Observation of Two-Photon Absorption Induced Soliton Fission

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Solitons are well known solutions of the nonlinear Schrödinger equation (NLSE). In optics, temporal solitons are localized wavepackets that travel unperturbed in dispersive Kerr media. They can be of different order, with only first order solitons strictly maintain their shape as they propagate, while higher order solitons periodically oscillate along the waveguide. If the propagation deviates from purely Kerr and quadratically dispersive, higher order solitons tend to split into several lower order solitons. This process, often called soliton fission, is the main mechanism underlying supercontinuum generation [1]. In silica fibers, the fission is most often induced by the Raman effect and third-order dispersion. The recent push for optical integration has led to a number of demonstrations of supercontinuum generation in semiconductor nanowaveguides [2]. But with the focus on coherent spectral broadening for frequency comb applications, few studies discuss the reason for the decay of the input soliton. It was shown last year that free carriers can, by blue-shifting the soliton, induce fission in Indium Gallium Phosphide (InGaP) nanowaveguides [3]. Moreover it was suggested that free carrier dispersion drives soliton fission in our recent experiments of supercontinuum generation in silicon wire waveguides [3,4].

We here present novel experimental data of soliton fission in silicon waveguides with the aim of identifying the most important perturbation to soliton propagation. Our experiment is performed with air clad fully etched 6 mm long wire waveguides on a silicon-on-insulator wafer with a 220 nm thick silicon device layer. We launch short pulses centred at 1553 nm with a full width at half maximum of 165 fs and a coupled peak power of 30 W. The spectra measured at the output of two different waveguides (with widths of 575 nm and 650 nm, corresponding to input solitons of order 6.3 and 9 respectively) are shown in Figure 1(a),(b). We readily note that the spectral broadening depends on the width (i.e. the dispersion) of the waveguide. In the wider waveguide, the lower group velocity dispersion allows for the emission of dispersive waves in the normal dispersion regime. We find excellent agreement with simulations of the generalized NLSE (note that we use the waveguide width as a parameter) commonly used to describe short pulse propagation in silicon waveguides [5]. It accounts for linear losses, higher order dispersion (HOD), two-photon absorption (TPA), self- steepening, the Raman effect as well as free carrier absorption and dispersion. Importantly, we find almost no impact on the dynamics from either carriers, the Raman effect or self-steepening [see Figure 1(a),(b)]. This leaves TPA or HOD as possibly inducing the fission. We further analyse the propagation dynamics in the narrower waveguide. As no dispersive wave is emitted, the role of HOD is likely to be limited. We show in Figure 1(c) the evolution of the temporal profile along the waveguide. We remark that the time reversal symmetry is nearly conserved throughout propagation, hinting at an important role played by TPA. We hence perform simulations with nonlinear losses as the lone perturbation to the NLSE [see Figure 1(d)]. The agreement is striking, indicating that it is TPA, not HOD or carrier dispersion that dominates the dynamics and induces soliton fission. To the best of our knowledge, it is the first time that TPA is shown to be responsible for the fission of a higher order temporal soliton.

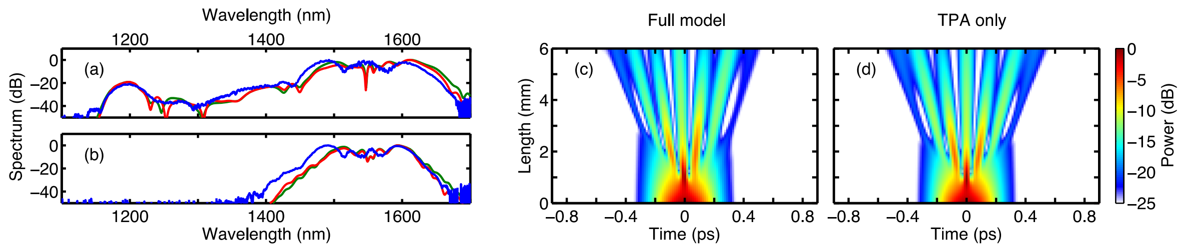

Fig. 1 (a,b) Experimental spectra (blue) measured at the output of (a) the 650 nm wide waveguide and (b) the 575 nm wide waveguide. Also shown are the simulation results of the full model (red) as well as the model without carrier effects, the Raman response function and self-steepening (green). (c,d) Evolution of the pulse profile during propagation along the 575nm waveguide as predicted by simulations (c) of the full model and (d) with TPA as the lone perturbation to the NLSE. Note that linear losses are included.

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