Stocker les photons : une illusion d'optique ??

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Réflexion menée dans le cadre du club des partenaires, au sein du GDR Ondes

- Contexte scientifique
- Objectifs du groupe de travail
- Membres

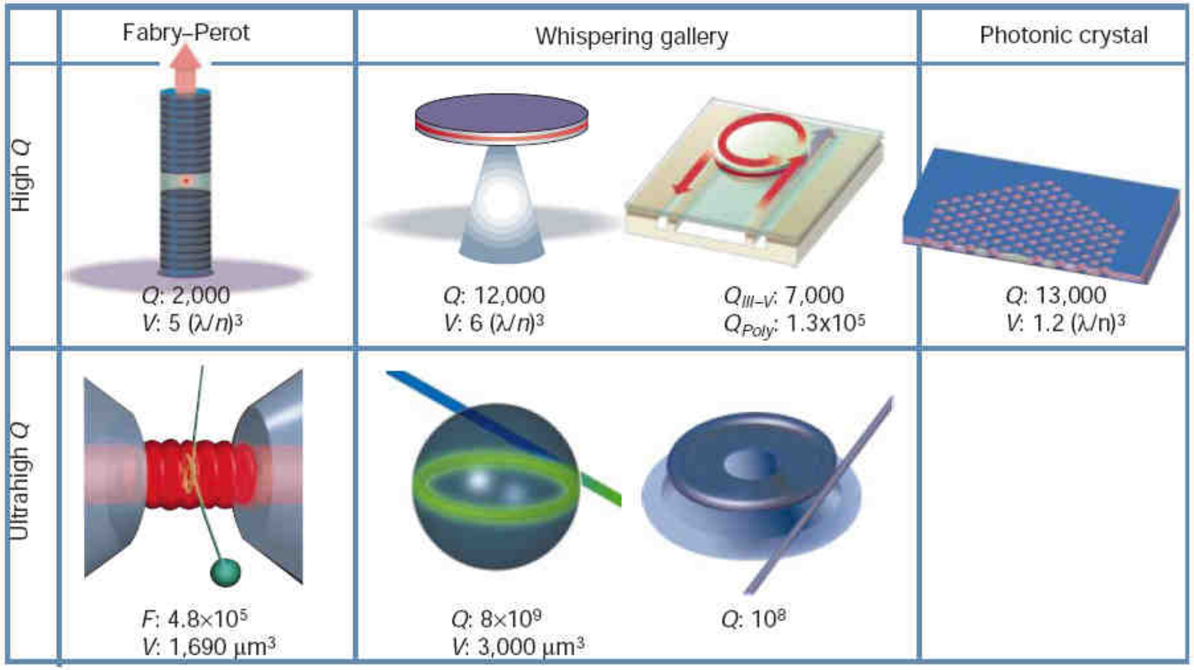
Du rêve….à la réalité,
que peut-on imaginer par *« stocker les photons » ?*

Stocker les photons ??!

- Les localiser
- Les « ralentir »

Stocker la lumière : localiser les photons ?

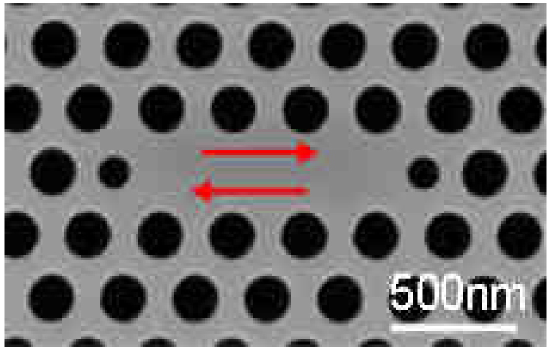
- Approche issue de l'école microcavités & cristaux photoniques : les résonateurs



NATURE | VOL 424 | 14 AUGUST 2003 |

Localiser les photons : micro - nano résonateurs & Q/V

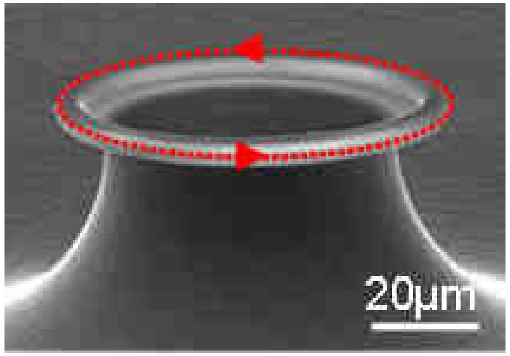
$Q = 10^6$



京都大学

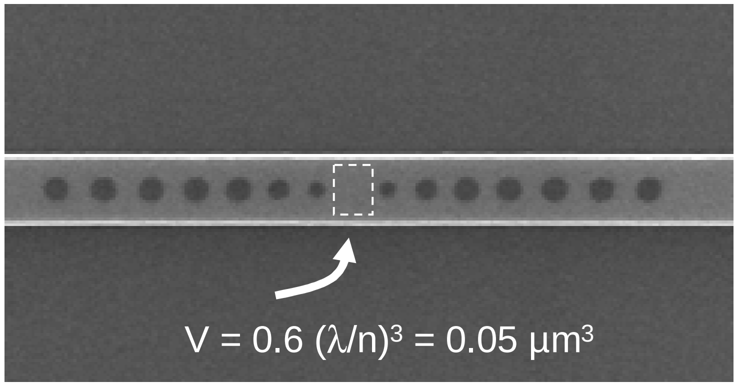
L - type nanocavity

$Q = 10^8$



WGM – type Microtoroid

$Q = 10^5$



FP - type nanocavity

Localiser / ralentir les photons : résonateurs couplés (CROW)

June 1, 1999 / Vol. 24, No. 11 / OPTICS LETTERS 711

Coupled-resonator optical waveguide: a proposal and analysis

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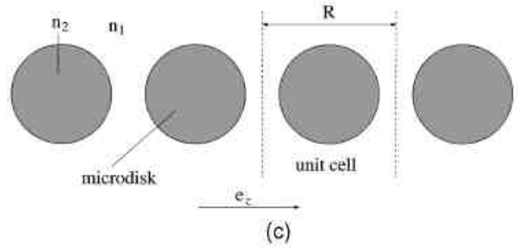
Received February 22, 1999

We propose a new type of optical waveguide that consists of a sequence of coupled high-*Q* resonators. Unlike other types of optical waveguide, waveguiding in the coupled-resonator optical waveguide (CROW) is achieved through weak coupling between otherwise localized high-*Q* optical cavities. Employing a formalism similar to the tight-binding method in solid-state physics, we obtain the relations for the dispersion and the group velocity of the photonic band of the CROW's and find that they are solely characterized by coupling factor κ_1. We also demonstrate the possibility of highly efficient nonlinear optical frequency conversion and perfect transmission through bends in CROW's.

OCIS codes: 130.2790, 190.0190, 230.7370.



Q * β

ARTICLES

Ultracompact optical buffers on a silicon chip

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On-chip optical buffers based on waveguide delay lines might have significant implications for the development of optical interconnects in computer systems. Silicon-on-insulator (SOI) submicrometre photonic wire waveguides are used, because they can provide strong light confinement at the diffraction limit, allowing dramatic scaling of device size. Here we report on-chip optical delay lines based on such waveguides that consist of up to 100 microring resonators cascaded in either coupled-resonator or all-pass filter (APF) configurations. On-chip group delays exceeding 500 ps are demonstrated in a device with a footprint below 0.09 mm^2. The trade-offs between resonantly enhanced group delay, device size, insertion loss and operational bandwidth are analysed for various delay-line designs. A large fractional group delay exceeding 10 bits is achieved for bit rates as high as 20 Gbps. Measurements of system-level metrics as bit error rates for different bit rates demonstrate error-free operation up to 5 Gbps.

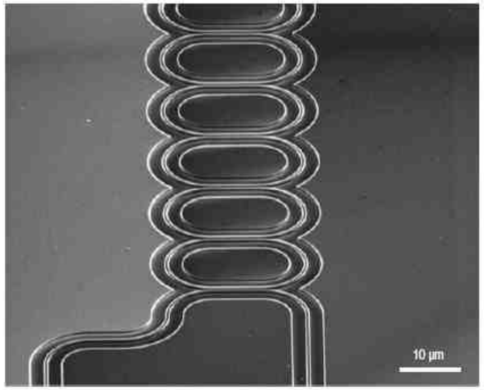

Figure 5 A CROW consisting of cascaded microrings fabricated on an SOI substrate. Multiple microrings are evanescently coupled with each other and the end microring is coupled with an access waveguide on the near side[81].

Délais +/- 500 ps

Large-scale arrays of ultrahigh-*Q* coupled nanocavities

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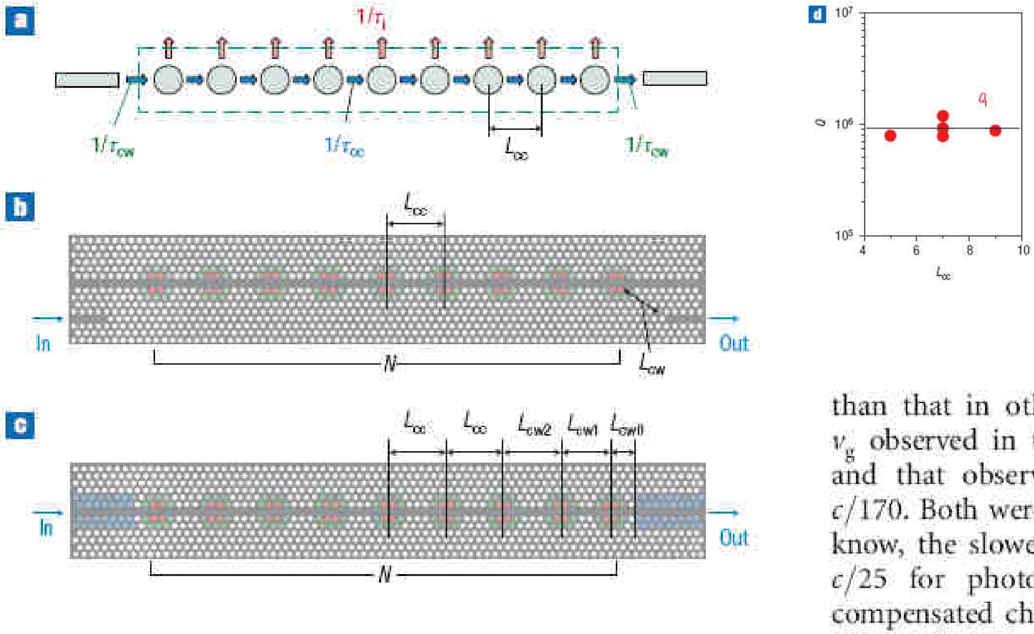
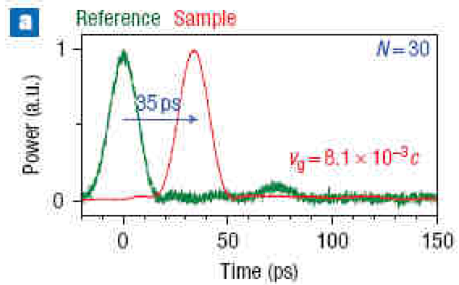
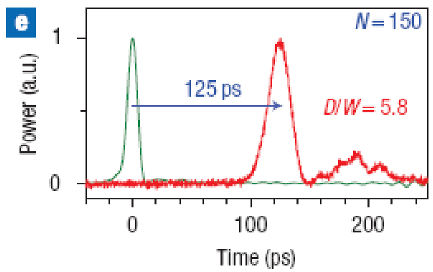


Figure 1 Coupled resonator based on ultrahigh-*Q* nanocavities.





than that in other types of slow-light waveguides. The slowest v_g observed in the spectral measurements was close to $c/1{,}000$, and that observed in the pulse propagation experiments was $c/170$. Both were obtained in a null GVD condition. As far as we know, the slowest v_g observed in the pulse delay experiments is $c/25$ for photonic-crystal waveguides[17], $c/42$ for dispersion-compensated chirped photonic crystal waveguides[18] and $c/35$ for CROWs[22]. This difference in v_g is primarily due to the smallness

c/100 – c/1000

INSTITUT NANOSCIENCES ET CRYOGÉNIE

Slow light now and then

What are the origins of slow-light research and where is the field heading? *Nature Photonics* spoke to Robert Boyd to find out.

nature photonics | VOL 2 | AUGUST 2008 |

- Approche issue de l'optique quantique & de la physique des effets non linéaires

- Approche issue des cristaux photoniques
  - Modes lents dans les CP

What is the physics behind the light control?

Broadly speaking, there are two procedures that can be used to control the group velocity of light. One of these is to exploit material resonances, such as the sharp absorption resonances of an atomic vapour. Control can be achieved, for example, by applying a strong optical field and using nonlinear effects to modify the optical response experienced in a signal pulse, as in the work of Hau *et al.*[3]. Examples of this approach are EIT and CPO. In addition to EIT and CPO, there are several other sorts of material resonances that can be used to produce slow-light effects. There has been particular success with the use of stimulated Brillouin scattering[8] [also described on page 474 of this issue[9]] and the use of stimulated Raman scattering[10]. In each of these processes, the strong gain feature induced by the presence of a strong pump field will also produce, as a consequence of the Kramers–Kronig relations, a rapid spectral variation in the refractive index, which in turn leads to strong slow-light effects.

The other procedure is to use material engineering to fabricate microstructured materials, such as arrays of microrings and photonic crystals that have artificially created resonances and optical responses. For instance, the group velocity of light in a photonic crystal can be slowed down dramatically near the band edge of the photonic Brillouin zone. [A detailed report

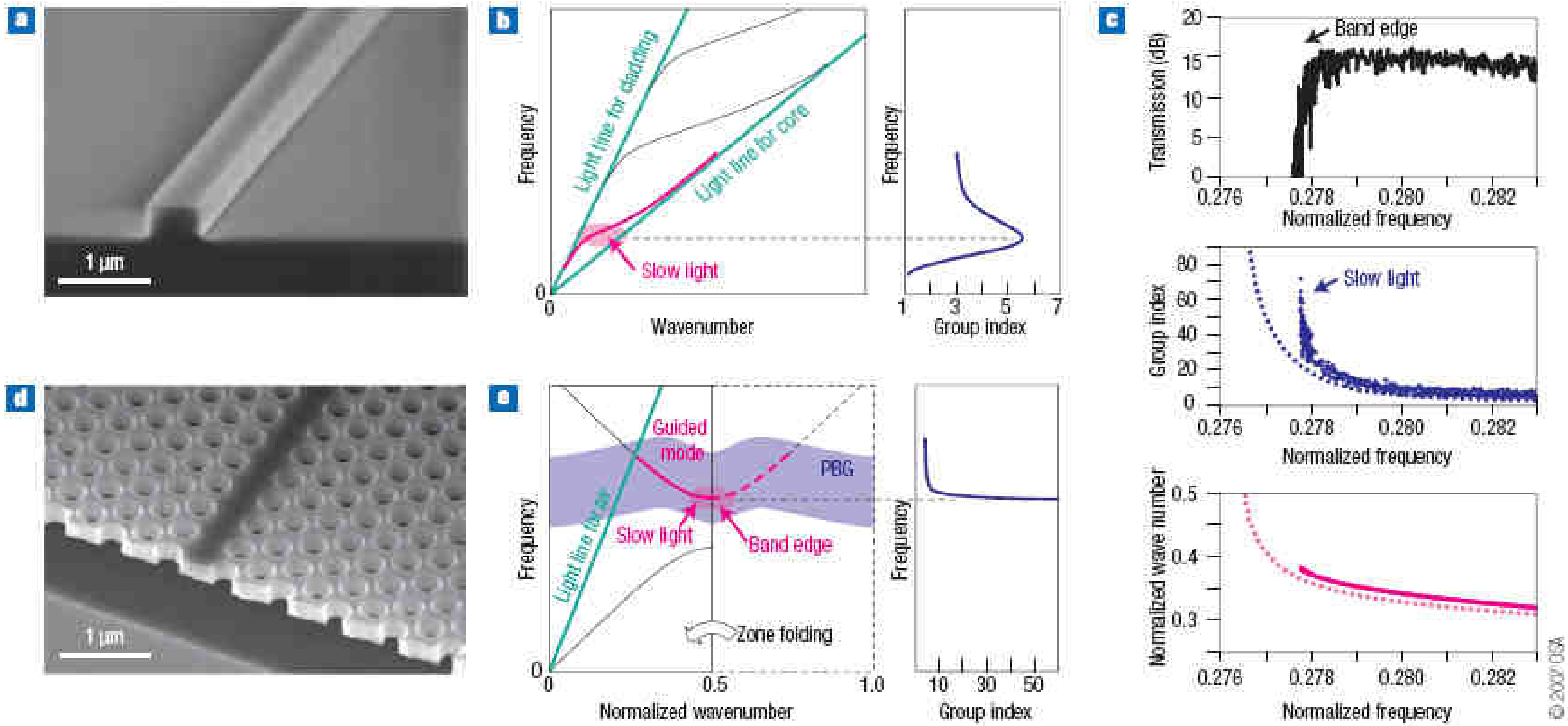


Figure 1 Waveguides, photonic bands and group-index characteristics. The normalized wavenumber means the wavenumber in units of reciprocal lattice $2\pi/a$, where a is the lattice constant. The normalized frequency is defined as $\omega a/2\pi c = a/\lambda$. **a**, Scanning electron microscope image and, **b**, schematic band diagram and group-index spectrum for a silicon PWW. **c**, Transmission spectrum, group-index spectrum and band diagram with respect to the normalized frequency for a silicon PCW. For the group-index spectrum and band diagram, dots denote experimental results obtained by the modulation phase-shift method, whereas dotted lines denote calculated results with an effective-index approximation. Adapted with permission from ref. 50. **d**, Scanning electron microscope image and, **e**, schematic band and group-index spectrum of a silicon PCW with respect to the absolute frequency.

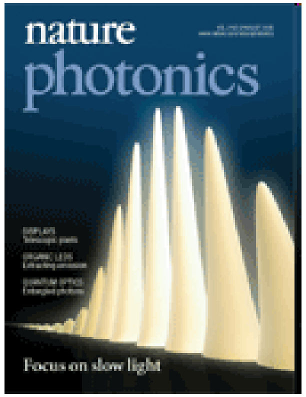
nature photonics | VOL 2 | AUGUST 2008 |

Commentaires

- Localiser et/ou ralentir la lumière relève de la même physique dans le cas des cristaux photoniques

- Les effets induits par une corrugation périodique sont spectralement définis
  - Compromis bande passante / délais
  - Stratégies / idées pour le contourner (voir notamment S. Fan et coll.)

Article de revue



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REVIEW ARTICLE | FOCUS

Slow light in photonic crystals

Slow light with a remarkably low group velocity is a promising solution for buffering and time-domain processing of optical signals. It also offers the possibility for spatial compression of optical energy and the enhancement of linear and nonlinear optical effects. Photonic-crystal devices are especially attractive for generating slow light, as they are compatible with on-chip integration and room-temperature operation, and can offer wide-bandwidth and dispersion-free propagation. Here the background theory, recent experimental demonstrations and progress towards tunable slow-light structures based on photonic-band engineering are reviewed. Practical issues related to real devices and their applications are also discussed.

Slow light now and then

What are the origins of slow-light research and where is the field heading? *Nature Photonics* spoke to Robert Boyd to find out.

Robert Boyd is a professor at the University of Rochester in the USA.

What are some of the applications of slow light?
The most obvious and arguably the most important application is in the construction of tunable optical delay lines. These devices have applications in many branches of optical technology, such as in the construction of optical buffers (temporary storage devices for light pulses), which will be useful for optical communications and optical data manipulation. Another potential application is the use of slow-light methods for interferometry. Under certain circumstances, the resolution of a spectroscopic interferometer can be increased dramatically by placing a slow-light medium within the interferometer[13]. Slow light has also gradually shown its potential in many other applications, such as optical switching, nonlinear optics and quantum optics [as listed on page 448 of this issue[14]].

Ligne à retard - Buffers

COMMENTARY | FOCUS

Why do we need slow light?

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Effets non-linéaires

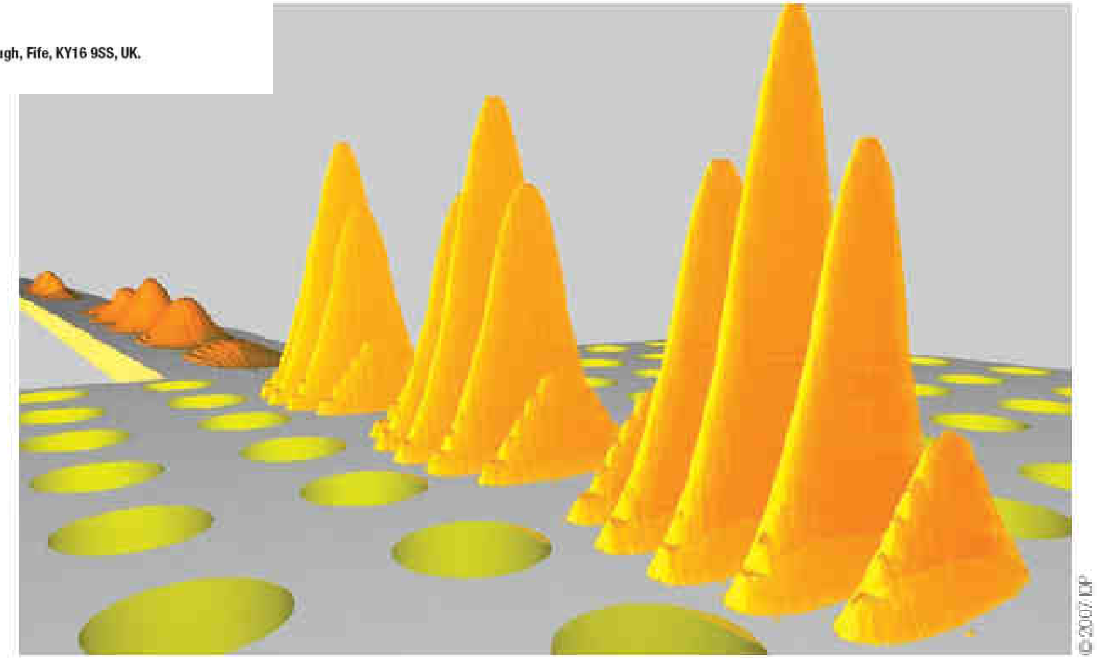

Figure 2 Illustration of the slow-light intensity enhancement. As a light pulse (left) enters a photonic-crystal waveguide operating in the slow-light regime, the pulse length is compressed resulting in increased intensity. Reprinted with permission from ref. 4.

Objectifs du groupe de réflexion

- Faire un bilan scientifique sur une thématique donnée et évaluer son potentiel en terme de perspectives d'applications :
  - État de l'art
  - Proposition d'actions, le cas échéant :
    - Workshop / école scientifique
    - Proposition d'appels à projet
    - Autres …

Composition du groupe

- Membres du groupe de réflexion au 01/11/09 :
  - Alexia Auffeves / CNRS - Institut Néel
  - Emmanuel Centeno / Université Montpellier > Clermont Fd
  - Alejandro Giacomotti / CNRS - LPN
  - François Reptin / DGA - Composants opto & hyper
  - Christian Seassal / CNRS - INL
  - Frédérique de Fornel / Groupe OCP - ICB
  - Emmanuel Hadji / laboratoire SiNaPS, INAC/SP2M - CEA/G

Merci de votre attention