing at both Monash and USyd using high-speed optical communication test-beds. The USyd test-bed (Fig. 2) generates signals at ultra-high speed of 1.28 Tb/s. Through LIEF grant funding received in 2010, facilities will be established to encode high-speed optical signals with more advanced modulation formats characteristic of next generation, high capacity optical communication systems.

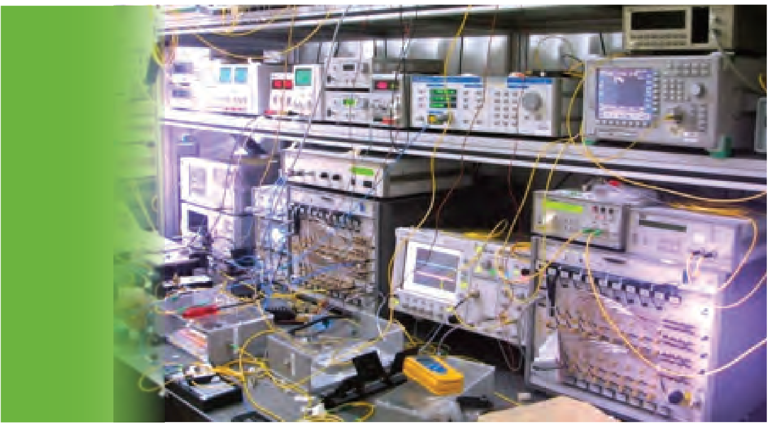

Fig. 2: High-speed optical communication facility at USyd for generating, transmitting and detecting high-speed optical signals with serial bit-rate up to 1.28 Tb/s. This system enables the testing of the bit-error rate performance of the nonlinear optical devices in broadband signal processing applications.

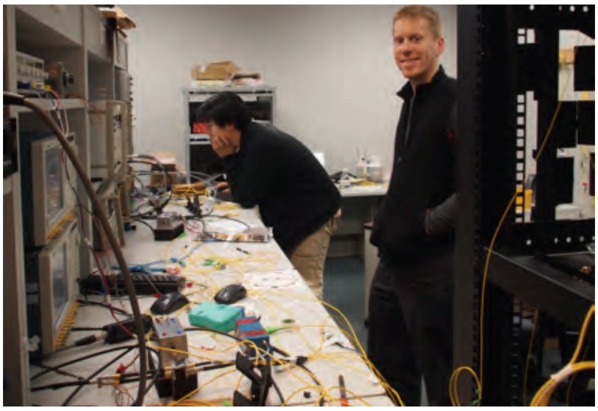

Fig. 3 CUDOS Researchers Liang Du and Jochen Schroeder testing all-optical processing of high-bit rate OFDM signals at Monash using the advanced Waveshaper technology from Finisar.

The optical communication system test bed at Monash (Fig. 3) generates high bit-rate optical signals using orthogonal frequency division multiplexing (OFDM), which is a unique approach for enabling higher-data capacity optical communications. This facility supports collaborative experiments between Monash, USYD and ANU researchers to demonstrate advanced processing techniques for OFDM signals using both novel photonic chips fabricated at ANU, and the Waveshaper technology developed by Finisar.

Progress

The 2011 project goals in broad terms were as follows,

- Demonstrating *an ultra-small foot print optical switch and logic gate at high bit rates >160 Gb/s* using slow light-enhanced ultrafast processing in an optical chip waveguide of length on the order of 100 µm (a million times shorter than the length of optical fibre typically required to perform the same function).
- Demonstrating *ultrafast multi-impairment monitoring and high-speed instrumentation*, enabled by advanced processing using nonlinear photonic chip devices or the Finisar Waveshaper that characterizes the noise and dispersion of complex modulated, high-speed optical signals.
- Demonstrating *Multi-terabit per second Ethernet* technology for the automated distortion compensation of an ultra-high speed 1.28 Tb/s OTDM signal, transmitted over a fibre link. We aimed to apply the Terahertz bandwidth, photonic chip-based RF spectrum analyser to monitor the dispersion of the signal, and provide a control signal to the Finisar Waveshaper, which would then equalize the signal dispersion for optimum transmission performance.
- *Overcoming the nonlinear Shannon limit* in optical fibre communications through the demonstration of a compact, photonic chip solution for compensating the optical signal distortion caused by the optical fiber nonlinearity in optical fiber transmission. We also aimed to demonstrate the viability of a chip-based parametric amplifier to regenerate complex optical signals from phase noise, based on the expected performance gain from reducing waveguide loss by the incorporation of on-chip tapers structures for As_2S_3 or Ge_{11}-As-Se rib waveguides. We also aimed to develop novel architectures and signal processing devices for improving the performance and data capacity of OFDM transmitter/receivers, drawing on the OFDM optical communication test bed at Monash.
- Surpass the existing sampling limit of state-of-the-art high-speed electrical sampling oscilloscopes *by demonstrating 100Gsa/s Photonic analog-to-digital-conversion (ADC)* using novel sampling approaches for increasing the aggregate digital sampling rate required for high-speed optical communications.

cudos
An ARC Centre of Excellence

Highlights

We harnessed the slow slight characteristics of specially designed photonic crystal waveguide to enable the ultra-fast gating of high-speed optically time-division multiplexed signals (Fig. 4(a)). We achieved error-free switching of a 10 Gb/s channel from a 160 Gb/s signal using a record-breaking short device length of just 96 µm [1] (Fig. 4(b)). In follow up experiments we showed the same ultra-compact platform could perform all-optical logic at 40 Gb/s [2]. These results mark an important milestone towards the project's goal of implementing hybrid integrated and slow-light structures to minimise the power, maximise the bandwidth and shrink the device footprint for high-speed optical signal processing.

We also demonstrated the capability for advanced nonlinear high-speed processing of phase encoded optical signals and at ultra-high bit rates using compact, photonic chip technology. Using waveguides based on chalcogenide and silicon we demonstrated all-optical logic at bit-rates of 40 to 160 Gb/s [3], and monitoring of the dispersion of optical signals at ultra-high bit-rates of 640 Gb/s [4].

Another highlight result was the breakthrough demonstration of automatic distortion compensation for an ultra-high speed, 1.28 Tb/s optical signal by using a chalcogenide waveguide (Fig. 5) as a dispersion monitor, which in turn controlled the Finisar Waveshaper to optimize the dispersion compensation of the signal [5]. In other experiments, we showed the capability of the Waveshaper to enable noise monitoring of ultra-fast 1.28 Tbaud optical signals, and demonstrated novel advanced signal processing capability for OFDM signals. Liang Du, Arthur Lowery (Monash),and Jochen Schröder (USyd) programmed a Finisar Waveshaper to perform an optical Fourier transform and in highlight experiments at Monash used it to demodulate optical OFDM channels.

We also demonstrated novel approaches for tackling the nonlinear Shannon limit in high capacity optical communications by applying nonlinear signal processing to compensate nonlinear signal distortion in optical fiber. The proof of concept experiments showed the capability for significant regeneration of 40 Gb/s phase-encoded optical signals.

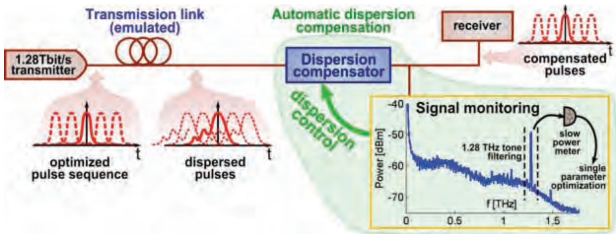

Fig. 5. System configuration for using highly nonlinear chalcogenide glass waveguide in combination with the Finisar Waveshaper for enabling simultaneous dispersion monitoring and automated feedback dispersion optimization of a 1.28 Tb/s signal.

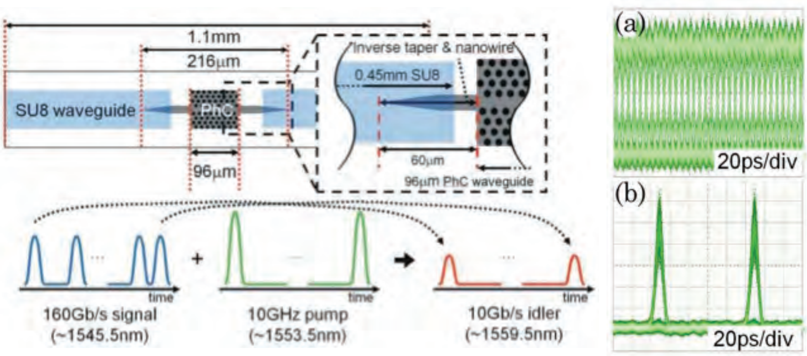

Fig. 4 (a) Schematic of photonic crystal waveguide using its slow light enhanced nonlinear response to enable ultra-fast gating of high-speed optical signals with an ultra-compact micro-metre scale optical chip platform, (b) "Eye diagrams" observed on a high-speed sampling oscilloscope showing (top) 160 Gb/s signal at the input of the photonic chip and (lower) 10 Gb/s gated signal at the output of the photonic chip enabled by the nonlinear signal processing in the record short length waveguide.

References

[1] Corcoran, B., Pelusi, M.D., Monat, C., Li, J., O'Faolain, L., Krauss, T.F., and Eggleton, B.J., "Ultracompact 160 Gbaud all-optical demultiplexing exploiting slow light in an engineered silicon photonic crystal waveguide," Opt. Lett. 36, 1728-1730 (2011).

[2] Husko, C., Vo, T. D., Corcoran, B., Li, J., Krauss, T. F., and Eggleton, B. J., "Ultracompact all-optical XOR logic gate in a slow-light silicon photonic crystal waveguide," Opt. Express 19, 20681-20690 (2011).

[3] Vo, T.D., Pant, R., Pelusi, M.D., Schröder, J., Choi, D.-Y., Debbarma, S.K., Madden, S.J., Luther-Davies, B. and Eggleton, B.J., "Photonic chip-based all-optical XOR gate for 160 Gbit/s DPSK signals,", Optics Letters, Vol. 36, Issue 5, pp. 710-712 (2011).

[4] Vo, T., Corcoran, B., Schroder, J., Pelusi, M.D., Xu, D.X., Densmore, A., Ma, R., Janz, S., Moss, D.J., and Eggleton, B.J., "Silicon chip based real-time dispersion monitoring for 640 Gbit/s DPSK signals,", J. Lightwave Technol., vol.29, no.12, pp. 1790 – 1796, (2011).

[5] Paquot, Y., Schröder, J., Van Erps, J., Vo, T.D., Pelusi, M.D., Madden, S., Luther-Davies, B., and Eggleton, B.J., "Single parameter optimization for simultaneous automatic compensation of multiple orders of dispersion for a 1.28 Tbaud signal," Opt. Express 19, 25512-25520 (2011).

Future Directions

In 2012, the goals will be to further demonstrate the energy-efficient and broadband capability of highly nonlinear chip scale devices, and apply the Finisar Waveshaper to more advanced signal processing of optical signals encoded with complex data modulation formats. With these objectives we will address the key issues in the generation, transmission and detection of high-bit rate signals for next generation optical communication systems, and apply the breakthroughs in device technology to overcome the nonlinear Shannon limit.

In 2012 we will focus on fabricating lower loss chalcogenide waveguides (<5dB total insertion loss for 7-14cm long waveguides), and on demonstrating the feasibility of a "lossless" waveguide" for application to more sophisticated nonlinear signal processing applications that require a higher nonlinear response with moderate optical power levels.

Project Leader

Mark Pelusi is a Senior Research Fellow and (from 2011) ARC Future Fellow in the School of Physics, University of Sydney. He graduated with a PhD in Electrical Engineering from the University of Melbourne in 1998, and has worked in world leading industry research labs and start-up companies in both the USA and Japan. His research interests are optical fibre communications, nonlinear optical signal processing and ultra-high speed optical technologies.