Periodic multilayers and FEL radiation

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Free electron laser (FEL)

- New facilities around the world (Europe, USA, Japan)
- Very intense ($10^{13} – 10^{15}$ photons per pulse)
- Very short pulse (10 – 100 fs)
- Wide range of wavelengths available (EUV, soft x-ray, hard x-ray)

- Time-dependence of the Bragg diffraction by a multilayer of nanometer period
- Distributed feedback laser (DFB) with a periodic multilayer

Time-dependence

- Propagation of a **single** ultra-short pulse

within a one-dimensional photonic crystal

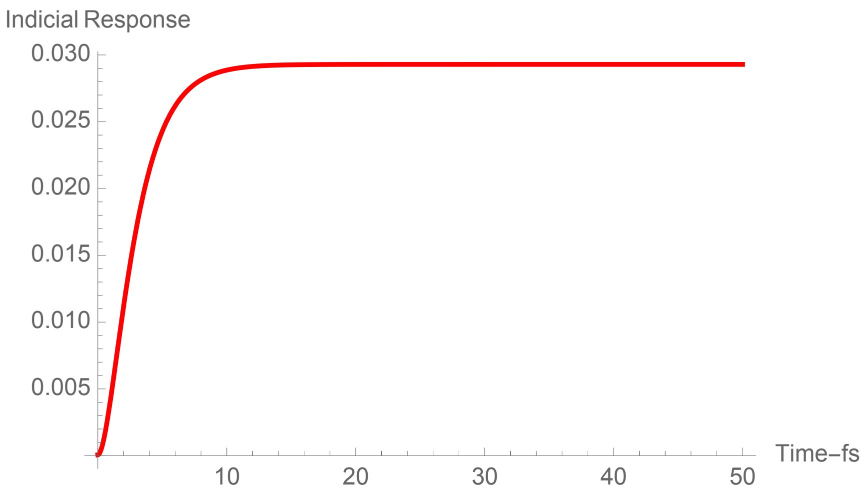
- Linear behaviour of the medium:

no non-linear effect coming from the high incoming intensity

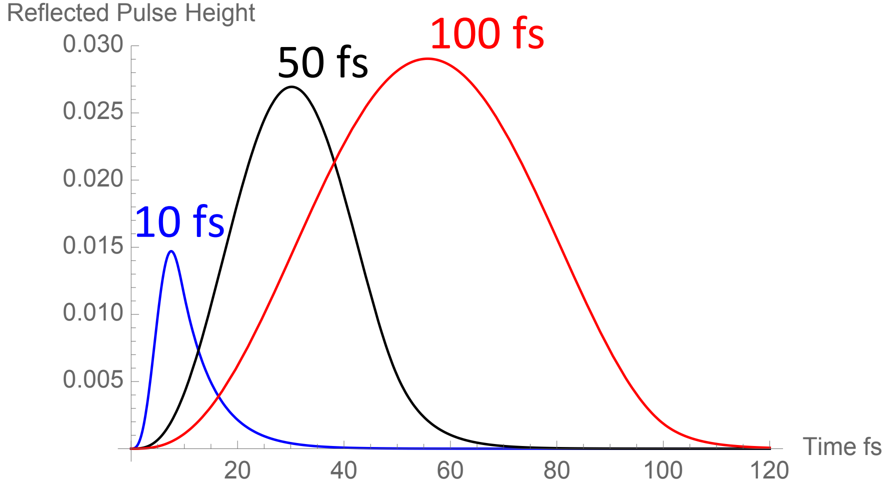
- Time-dependent coupled-wave theory
- Calculation in the time domain

Time-dependence

- Ti/Si multilayer: [Ti (35 nm) /Si (35 nm)]x7
- Photon energy: 20 eV
- Pulse: sine-square function, various pulse lengths
- Diffraction angle: 60°



Indicial response

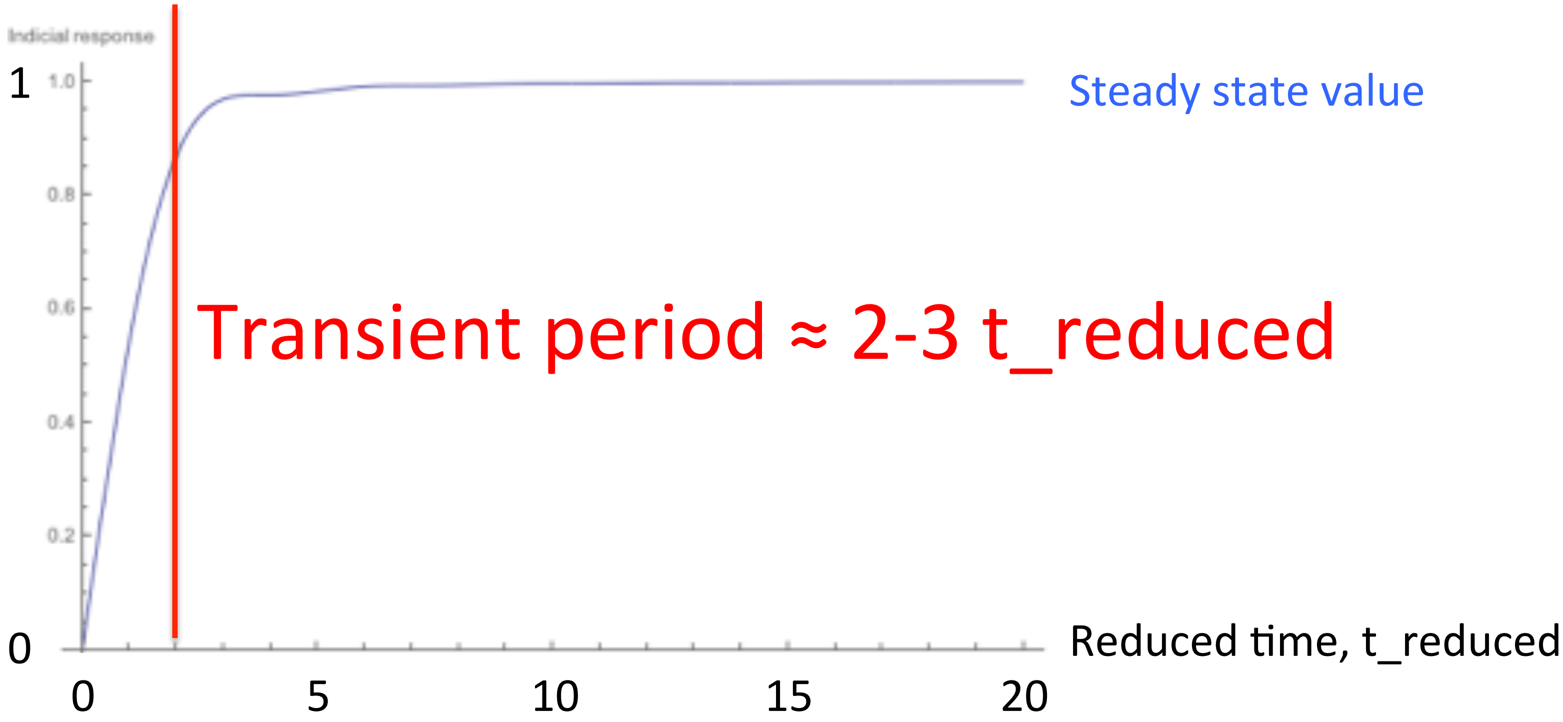


Pulse response

Time-dependence

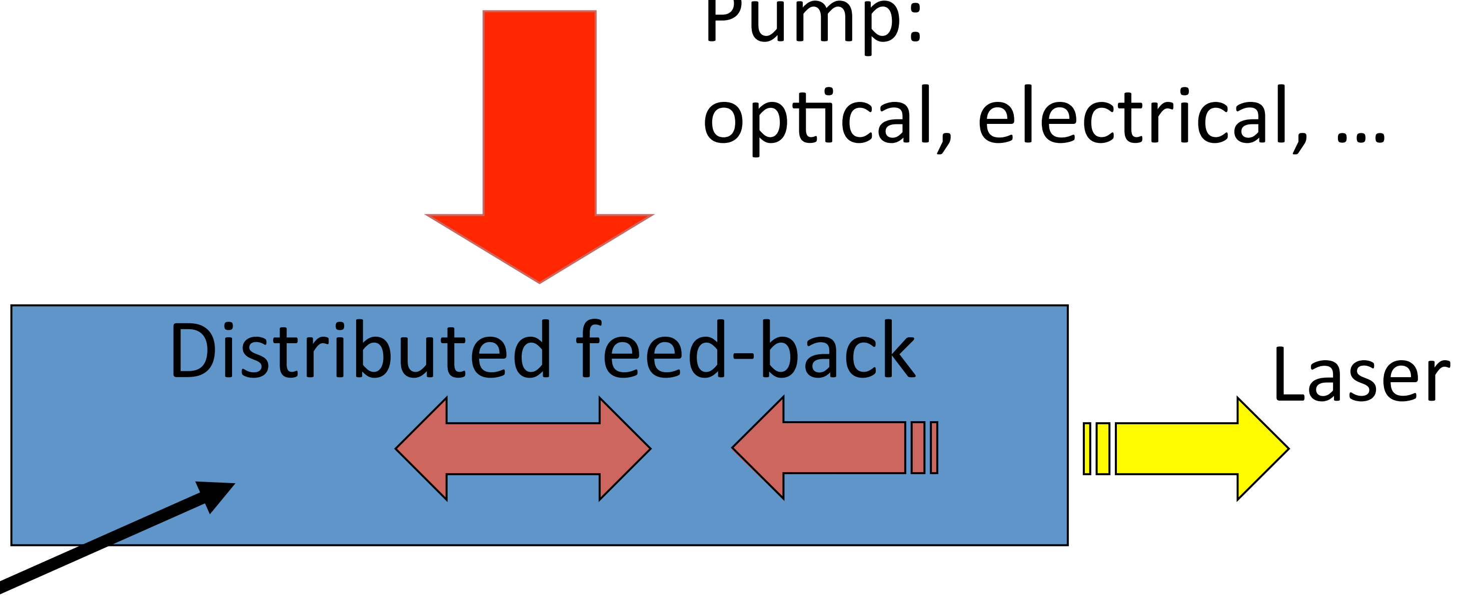
Universal indicial response:

peak reflectance vs reduced time



$t\_reduced = t\,\frac{\pi \sin\theta\; c}{\Lambda}$ with Λ the extinction length

DFB laser



Resonant cavity =

- periodic medium: crystal / Fabry-Pérot / Bragg mirror

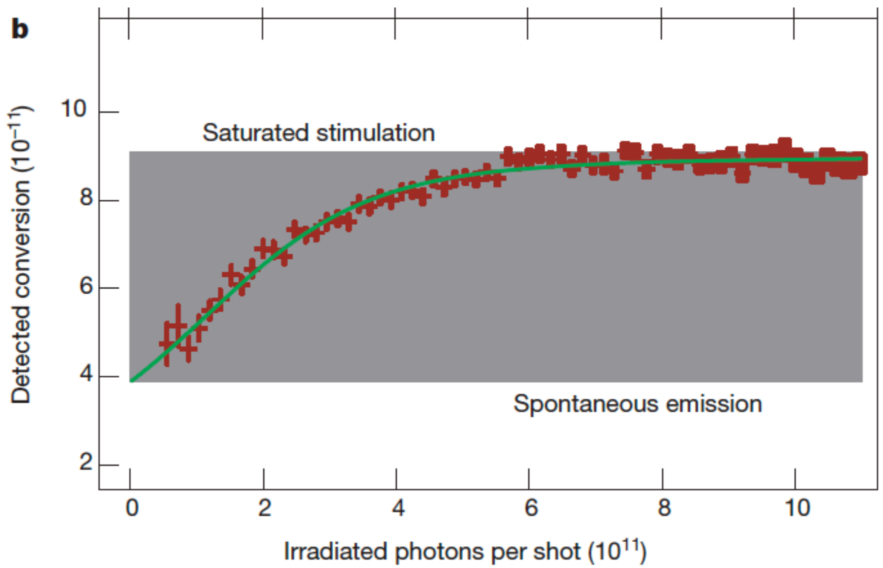
  +

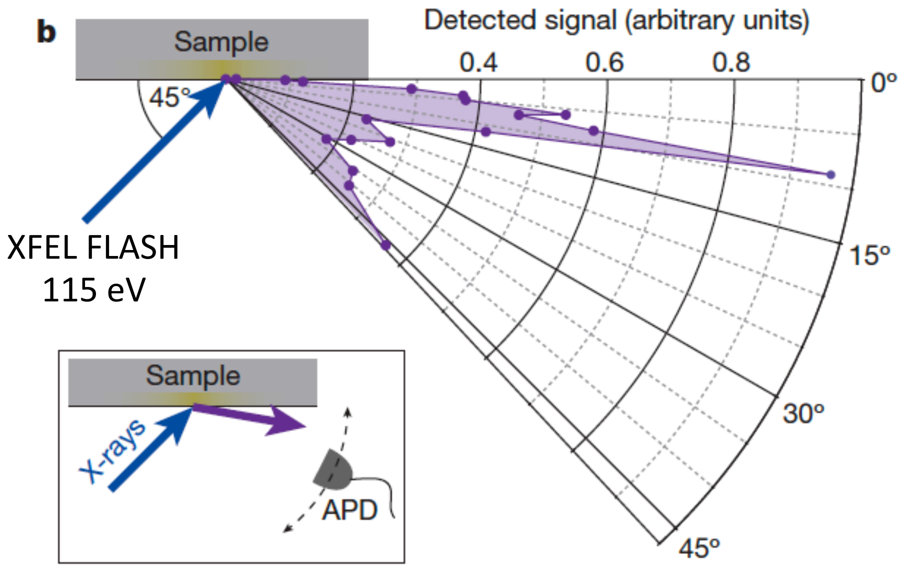
- active medium necessary for stimulated emission

No external mirrors, no alignment

DFB laser

X-ray stimulated emission in a solid (silicon)





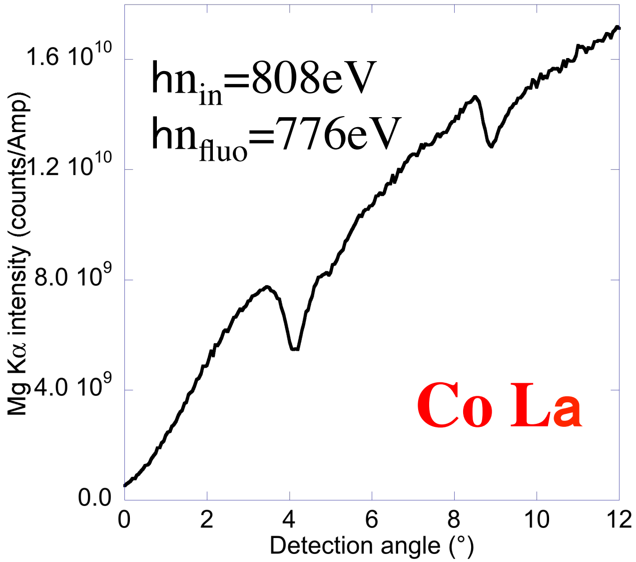
Si L2,3 (3sd – 2p) emission

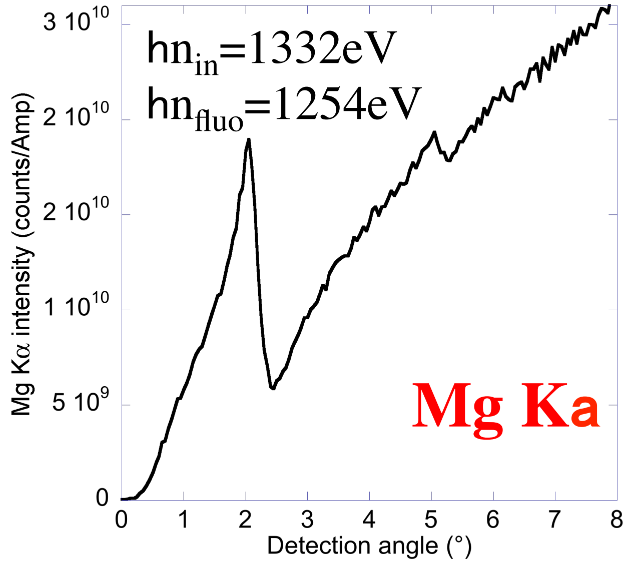
M. Beye et al. Nature 12, 449 (2013)

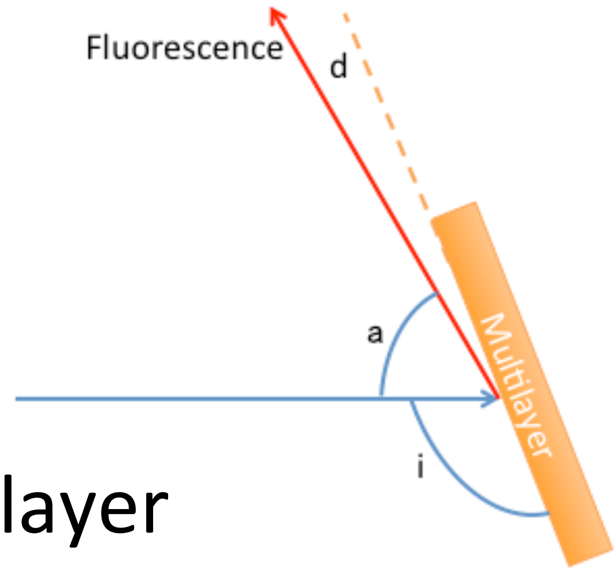
First observation of the stimulated emission in a solid with pumping by an X-FEL

Threshold: 10^{11} photons/shot

DFB laser





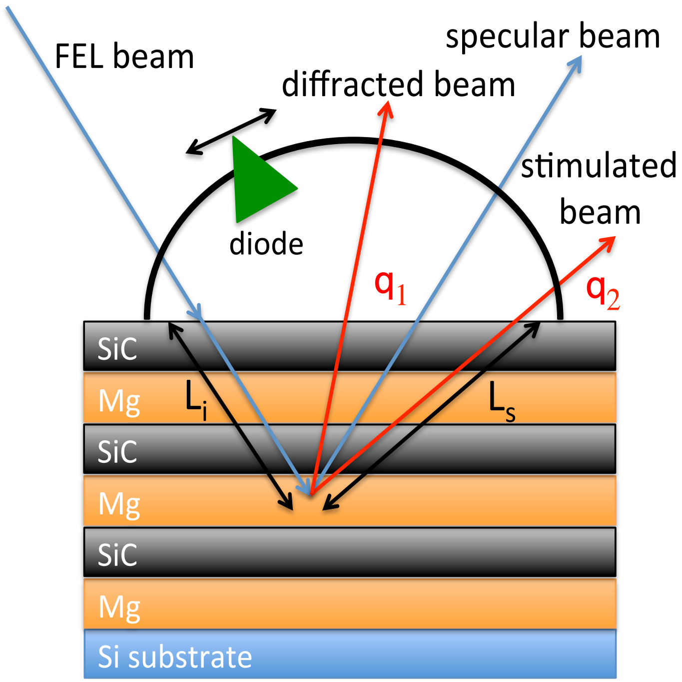


- Mg/Co multilayer
- Spontaneous emission
- Mg Ka and Co La fluorescence

Kossel effect =
Diffraction of
spontaneous emission

P. Jonnard et al., J. Phys. B47, 165601 (2014)

DFB laser



- Stimulated emission

Mg $L_{2,3}\,(3sd-2p)$ @ 49 eV

- FEL pump @ 57 eV
- Cavity

Mg/SiC periodic multilayer

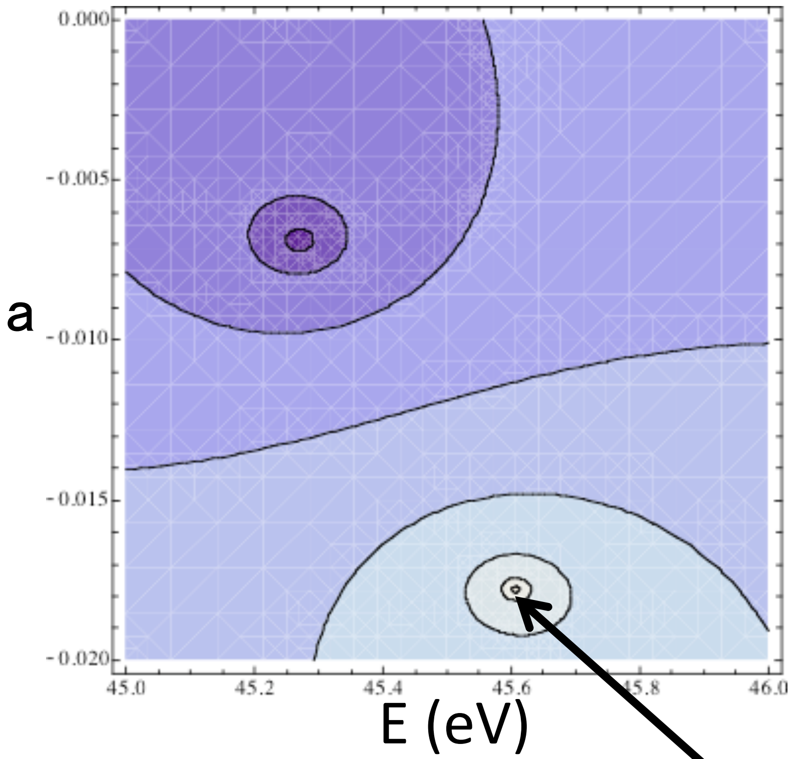
- Detection angle, optimal for q_1

Stimulated emission @ 21°

(Beye *et al.* criterion)

J.-M. André et al., Laser Phys. 24, 085001 (2014)

DFB laser



Threshold for gain and lasing energy given by the relectivity poles of R(E, a) curves (Yeh-Yariv criterion)

E : photon energy
a : gain of active medium

Iso-reflectivity curves in the E, a plane

Pole: E_{lasing} = 45.6 eV
$a_{threshold} = 17.8\ 10^{-3}$ or $78600\ cm^{-1}$

Conclusion

- Time dependence

  + transient period conditioned by the extinction length

  + reflectivity could be much lower than in the steady state

- DFB

  + stimulated emission in a specific direction

  + no spectral jitter

  + mono-mode