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Slow and Fast Light

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The speed of light in vacuum is one of the most fundamental constants in nature, which underlies many of the basic properties of the universe. There is no wonder, therefore, that the first attempts to understand and control the speed of light can be traced back to some of the pioneers of electromagnetic waves theory such as Lorentz, Sommerfeld, and Brillouin. The efforts to understand the fundamental properties of light propagation through slow- and, in particular, fast-light media triggered a plethora of studies, intense debates, and controversies.

The recent and rapid development of several technologies such as nanofabrication, narrow-linewidth lasers, and low-noise detectors transformed slow and fast light from a fundamental science to an applied research topic. Slow and fast light is a rapidly growing field, utilizing diverse physical platforms such as low-pressure metal vapors, fibers, semiconductors, liquid crystal, and integrated optics. Slow/fast-light devices and platforms are expected to become key ingredients in future applications such as high-throughput telecommunication systems, sensing, precise measurements, and many more.

In this special section of *Optical Engineering*, we present a collection of papers that represents to a certain extent a snapshot of the current state of the art in slow- and fast-light research and technology. Seven out of the eleven papers in this section focus on slow-light effects, while the other four papers focus on fast light and combined slow/fast phenomena and applications.

The first paper, titled “Enhanced negative group velocity propagation in a highly nonlinear fiber cavity via lased stimulated Brillouin scattering,” by Liang Zhang et al., employs nonlinear effects for realizing fast light. Advancements of up to 366 ns are demonstrated for a modulated signal in a fiber-cavity incorporating a 10-m long highly nonlinear fiber. The cavity configuration adopted in this research relaxes the requirements for pump power which is often an obstacle for short Brillouin scattering-based devices.

S. Shen, X. Xu, and Y. Xiao in their paper “Amplified slow light beam splitter and 1 s optical memory” use phase-sensitive degenerate four-wave mixing in order to amplify the signal of a slow-light atomic beam splitter. With this scheme they

were able to demonstrate efficient light storage and long-lasting optical memory exceeding 1 second.

U. Bortolozzo et al. in the paper “Slow light in liquid crystal media,” present slow-light propagation in liquid crystals using two approaches: exploiting photoisomerization-induced transparency in dye-doped chiral liquid crystals, and two-wave mixing optical resonance in pure nematics. Using these methods they predict a group index approaching 10^3 over a narrow linewidth of ~ 10 Hz.

The paper titled “Slow light propagation in tunable nanoscale photonic crystal cavity filled with nematic liquid crystal,” by K. R. Khan et al., shows theoretically that the properties of a photonic crystal (PhC) cavity filled with nematic liquid crystal can be widely tuned by applying temperature changes or electric field. Both positive and negative group indices are obtained depending on the specific mode propagating through the PhC.

S. Schwartz, F. Goldfarb, and F. Bretenaker in their paper “Some considerations on slow- and fast-light gyros,” present a discussion of the limitation of slow- and fast-light phenomena for enhancing the sensitivities of optical-rotation-sensing devices. This topic attracted much attention during the past several years, being the focus of a long-lasting debate, as it deals with both fundamental and practical issues.

The paper “‘Heavy’ and ‘light’ photon bands induced by symmetry in a linear array of Sagnac reflectors,” by J. Scheuer, proposes a new type of a slow-light structure consisting of a linear array of Sagnac reflectors. The directional coupler in each unit-cell breaks some of the symmetry properties of the structure, yielding a slow and a fast branch in the dispersion diagram which can be tuned by modifying the coupling ratio. The suggested scheme offers new and alternative ways to control and manipulate the group velocity and the dispersion of periodic structures.

P. Singh et al. in the paper “Detection of Coriolis force and rotational Doppler effect by using slow light,” utilize slow-light effects in an atomic vapor cell to enhance the Fizeau drag and rotational Doppler effect. Their theoretical study predicts a substantial enhancement of these effects when an ultradispersive media is used. Applications of the effect could include the detection of weak forces exerted on a single atom.

The paper "Four-wave mixing in a ring cavity," by E. E. Mikhailov et al., investigates a four-wave-mixing process in an N -type scheme in Rb vapor placed inside a low-finesse ring cavity. The authors show their scheme to be a promising candidate for the realization of tunable "slow-to-fast" light medium with a positive gain, which is particularly interesting for the experimental demonstration of "fast-light" enhancement of optical-gyroscope performance.

T. Schneider and A. Wiatrek in their paper titled "Broadening-free stimulated Brillouin scattering-based slow and fast light in optical fibers," explore methods for obtaining zero-broadening stimulated Brillouin scattering (SBS)-based slow-light propagation in fibers. By reshaping the original pulse via saturation of the SBS process, or by utilizing a superposition of two gains, the authors demonstrate an almost ideal overall gain and phase function over the bandwidth of the pulses. Thus, SBS-based slow light can provide broadening-free and almost distortion-free delay of the optical pulses, a property which is highly attractive for various telecommunications applications.

The paper "Performance of a resonator-based interferometric fiber-optic gyroscope under the square wave phase bias modulation," by X. Zhang et al., studies a resonator-based interferometric fiber-optic gyroscope (R-IFOG) under square-wave phase bias modulation. The authors predict that incorporating the modulation can lead to a substantial reduction of the necessary fiber length compared to a

conventional IFOG possessing the same sensitivity, in particular for the slow rotation range.

The final paper in the special section, authored by Y. Blau et al. and titled "Optimal excitation of the Bloch modes of coupled resonator optical waveguides," studies the impact of the excitation scheme on the performances of coupled resonator optical waveguides (CROWs). Specifically, the authors consider the practicality of several methods to overcome the symmetry related dispersion, taking into account the impact of fabrication errors, waveguide roughness, etc. They show that by properly exciting the CROWs, the symmetry related dispersion and pulse distortion can be almost completely avoided for bit rates as high as 40 Gb/s.

Selim Shahriar is a professor in the Departments of EECS and Physics and Astronomy at Northwestern University. He received his PhD from MIT in 1992. His research interests include slow and fast light, quantum computing, gravitational wave detection, tests of general relativity, holographic and polarimetric image processing, atomic clocks, and atom interferometry. He has published 390 journal and conference papers. He is a Fellow of SPIE and OSA.

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