Supercontinuum comb sources for broadband communications based on AlGaAs-on-insulator

Hu, Hao; Pu, Minhao; Da Ros, Francesco; Galili, Michael; Yvind, Kresten; Morioka, Toshio; Oxenløwe, Leif Katsuo

Published in:
Proceedings of SPIE

Link to article, DOI:
[10.1117/12.2256032](https://doi.org/10.1117/12.2256032)

Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):

Hu, H., Pu, M., Da Ros, F., Galili, M., Yvind, K., Morioka, T., & Oxenløwe, L. K. (2017). Supercontinuum comb sources for broadband communications based on AlGaAs-on-insulator. In *Proceedings of SPIE* (Vol. 10088). [100880C] SPIE - International Society for Optical Engineering. Proceedings of SPIE - The International Society for Optical Engineering <https://doi.org/10.1117/12.2256032>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Supercontinuum comb sources for broadband communications based on AlGaAs-on-insulator

Hao Hu*, Minhao Pu, Francesco Da Ros, Michael Galili, Kresten Yvind, Toshio Morioka,
Leif K. Oxenløwe
DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, DK-2800,
Lyngby, Denmark.

ABSTRACT

We experimentally demonstrated 10 GHz frequency comb spectral broadening in an AlGaAsOI nano-waveguide with the peak power of only several watts. The spectral broadened 10 GHz frequency comb has high optical signal to noise ratio (OSNR) at the output of the nano-waveguide. As far as we know, it is the first photonic chip based frequency comb, relying on spectral broadening of a 10 GHz mode-locked laser comb in an AlGaAsOI nano-waveguide, with a sufficient comb output power to support several hundred Tbit/s optical data.

Keywords: Supercontinuum generation, fiber optics communications, nonlinear optics, integrated optics, waveguide

1. INTRODUCTION

As cost and energy consumption are becoming limiting factors in high-capacity systems, using fewer lasers with less energy consumption grows desirable and demonstrations of ultra-high-capacity optical transmission based on nonlinear fiber based spectral broadening of a seed laser frequency comb have been reported^{1, 2, 3, 4}. The prospect of moving the fiber-based frequency comb sources onto a photonic chip platform holds many attractive features, including ultra-high bandwidth, stable polarization and phase, absence of stimulated Brillouin scattering (SBS), and the possibility of photonic integration with a seed laser⁵.

AlGaAs-on-insulator (AlGaAsOI) has shown to be an ultra-efficient nonlinear material platform^{6, 7, 8}. It combines high intrinsic material nonlinearity (on the order of 10^{-17} W/m²), large index contrast between AlGaAs (3.3) and silica cladding (1.5), and low linear and nonlinear losses. The bandgap of AlGaAs can also be engineered by changing the Al concentration to avoid two-photon absorption (TPA) in the telecom wavelengths.

In this paper, we present the photonic chip based frequency comb, relying on spectral broadening of a mode-locked laser comb in an AlGaAsOI nano-waveguide, with a sufficient comb output power to support several hundred Tbit/s optical data⁹. We use a 33.6 nm wide part of the generated comb spectrum to carry 80×40 Gbaud WDM channels with PDM-16-QAM modulation format. The high comb OSNR allows us to send the signal over 30 spatial channels, and we demonstrate successful 9.6 km transmission in a heterogeneous 30-core fiber reaching a total of 661 Tbit/s after FEC overhead subtraction.

2. SPECTRAL BROADENING OF A 10 GHz MODE-LOCKED LASER COMB

Figure 1 shows the experimental setup for frequency comb spectral broadening in an AlGaAsOI nano-waveguide. An erbium glass oscillator (ERGO) generates a 10 GHz pulse train at 1550 nm with picosecond pulse width. The 10 GHz modulation frequency is locked to a microwave oscillator with an accuracy of ~Hz and the absolute frequency of the pulse can be fine-tuned without the need of external reference laser. After amplification in an erbium-doped fiber amplifier (EDFA), the pulses are launched into the AlGaAsOI nano-waveguide. A polarization controller is used to align the pulses to the transverse electric (TE) mode of the waveguide and an optical spectrum analyzer is used to record the output spectrum.

*huhao@fotonik.dtu.dk; phone +45 45253783; fax +45 45936581; www.fotonik.dtu.dk

Figure 1. Experimental setup for frequency comb spectral broadening using an AlGaAsOI nano-waveguide.

Figure 2. Optical spectra of 10 GHz mode-locked laser frequency comb (a) and spectrally broadened frequency comb at the output of the AlGaAsOI nano-waveguide (b).

Figure 2 (a) shows the spectrum of the ps pump pulse at the input of AlGaAsOI nano-waveguide (Fig. 3(a)) and Figure 2 (b) shows the spectrum at the output of the waveguide with an average launched power of 19.3 dBm (peak power of ~ 5.6 W). The broadened spectrum at the output of the AlGaAsOI nano-waveguide has a 20-dB bandwidth of ~ 44 nm, which is used as the wavelength division multiplexed (WDM) light source.

3. SINGLE SOURCE OPTICAL TRANSMISSION USING THE SPECTRALLY BROADENED FREQUENCY COMB

Figure 3 (c) shows the experimental setup of single source optical data transmission using the spectrally broadened frequency comb. The single source laser in the transmitter is an Erbium glass oscillating mode-locked laser, which produces 10-GHz pulses (1542 nm, 1.5-ps FWHM). The pulses are amplified and used to generate an optical frequency comb based on self-phase modulation (SPM) in the AlGaAsOI photonic chip (Fig. 3 (b)).

The estimated OSNR is ~ 43 dB at 1552 nm and ~ 30 dB at 1563 nm. The broadened spectrum is equalized in a wavelength selective switch (WSS) and the inhomogeneous part in the center is replaced by the original spectrum from the mode-locked laser through another path, which results in a flat and stable frequency comb¹. The equalized frequency comb works as the light sources for 80 WDM channels with 50 GHz spacing. For each WDM channel, the signal is modulated with PDM-16-QAM and then OTDM multiplexed to 40 Gbaud. The signal is transmitted through the 9.6-km 30-core single-mode fiber, with a total data capacity of 661 Tbit/s⁹.

Figure 3. (a) SEM picture of a fabricated AlGaAsOI nano-waveguide (denoted by the artificial blue color). (b) Photograph of the AlGaAsOI photonic chip. (c) Schematic of the experimental setup for the 661 Tbit/s single-source AlGaAs frequency comb transmitter for 30-core transmission demonstration.

4. CONCLUSION

We have demonstrated 10 GHz spectrally broadened frequency comb based on an AlGaAsOI nano-waveguide, which has a 20-dB bandwidth of ~ 44 nm and cover the telecom C band. The spectrally broadened 10 GHz frequency comb has enough OSNR to carry 661 Tbit/s data in a fully loaded 30-core fiber. This is the highest reported amount of data carried on the light generated from a chip-based single-source transmitter, and we demonstrate successful 9.6 km transmission.

REFERENCES

- [1] D. Hillerkuss, R. Schmogrow, T. Schellinger, M. Jordan, M. Winter, G. Huber, T. Vallaitis, R. Bonk, P. Kleinow, F. Frey, M. Roeger, S. Koenig, A. Ludwig, A. Marculescu, J. Li, M. Hoh, M. Dreschmann, J. Meyer, S.B. Ezra, N. Narkiss, B. Nebendahl, F. Parmigiani, P. Petropoulos, B. Resan, A. Oehler, K. Weingarten, T. Ellermeyer, J. Lutz, M. Moeller, M. Huebner, J. Becker, C. Koos, W. Freude, J. Leuthold, "26 Tbit/s line-rate super-channel transmission utilizing all-optical fast Fourier transform processing," *Nat Photon* 5, 364–371 (2011).
- [2] V. Ataie, E. Temprana, L. Liu, Y. Myslivets, P. P. Kuo, N. Alic, and S. Radic, "Flex-grid Compatible Ultra Wide Frequency Comb Source for 31.8 Tb/s Coherent Transmission of 1520 UDWDM Channels," in *Optical Fiber Communication Conference: Postdeadline Papers*, (Optical Society of America, 2014), paper Th5B.7 (2014).
- [3] H. Hu, F. Ye, A. K. Medhin, P. Guan, H. Takara, Y. Miyamoto, H. C. H. Mulvad, M. Galili, T. Morioka, and L. K. Oxenlowe, "Single Source 5-dimensional (Space-, Wavelength-, Time-, Polarization-, Quadrature-) 43 Tbit/s Data Transmission of 6 SDM $\times$ 6 WDM $\times$ 1.2 Tbit/s Nyquist-OTDM-PDM-QPSK," in *CLEO: 2014 Postdeadline Paper Digest*, OSA Technical Digest (online) (Optical Society of America, 2014), paper JTh5B.10 (2104).
- [4] B. J. Puttnam, R. S. Luís, W. Klaus, J. Sakaguchi, J.-M. Delgado Mendinueta, Y. Awaji, N. Wada, Y. Tamura, T. Hayashi, M. Hirano, and J. Marciante, "2.15 Pb/s transmission using a 22 core homogeneous single-mode multi-core fiber and wideband optical comb," in *Proc. ECOC, PDP.3.1* (2015).
- [5] J. Pfeifle, A. Kordts, P. Marin, M. Karpov, M. Pfeiffer, V. Brasch, R. Rosenberger, J. Kemal, S. Wolf, W. Freude, t. kippenberg, and C. Koos, "Full C and L-Band Transmission at 20 Tbit/s Using Cavity-Soliton Kerr Frequency Combs," in *CLEO: 2015 Postdeadline Paper Digest*, (Optical Society of America, 2015), paper JTh5C.8 (2015).
- [6] M. Pu, H. Hu, L. Ottaviano, E. Semenova, D. Vukovic, L. K. Oxenlowe, and K. Yvind, "AlGaAs-On-Insulator Nanowire with 750 nm FWM Bandwidth, -9 dB CW Conversion Efficiency, and Ultrafast Operation Enabling Record Tbaud Wavelength Conversion," in *Optical Fiber Communication Conference Post Deadline Papers*, OSA Technical Digest (online) (Optical Society of America, 2015), paper Th5A.3 (2015).

- [7] Luisa Ottaviano, Minhao Pu, Elizaveta Semenova, and Kresten Yvind, "Low-loss high-confinement waveguides and microring resonators in AlGaAs-on-insulator," *Opt. Lett.* 41, 3996-3999 (2016).
- [8] Minhao Pu, Luisa Ottaviano, Elizaveta Semenova, and Kresten Yvind, "Efficient frequency comb generation in AlGaAs-on-insulator," *Optica* 3, 823-826 (2016).
- [9] H. Hu, F. Da Ros, F. Ye, M. Pu, K. Ingerslev, E. Porto da Silva, M. Nooruzzaman, Y. Amma, Y. Sasaki, T. Mizuno, Y. Miyamoto, L. Ottaviano, E. Semenova, P. Guan, D. Zibar, M. Galili, K. Yvind, L. K. Oxenløwe, and T. Morioka, "Single-Source AlGaAs Frequency Comb Transmitter for 661 Tbit/s Data Transmission in a 30-core Fiber," in *Conference on Lasers and Electro-Optics*, OSA Technical Digest (online) (Optical Society of America, 2016), paper JTh4C.1 (2016).