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Spotlight on "Observation of ~20-ns group delay in a low-loss apodized fiber Bragg grating"

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Spotlight summary:

Slowing the light down to its lowest limit is a challenge that in recent years has attracted the attention of a large number of researchers. And not only because of pure scientific curiosity, but mostly because slow light can really bring benefits in many applications, such as sensing, optical communications, and nonlinear optics. In fact, light speed reduction is inherently associated with a large delay, or equivalently with a high group index experienced by the propagating field, that results in a strongly enhanced efficiency of any light-matter interactions.

But (unfortunately there is always a "but"), if we want to make slow light really exploitable, we need to keep in mind two things: first, to be of practical use and not merely a wonderful lab experiment, slow light has to be generated and controlled in an easy and reliable way. Second, regardless of the physical phenomenon we exploit, when we dream of slow light, loss is the worst nightmare we can have. In other words, the ideal slow-light medium should be simple to fabricate and manipulate, low cost and (almost) loss free. Probably, reading these lines, most of you are now thinking of the same medium... optical fibers!

And indeed this would be a very good choice, because, considering the requirements above, it would be very hard to find anything better. Also the generation of slow light in optical fibers is quite easy, at least in principle, because one of the most established fiber optic components, the fiber Bragg grating (FBG), is itself a slow-light device. At wavelengths just outside the bandgap, a uniform FBG acts as an interferometer: here, constructive interference occurs producing transmission peaks where the light experiences a large group delay. Moreover, suitable optimized designs for apodized and π-shifted FBGs, as well as grating pairs arranged in Fabry-Perot cavities, can be used to realize high Q-factor resonators with a high group index. Unfortunately conventional UV-writing techniques employed to realize FBGs are not loss-free. Typical FBG loss coefficients range around 1 m^{-1} (i.e. nearly four orders of magnitude higher than in the bare optical fiber) for a refractive index modulation of about 10^{-3}, this loss being the main limiting factor to the maximum group index that can be achieved in FBGs.

In their work, G. Skolianos and co-workers demonstrate that the loss of a FBG can be dramatically reduced using a femtosecond laser technique instead of conventional UV-writing. With this technique, a loss coefficient as low as 0.12 m^{-1} was achieved, with no reductions of the refractive index modulation. Such a small loss enabled them to realize FBGs with a group delay of about 19.5 ns, corresponding to a record group index of 292 (or a Q-factor of 1.5×10^{7}). Actually this achievement was not only the result of technology improvements in the FBG writing, but also of an optimized design of the FBG refractive index profile. In fact, a strong Gaussian-like apodization was employed, leading to the creation of Fabry-Perot interference effects associated with much stronger slow-light resonances than in uniform FBGs of comparable index modulation. This combined technology and design optimization was the enabling key for a 4-fold increase of the group index compared to the previous record value. But nothing is for free and a narrow bandwidth (as small as 0.1 pm in the reported experiment) is the price to be paid for slow-light.

From this work we learn that we must never make the error of considering well-know devices, such as FBGs, scientifically obsolete. Not only is the Devil in the details, but sometimes also some treasures are there. And in this work, both in design and technology optimization, details enabled to pull the rabbit from the hat.

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