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## Light by light manipulation in multimode fibers

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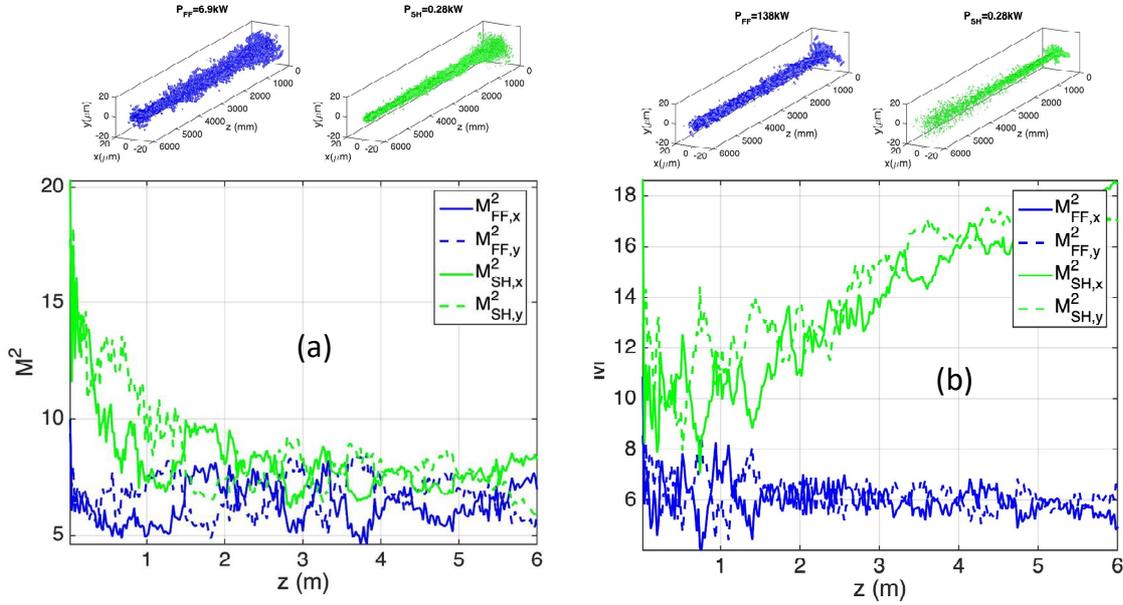
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**Abstract:** We demonstrate that a low-intensity beam can be severely cleaned or distorted by a high-energy pump beam copropagating in a multimode optical fibre at different wavelengths. Thus, the  $M^2$  coefficient of the weak beam is either enhanced or degraded relative to the pump intensity, allowing an ultra-fast light-by-light control. This unconventional development extends the concept of the self-cleaning process where a single beam undergoes a significant brightness improvement under its own peak power.

Providing additional degrees of freedom, a multimode beam propagation has been attracting a great interest, as it allows unveiling various new processes based on its highly complex dynamics [1-4]. Among others, Kerr-induced beam self-cleaning is one of the most debating phenomenon recently discovered. It permits changing a speckled structure into a quasi-single mode beam by using the light intensity itself. Such a self-transformation can be explained in terms of four-wave-mixing interactions, so far, demonstrated only at a single wavelength due to a nonlinear non-reciprocity of the mode coupling process [4]. This behaviour arises from a presence of self-phase-modulation differently impacting high-order and low-order modes. However, up to now this process seems resulting only in particular, Rayleigh-Jeans, energy distribution without allowing an on-demand control of the energy distribution over the guided modes [5].

In this paper, we demonstrate experimentally that an incoherent speckled propagation of a weak beam can be controlled by means of a cross-phase-modulation enabled by an additional high power pump beam at a different wavelength, instead. We show that the change in modal energy distribution leading to the brightness enhancement (i.e.  $M^2$  decrease) (see figure 1(a)), can be controlled and properly adapted. Interestingly, we notice a monotone evolution of the entropy while improving  $M^2$  coefficient. Differently from previous studies we also show that by modifying the initial modal structure of the pump wave it is possible to obtain the opposite effect, observed as a beam defocusing or a beam degradation (i.e.  $M^2$  increase) (see figure 1(b)), due to a change of modal energy distribution to the benefit of high-order modes. Our findings allow to generalise the concept of light control by light in multimode optical fibers. Numerous applications ranging from ultrafast focus control for nonlinear imaging or beam quality control for lidar can be addressed. A further extension of the light self-organization approach to the time domain can also be envisaged while allowing to control, for instance, multimode laser dynamics based on amplifying fibers or supercontinuum generation in passive fibers. We believe that our results may also add new building blocks and strengthen the research activity in thermodynamic-based description of beams propagation in complex media since a large number of modes may lead to averaging approach, as well [6].



**Figure 1:** Numerical simulations of the  $M^2$  coefficient evolution of a weak and a strong beams (pump) copropagating in a graded index optical fiber for two different cases. (a) cross-cleaning of the weak beam because of the pump beam intensity; (b) cross-defocusing of the weak beam because of the pump beam intensity

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