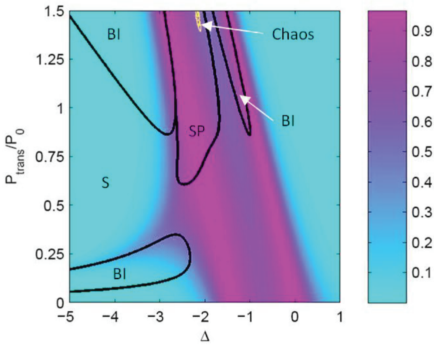
Self-pulsing and chaos in networks of nonlinear resonators

B. Maes, M. Fiers, and P. Bienstman

Photonics Research Group, Ghent University, St.-Pietersnieuwstraat 41, Ghent, Belgium
e-mail: bjorn.maes@ugent.be

Nonlinear optical phenomena experienced a boost by embracing the strong confinement in high-quality resonators, such as photonic crystal cavities or ring resonators. Two trends are currently developing: Experimentalists are successfully fabricating complex structures with multiple, even hundreds of cavities, in order to demonstrate novel functionalities, e.g. with slow-light, higher order filters or disorder. Secondly, advanced material systems are characterized which exhibit a large Kerr effect, but have a small two-photon absorption coefficient. Examples here are chalcogenide materials or hybrid structures such as a highly nonlinear organic layer on top of silicon. In this talk we explore the combination of these trends: we examine the dynamical behavior of networks with multiple Kerr-nonlinear resonators.

More specifically we start out with short lines of evanescently coupled cavities, with a single constant input signal from one side. Already with two consecutive resonators we uncover a rich range of dynamics, including self-pulsing instabilities and chaotic behavior. Using coupled-mode theory we can describe a large parameter space. Understandably, the particular behavior is strongly influenced by the frequency detuning from resonance and the phase relation between the resonators. Linear stability analysis, checked with time domain calculations, distinguishes between: (S) steady state solutions: constant output power, (BI) bistable instability: the conventional, negative-slope repulsive states, (SP) self-pulsing: oscillating output signal. Within the self-pulsing regions we further check for chaos, by determining the maximal Lyapunov coefficient. For two cavities this leads to the graph in the figure.



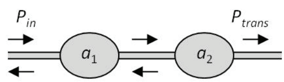


Figure: (left) Dynamical behaviour of two Kerr cavities. Transmitted power versus normalized detuning. The colorbar shows the transmission. (right) Schematic of the device

During the talk we examine this behavior for different cases, and connect it with the linear transmission curves. The model is validated with rigorous FDTD simulations on 2D photonic crystal cavities. Furthermore, we discuss the correspondence with gap soliton modes which are well studied in Bragg reflectors. Our study of nonlinear dynamics in passive structures complements e.g. the fruitful area of laser dynamics.

We acknowledge the Fund for scientific research - Flanders (FWO Vlaanderen), the Institute for the Promotion of Innovation through Science and Technology in Flanders (IWT) and COST Action MP0702.