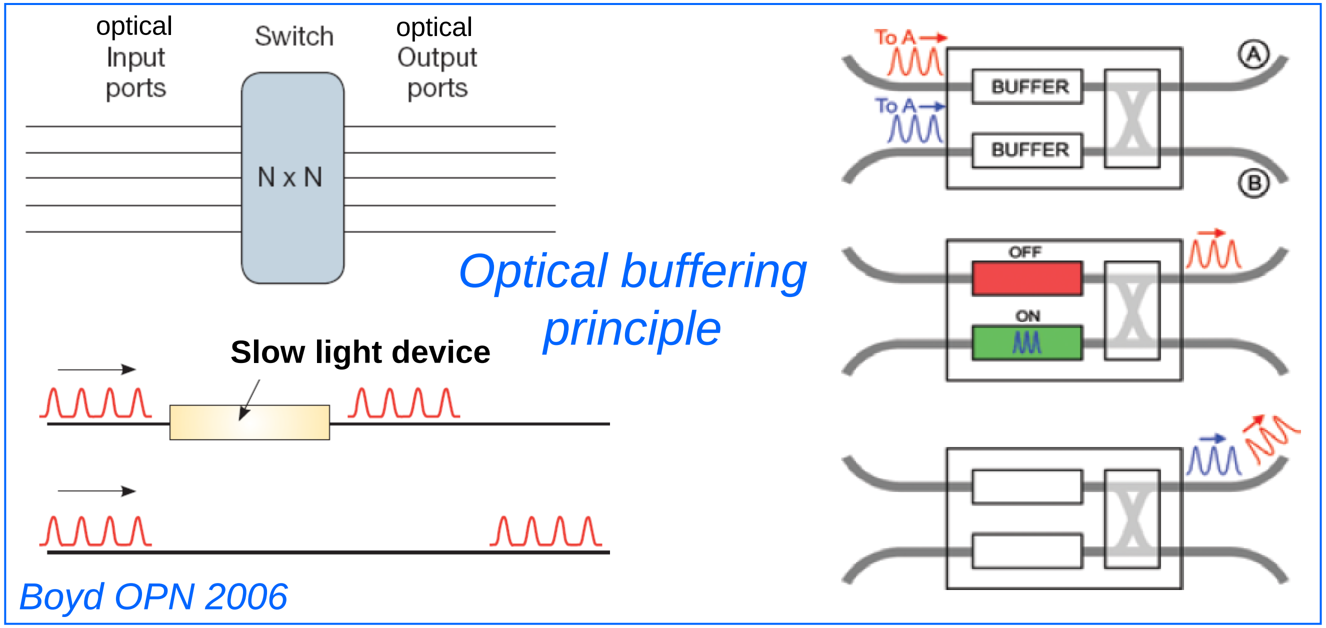
SLOW LIGHT WORKSHOP
16 June 2006

INTRODUCTION

Boyd et al, OPN 2006

Motivations for slow light

- Optical delay lines: optical buffering, optical data synchronization, all-optical routers…



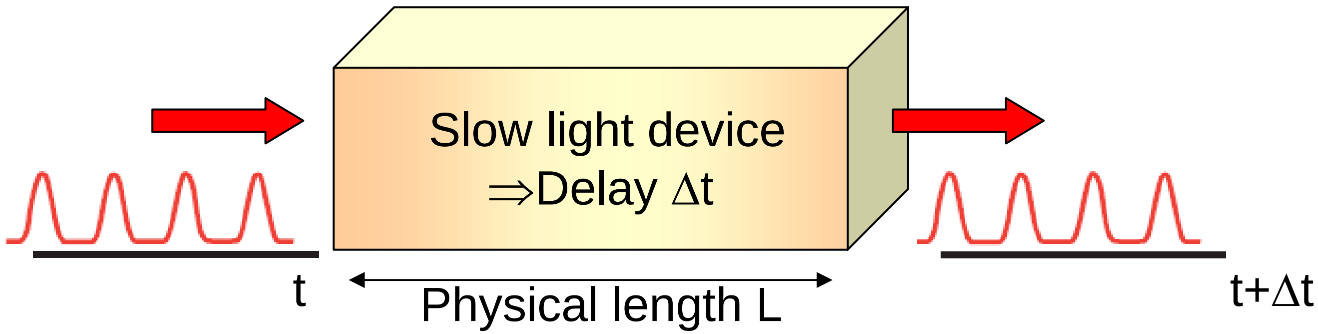
High interest for CUDOS

"ultrahigh-speed all-optical signal processing on a single photonic chip for the next generation of ultrahigh bandwidth optical communication systems"

- All kinds of Nonlinear optical devices & sensors (light intensity and interaction times are enhanced)
- Quantum information science

Slow light devices for buffering

Reduced speed at which light pulses travel = the basis of an optical buffer



Group velocity $v_g = c/n_g$,

Group delay or time for a pulse to cross the device:

$$\Delta t = L/v_g = L \times n_g / c$$

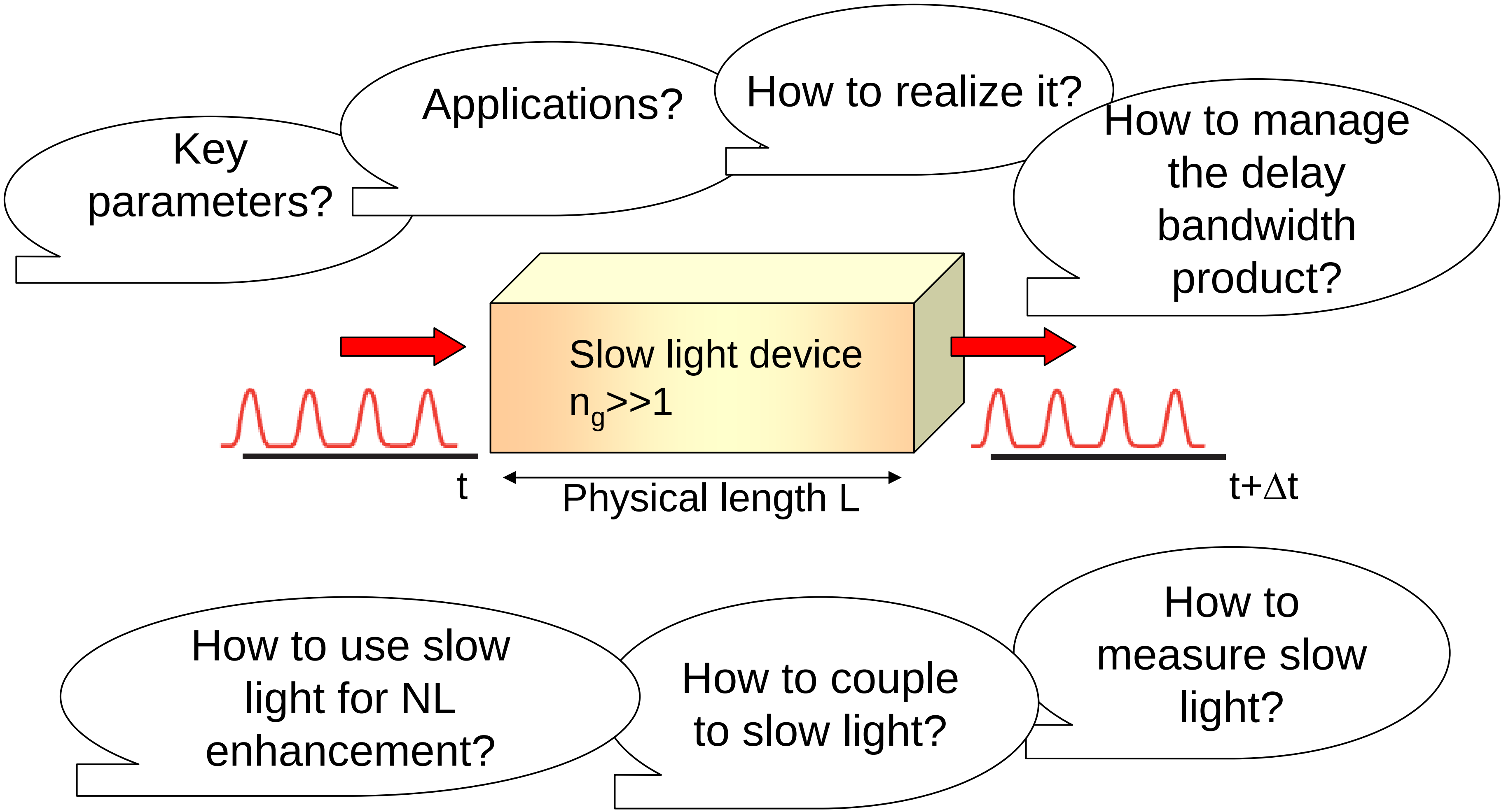
↗ ↗ $n_g >> 1$

The realized slow light device should:

- ✓generate high time delays
- ✓slow high bandwidth signals without distortion
- ✓display a tunable time delay
- ✓be integrated & compact

Workshop motivations

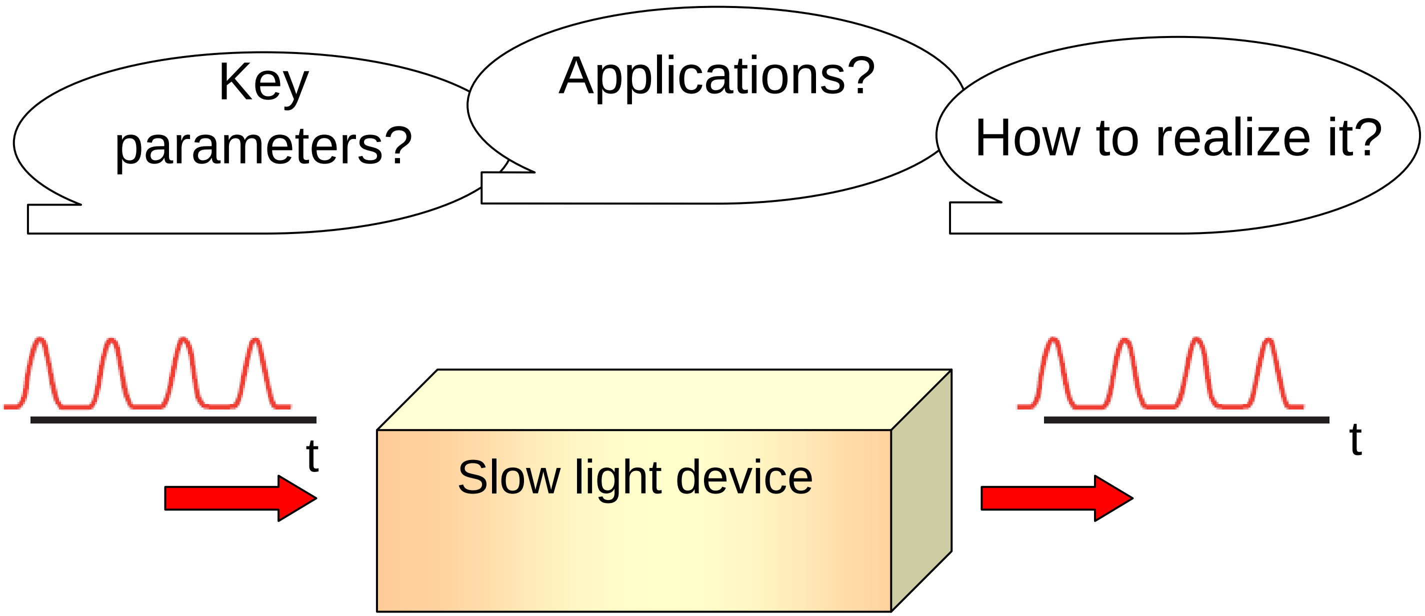
Identify, understand and answer some problems/questions related to slow light



PROGRAM OF THE DAY

I. Slow light basics 10:30am
II. Managing the bandwidth-delay product 1:00pm
III. Manipulating slow light 3:30pm

I. Slow light basics



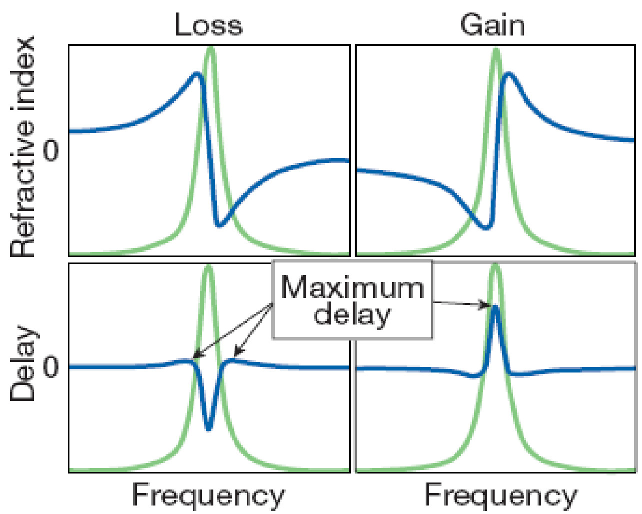
- Requirements, parameters and application of slow light (optical buffers) *Martin de Sterke*

- The different approaches to slow down light:
  - -Generic approach I, EIT vs coupled resonator, *Mike Steel*
  - -Generic approach II, Raman, SBS and Nonlinear, *Andrey Sukhorukov*

Overview of the 2 generic approaches

A) Material resonance engineering (absorption or gain)

Absorption or gain resonance ⇔ increase of group index



Kramers Kronig

$$n(\omega) = 1 + \frac{c}{\pi}\int_0^\infty \frac{\alpha(\omega')}{\omega'^2 - \omega^2}\, d\omega'$$

$$n_g = n + \omega \frac{dn}{d\omega} \qquad V_g = c/n_g$$

Mok et al, Nature 2005

Absorption engineering:
Electromagnetically induced transparency,
Coherent population oscillation
Hau Nature 397, 594, 1999
Bigelow PRL 90, 113903, 2003

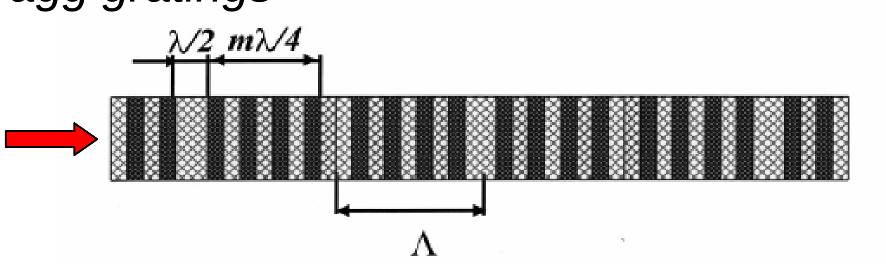
Gain engineering:
Stimulated Brillouin Scattering,
Stimulated Raman Scattering
Song Opt Exp 13, 82, 2005
Sharping Opt Exp 13, 6092, 2005

Variety of materials investigated: cold Na atoms, Ruby, Semiconductors, Quantum dots, Silica fibers…

B) Photonic resonance engineering: coupled micro-resonators

Structuration of the optical environment to enhance the effective length of the light ⇔ reduction of v_g

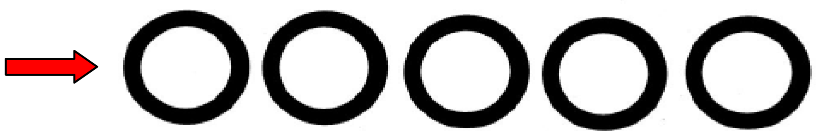
Bragg gratings



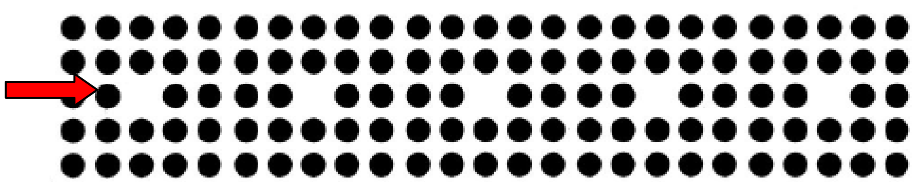
Eggleton JOSAB 14, 2980, 1997

More flexible, compact devices,…

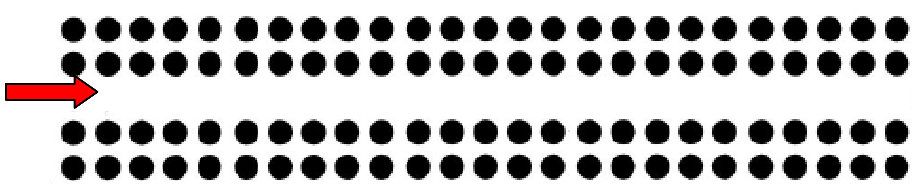
Ring resonators



Heebner JQE 40, 726 2004

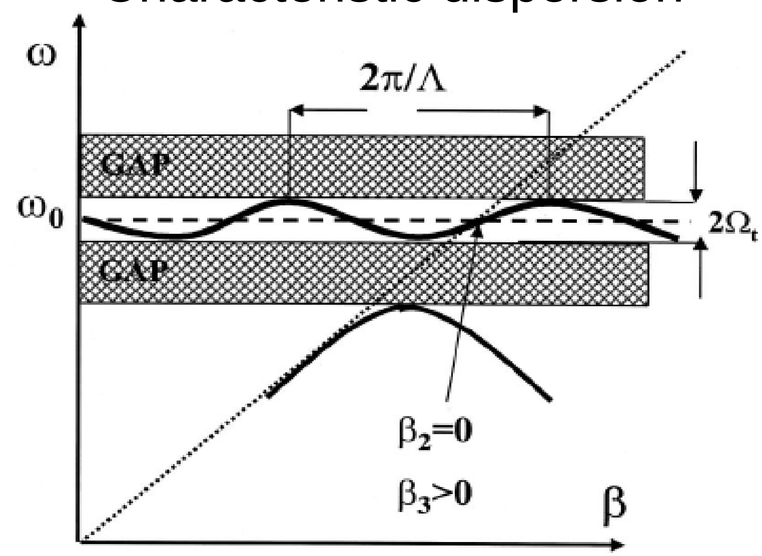


Planar photonic crystals



Notomi PRL 87, 253902 2001
Vlasov Nature 438, 65 2005

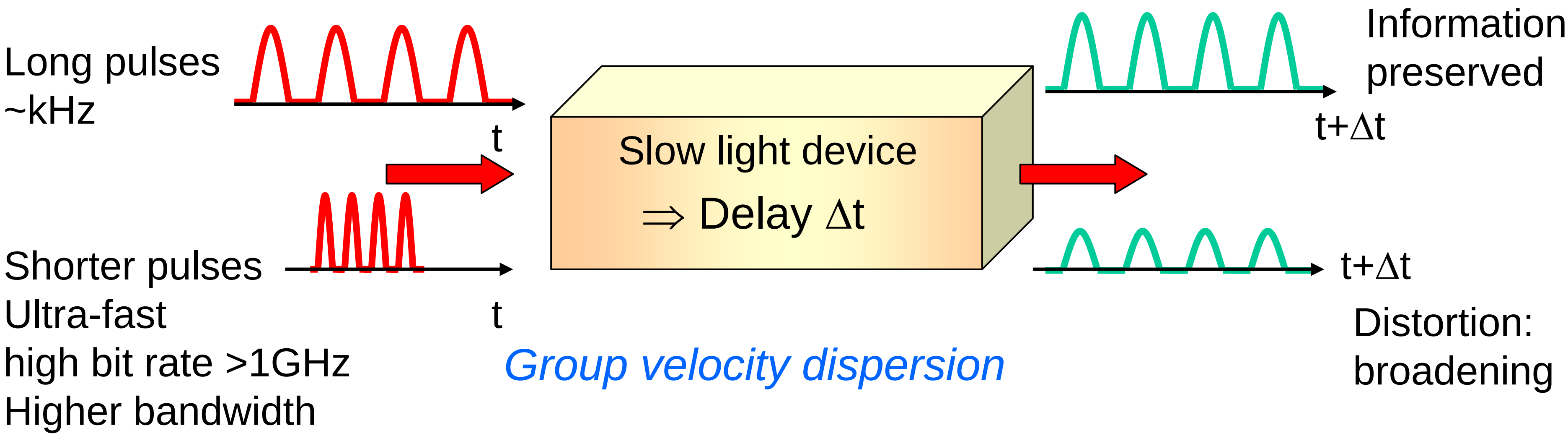
Characteristic dispersion



Khurgin JOSAB, 22, 1062 2005

II. Managing the delay-bandwidth product

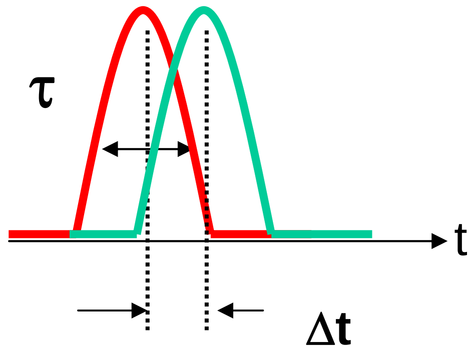
Issue existing for all the approaches



<u>Tradeoff</u>: achieved delay Δt /
Bandwidth of the signal (slowed without distortion)

Key parameter: **Δt/τ**

How many pulse widths the pulse is delayed by



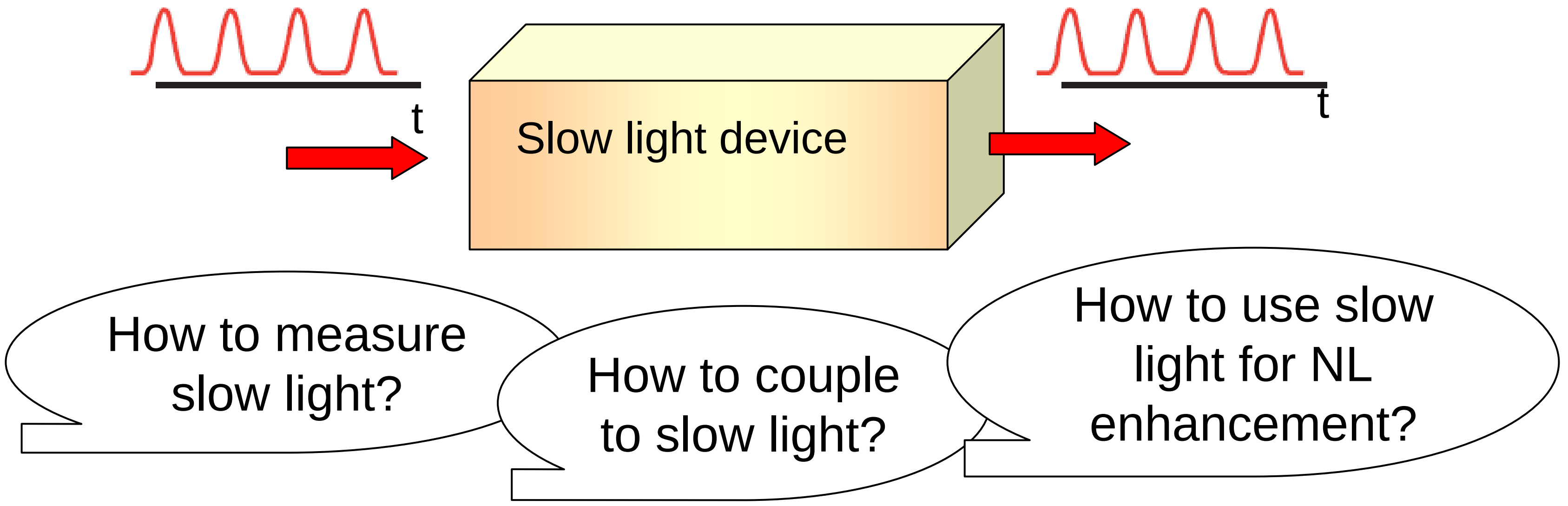
Different approaches to manage Δt*BW

(esp. relevant to CUDOS researches)

How to manage the delay bandwidth product?

- Dispersion engineering with 2D PCs, *Tom White*
- Fan approach, *Ara Asatryan*
- Plasmonics in PCs, *Ross Mac Phedran*
- Gap solitons, *Joe Mok*
- Slow light diffraction management and spatio-temporal localization, *Andrey Sukhorukov*

III. Manipulating slow light



Interaction with a slow light device

- Measurement of slow light, *Luke Stewart*
- Slow light coupling and losses, *Boris Kuhlmey*
- Adiabatic coupling method, *Kokou Dossou*

Enhanced interaction time within a slow light device

- ~~Nonlinear enhancement, *Andrey Miroshnichenko*~~ **CANCELED**

Several figures in the race towards slow light

Material resonances: absorption or gain engineering

- Electromagnetically induced transparency
  - -17m/s observed in ultracold gas of Na atoms *Hau Nature 397, 594, 1999*
  - -stopped light in cold cloud of Na atoms *Liu Nature 409, 490, 2001*
  - -SC slow light device with SC QDs at RT, *C. J. Chang-Hasnain Proc IEEE 9, 1884, 2003 and Ku Electron Lett 38, 1581, 2002*
- Coherent population oscillation at RT, solid state
  - -60m/s in solid state crystal: 0.71ms delay for 30ms pulses (BW<1kHz) *Bigelow PRL 90, 113903, 2003*
  - -3m/s→100m/s in Erbium doped crystal (BW<1kHz) *Baldit PRL 95, 143601, 2005*
  - -tunable delay of 68fs for 170fs pulses (2.6THz) in QD SC amplifier *van der Poel Opt Exp 13, 8032, 2005*
  - -vg/3 @16.7GHz, in SC 100μm-waveguide *Mork Opt Exp 13, 8136, 2005*
  - -SC VCSEL below threshold @2.8GHz, vg/10^6 100ps delay *Zhao Opt Exp 13, 7899, 2005*
- Stimulated Brillouin Scattering: BW~100MHz
  - - 20ns delay for 15ns pulses in SMF *Okawachi PRL 94, 153902, 2005*
  - - 30ns for 100ns pulse in SMF *Herraez APL 87, 081113, 2005 and Song Opt Exp 13, 82, 2005*
  - - Optimisation to increase the BW (10GHz) *Herraez Opt Exp 14 1395, 2006 and Stenner Opt Exp 13, 9995, 2005*
- Stimulated Raman Scattering: variant faster (up to 3THz for SiO_2 glass)
  - - Fiber amplifier delay of 370fs for 430fs input pulse (delay= 85% of the pulse width), *Sharping Opt Exp 13, 6092, 2005*
- Wavelength conversion and dispersion
  - - 800ps tunable delays for pulses of 10ps duration *Sharping Opt Exp 13, 7872, 2005*

Photonic resonances

- Fibre bragg gratings:
  - - 690ps delay for 250ps pulses *Longhi Electron Lett 41, 1075, 2005 and Janner Phys Rev E 72, 056605 (2005)*
- Ring resonators: 27ns delay for 51ns pulse *Heebner JQE 40, 726, 2004*
- Planar photonic crystals: vg=c/100 *Notomi PRL 87, 253902, 2001 and* vg= c/300 *Vlasov Nature 438, 65, 2005*

Thank you to:

- ✓The speakers
- ✓The organizers
- ✓The attendees