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Slow-light: Fascinating physics or potential applications?

Foreword

The velocity of light when propagating in vacuum, usually labelled c, is a physical constant fixed since 1983 by the *Bureau International des Poids et Mesures*. Its value is exactly 299 792 458 metres per second. When propagating in media, the light velocity depends, however, on an optical property of the media, the index of refraction, and changes slightly from its value in vacuum. In recent years, a growing attention has been paid to media in which the refractive index changes drastically with the optical frequency of the electromagnetic radiation in such a way that the corresponding group velocities of optical pulses can be modified by a large amount and eventually controlled dynamically. We refer to those phenomena as slow light or fast light. Beyond the fascinating fundamental physics, slow or fast light has drawn considerable attention for applications such as all-optical packet switching and routing, microwave photonics and all-optical signal processing.

Slow-light propagation has been observed in various materials and devices, including low-pressure metal vapors, semi-conductors and optical fibers. All of those share a common principle: a sharp resonance of the light–matter interaction. A different category of slow light stems for the highly dispersive nature of nanostructured photonic devices. This special issue "Slow-light: Fascinating physics or potential applications?" of the *Comptes Rendus Physique* gathers 10 papers reporting the latest achievements in the field from scientific institutes in France and Europe.

One of the first efficient demonstrations of slow light was achieved via Electromagnetically Induced Transparency (EIT). F. Goldfard et al. from the Laboratoire Aimé-Cotton of CNRS in Orsay in "*Electromagnetically-induced transparency, slow light, and negative group velocities in a room temperature vapor of* $^4He^*$" demonstrate the transition from slow light to negative group velocity by tuning the coupling beam out of optical resonance in a scheme using optically detuned resonances (Fano-like profiles). The second article "*Light propagation in a solid doped with erbium ions: From ultraslow light to the superluminal regime*" by E. Baldit et al. from Laboratoire de photonique et de nanostructures of CNRS in Marcoussis achieved a very low group velocity (3 m/s) through Coherent Population Oscillations effect (CPO) in a Er^{3+}:Y_2SiO_5 crystal. In their article entitled "*Slow-light through nonlinear wave-mixing in liquid crystal light-valves*", U. Bortolozzo et al. from Université de Nice demonstrate the slowing down of light to 0.2 mm/s through nonlinear wave-mixing in a liquid crystal light-valve. A practical outcome of this result is an adaptive holographic interferometric system purposed at the detection of sub-picometer displacements.

Waveguide-based two-dimensional photonic crystals (PhC) are now recognized as a viable technology for highly integrated photonic circuits. Efficient group velocity reduction was demonstrated in PhC structures, in conjunction with a wide bandwidth and the possibility of controlling high-order dispersion. In "*Slowing down the light for delay lines implementation: Design and performances*", A. Talneau, from Laboratoire de photonique et de nanostructures of CNRS, evaluates experimentally the performances achieved with different PhCs designs and points out the impact of the fabrication imperfections. T. Nielsen et al. from Technical University of Denmark, in "*Slow light pulse propagation in dispersive media*", investigates theoretically slow light pulse propagation in a semiconductor PhC waveguide with embedded quantum dots in a regime where the pulse is subjected to both waveguide and material dispersion. Finally, theoretical and experimental analysis of active single and coupled resonators is reported in "*Artificial dispersion of active optical coupled resonator systems*" by S. Trébaol et al. from ENSSAT-FOTON.

Optical fibers still offer an excellent playground for the implementation of original slow light schemes. Strict control over the polarization is crucial for efficient slow and fast light based on optical parametric amplification in optical fibers. M. Santagiustina et al. from University of Padova, Italy in "*Polarization control for slow and fast light*

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in fiber optical, Raman-assisted, parametric amplification" propose a theoretical and numerical analysis of waves interaction focused on high birefringence and spun fibers. For practical applications of slow light, semiconductor devices, particularly Semiconductor Optical Amplifiers (SOA), are very attractive because of their compactness and room temperature operation. Furthermore, they are controlled electronically. In "*Slow light using semiconductor optical amplifiers: Model and noise characteristics*" P. Berger et al. from Thales Research & Technology propose an improved model in order to accurately predict the gain compression and phase delay depending on current and on the optical input. In addition, this model is efficient in describing the additive noise of the SOAs. A. Martinez et al. from Laboratoire de photonique et de nanostructures of CNRS in "*Slow and fast light in quantum dot based semiconductor optical amplifiers*" report on the potential of InAs/InP quantum-dash based SOAs in comparison with bulk SOA for slow and fast light applications. The last paper of this special issue "*Wideband delays generated in an all-optical tunable delay line, preserving signal wavelength and bandwidth*" by L. Thevenaz et al. from École polytechnique fédérale de Lausanne, Switzerland concerns a novel technique to produce a large delay controlled all-optically. That is achieved with an all-fibered scheme consisting in a SOA for wavelength conversion and a dispersive optical fiber.

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