Generating novel waveguides for stimulated Brillouin scattering with genetic algorithms

Jesper Håkansson[1], **Dries Van Thourhout**[1]
Photonics Research Group, Ghent University & IMEC
Center for Nano- and Biophotonics
Technologiepark-Zwijnaarde 126, 9052 Ghent, Belgium

Over the last few years a rapid development has been going on in demonstrating stimulated Brillouin scattering (SBS) in chip-integrated optical waveguides. Most of the work has focused on finding good materials for achieving net gain however[1], rather than on exploring novel waveguide designs. To design a waveguide for high SBS gain is difficult because one needs to compromise between having a good optical waveguide, a good mechanical resonator, and a strong coupling between the two, all in the same physical structure. To approach this problem we used genetic algorithms (GA) and explored a wide range of possible waveguide shapes to achieve high gain in silicon and silicon oxide based integrated platforms. GAs have been shown to often provide counter intuitive but educational answers in domains ranging from the growth of plants and website design to Othello strategies[2,3].

By using COMSOL Multiphysics and MATLAB we were able to simulate several 10s of thousands of waveguides in the process of optimizing the SBS gain over a wide range of the mechanical frequency span. The accumulated results of the simulated waveguides are shown in fig. 1 (a). By focusing on the Pareto-optimal designs,i.e., those providing the highest gain for a given frequency, or simplified versions of these optimal designs, we find several distinct competitive waveguides. With such a large number of waveguides simulated it is possible to discuss the general trends and analyze the Pareto-frontier of the data generated. While the search space is not exhausted, the results obtained provide a way to benchmark a new waveguide in relation to the bulk of possible waveguides.

The result is a range of novel waveguide designs operating over a wide range of mechanical frequencies. Several of the waveguides found have a simulated gain in excess of 10^8 $(\mathrm{Wm})^{-1}$, far above anything previously demonstrated. Initial tests also show it is possible to generate high gain waveguides for inter-modal SBS. However due to the increased non-linearity of the problem, convergence is slower.

This work was partly funded by the EU 2020 FET proactive programme under grant agreement No 732894, HOT.

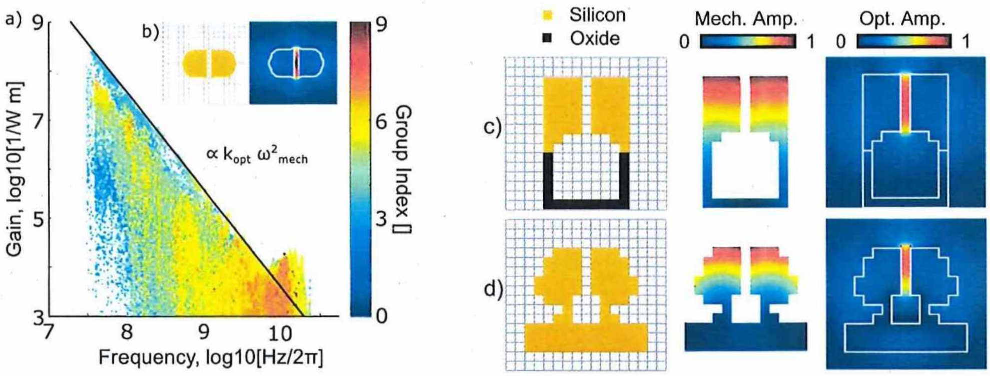

Fig. 1 a) Shows the gain, mechanical frequency and group index of all the simulated optomechanical mode pairs. The black line shows the frequency independent gain for (b) the locally optimized slot waveguide. c) and d) are examples of the waveguides that perform best at their respective frequencies. In order from left to right the material composition, mechanical and optical mode.

References

[1] M. Merklein, A. Casas-Bedoya, D. Marpaung, T. FS Büttner, M. Pagani, B. Morrison, I. V Kabakova and B. J Eggleton, "Stimulated Brillouin scattering in photonic integrated circuits: novel applications and devices,"IEEE J. Sel. Top. Quant **22**, 336–346 (2016)

[2] J. C. Quiroz, S. J. Sushil, A. Shankar, and S. M. Dascalu. "Interactive genetic algorithms for user interface design." In Evolutionary Computation, 2007. CEC 2007. IEEE Congress on, pp. 1366-1373. IEEE, 2007.

[3] L. Xu, M. Tao, and H. Ming. "A hybrid algorithm based on genetic algorithm and plant growth simulation algorithm." Measurement, Information and Control (MIC), 2012 International Conference on. Vol. 1. IEEE, 2012.

reproduces experimental data we investigate the formation of patterns in broadband and rapidly swept Fourier domain mode locked (FDML) lasers which are of great fundamental as well as practical relevance.

EF-P.6 TUE

Raman response induces moving cavity solitons in optical resonators

•*M. Tlidi*[1], *S. Coulibaly*[2], *and M. Clerc*[3]; [1]*Université Libre de Bruxelles, Bruxelles, Belgium;* [2]*Université de Lille, Lille, France;* [3]*Universidad de Chile, Santiago, Chile*

We shown analytically and numerically that the noninstantaneous Raman response stabilizes traveling cavity solitons. We illustrate this mechanism on Kerr optical resonators and on a generic bistable model.

EF-P.7 TUE

Generating novel waveguides for stimulated Brillouin scattering with genetic algorithms

•*J. Håkansson*[1,2] *and D. Van Thourhout*[1,2]; [1]*Ghent University, Gent, Belgium;* [2]*Center for Nano and Biophotonics, Gent, Belgium*

Designing waveguides for stimulated Brillouin scattering is difficult because one must combine good mechanical and optical properties with a strong coupling between them. Using genetic algorithms we have found several novel and competitive waveguide designs.

EF-P.8 TUE

Spontaneous Symmetry Breaking and Nonlinear Population Inversion Grating in a Low-Q CW Laser

•*V. Kocharovsky*[1], *I. Koryukin*[1], *E. Kocharovskaya*[1], *V. Kocharovsky*[1,2], *I. Ryabinin*[1], *and S. Tarasov*[1]; [1]*Institute of Applied Physics, Russian Academy of Science, Nizhny Novgorod, Russia;* [2]*Department of Physics and Astronomy, Texas A&M University, College Station, USA*

We find a new effect of superradiant lasing in a low-Q symmetric cavity, namely, the asymmetry of counterpropagating waves and the profiles of the field, polarization and population inversion owing to the nonlinear population inversion grating.

EF-P.9 TUE

Polarization properties of cavity solitons in Kerr resonators

E. Averland[1], *K. Panajotov*[2,3], *and* •*M. Tlidi*[1]; [1]*Université Libre de Bruxelles, Bruxelles, Belgium;* [2]*Vrije Universiteit Brussel, Brussels, Belgium;* [3]*Institute of Solid State Physics, Sofia, Bulgaria*

We theoretically investigate a weakly birefringent all-fiber cavity subject to linearly polarized optical injection. We show that vector cavity solitons exhibit multistability involving different polarization states with different energies.

EF-P.10 TUE

Random Mode Coupling Assists Kerr Beam Self-Cleaning in a Graded-Index Multimode Optical Fiber

•*O.S. Sidelnikov*[1], *E.V. Podivilov*[1,2], *M.P. Fedoruk*[1,3], *and S. Wabnitz*[1,4]; [1]*Novosibirsk State University, Novosibirsk, Russia;* [2]*Institute of Automation and Electrometry SB RAS, Novosibirsk, Russia;* [3]*Institute of Computational Technologies SB RAS, Novosibirsk, Russia;* [4]*Dipartimento di Ingegneria dell'Informazione, Elettronica e Telecomunicazioni, Sapienza Università di Roma, Roma, Italy*

In this paper, we numerically investigate the process of beam self-cleaning in graded-index multimode optical fibers using the coupled-mode model. The results of numerical investigations are in complete agreement with our experimental data.

EF-P.11 TUE

Delay-induced dynamics of pinned cavity soliton in an inhomogeneous Kerr resonator

F. Tabbert[1], *S. Gurevich*[1], *K. Panajotov*[2,3], *and* •*M. Tlidi*[4]; [1]*University of Munster, Munster, Germany;* [2]*Vrije Universiteit Brussel, Brussels, Belgium;* [3]*Institute of Solid State Physics, Sofia, Bulgaria;* [4]*Université Libre de Bruxelles, Bruxelles, Belgium*

The influence of inhomogeneity and time-delayed feedback on cavity solitons is investigated. Depending on the strength of the inhomogeneity, a single cavity soliton can undergo either an Andronov-Hopf bifurcation or escape from the defect.

EF-P.12 TUE

Spectral properties of cascaded second-order nonlinear processes induced by high-gain parametric down-conversion

•*D.A. Kopylov*[1], *K.Y. Spasibko*[2,3], *A.V. Rasputnyi*[1], *T.V. Murzina*[1], *and M.V. Chekhova*[2,3,1]; [1]*M.V. Lomonosov Moscow State University, Moscow, Russia;* [2]*Max Planck Institute for the Science of Light, Erlangen, Germany;* [3]*University of Erlangen-Nürnberg, Erlangen, Germany*

We study, experimentally and theoretically, the spectral properties of visible radiation generated through cascaded second-order nonlinear processes that are induced by bright squeezed vacuum.

EF-P.13 TUE

Generation of rogue-like pulses via stimulated soliton collision in dispersion oscillating optical fiber

•*A. Koniukhov*[1], *A. Sysoliatin*[2], *and L. Melnikov*[3]; [1]*Saratov State University, Saratov, Russia;* [2]*Prokhorov General Physics Institute, Moscow, Russia;* [3]*Saratov State Technical University, Saratov, Russia*

An approach for the generation of high-intensity pulses via inelastic collision of solitons in dispersion variable fiber is proposed. The rogue-like pulse arises due to stimulated soliton collisions and non-adiabatic variation of the fiber dispersion.

EF-P.14 TUE

Effect of Initial Chirp on Soliton Pulse Compression in the Ionization Regime

•*Y. Wan and W. Chang; Nanyang Technological University, Singapore, Singapore*

We investigate the effect of initial chirp on soliton pulse compression in the ionization regime in a gas-filled hollow-core fiber. A positively-chirped pump undergoes a stronger effect of the ionization caused by the enhanced compression.

EF-P.15 TUE

Swift-Hohenberg equation with third order dispersion for optical resonators

M. Tlidi[1], •*B. Kostet*[1], *A. Hariz*[2], *L. Bahloul*[2], *L. Cherbi*[2], *M. Clerc*[3], *M. Ferré*[3], *and K. Panajotov*[4,5]; [1]*Université Libre de Bruxelles, Bruxelles, Belgium;* [2]*Université des Sciences et de la Technologie Houari Boumediene, Bab Ezzouar, Algeria;* [3]*Universidad de Chile, Santiago, Chile;* [4]*Vrije Universiteit Brussel, Brussels, Belgium;* [5]*Institute of Solid State Physics, Sofia, Bulgaria*

A generalized Swift-Hohenberg equation with a third order dispersion is derived for the photonic crystal fiber resonators. Moving temporal localized structures often called cavity solitons and their speed are analyzed numerically and analytically.

EF-P.16 TUE

Controlling the temporal trajectory of solitons in silver nanoparticle doped fibre

•*S. Bose*[1,2], *G. Steinmeyer*[3], *U. Morgner*[1,2], *and A. Demircan*[1,2,4]; [1]*Institute of Quantum Optics, Leibniz University, Hannover, Germany;* [2]*Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering-Innovations Across Discipline), Hannover, Germany;* [3]*Max-Born-Institute, Berlin, Germany;* [4]*Hannover Centre for Optical Technologies, Hannover, Germany*

We investigate different regimes of soliton propagation dynamics in fibres containing a variable zero-nonlinearity point, allowing control of the soliton trajectories during supercontinuum generation process.

EF-P.17 TUE

Nonlinear Fourier Transform for Analysis of Coherent Structures in Dissipative Systems

•*I.S. Chekhovskoy*[1,2], *O.V. Shtyrina*[1,2], *M.P. Fedoruk*[1,2], *S.B. Medvedev*[1,2], *and S.K. Turitsyn*[1,3]; [1]*Novosibirsk State University, Novosibirsk, Russia;* [2]*Institute of Computational Technologies, SB RAS, Novosibirsk, Russia;* [3]*Aston Institute of Photonic Technologies, Aston University, Birmingham, United Kingdom*

Using the example of the cubic Ginzburg-Landau equation, we show how the nonlinear Fourier transform can be used to characterize coherent structures in dissipative nonlinear systems and reduce the number of effective degrees of freedom.

EF-P.18 TUE

Nonlinear Sculpturing of Optical Pulses in Fibre Systems

S. Boscolo[1], *I. Gukov*[2], •*A. Tonello*[3], *and C. Finot*[4]; [1]*Aston Institute of Photonic Technologies, School of Engineering and Applied Science, Aston University, Birmingham, United Kingdom;* [2]*Moscow Institute of Physics and Technology & Skolkovo Institute of Science and Technology, Moscow, Russia;* [3]*Laboratoire XLIM, UMR 7252 CNRS - Universite' de Limoges, Limoges, France;* [4]*Laboratoire Interdisciplinaire Carnot de Bourgogne, UMR 6303 CNRS - Universite' Bourgogne Franche-Comte', Dijon, France*

We present a general method for the design of fibre-based nonlinear pulse shaping. By combining direct numerical simulations with machine-learning strategies, we efficiently identify the optimal working parameters for achieving a given pulse target.

EF-P.19 TUE

Tunable self-pulsations in a quantum-dot external-cavity laser emitting across the excited state

S. White[1,2] *and* •*M.A. Cataluna*[2,3]; [1]*IOP Publishing, Bristol, United Kingdom;* [2]*Previously also with the School of Science and Engineering, University of Dundee, Dundee, United Kingdom;* [3]*Institute of Photonics and Quantum Sciences, School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, United Kingdom*

Self-sustained optical pulsations were observed from a tunable external-cavity quantum dot laser using a single-section amplifier, emitting solely in the excited state. The pulsations were tunable both in wavelength (1160-1196 nm) and frequency (3.76-3.82 GHz).

EF-P.20 TUE

Phase evolution of Peregrine-like solitons in nonlinear fiber optics

•*G. Xu*[1], *K. Hammani*[1], *A. Chabchoub*[2], *J. Dudley*[3], *B. Kibler*[1], *and C. Finot*[1]; [1]*Laboratoire Interdisciplinaire Carnot de Bourgogne, Dijon, France;* [2]*The University of Sydney, Sydney, Australia;* [3]*Institut FEMTO-ST, Besançon, France*

We report the longitudinal evolution of the temporal phase profile of Peregrine-like solitons in optical fibers. The experimental results reveal the phase difference between the central part of the pulse and the continuous background.