Optimization of the coupling between Er ions and Si-nc sputtered waveguides

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Outline

Introduction and overview of the issues to address

Material optimisation:

Total lifetime and cooperative up-conversion
Carrier absorption
Er concentration coupled to Si-nc

Conclusions

General Requirements for Optical Gain

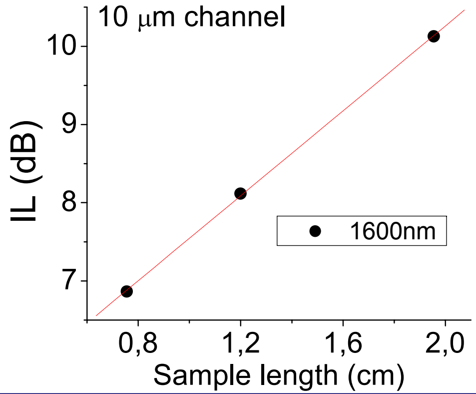
Good waveguides

➢Good modal confinement

Γ=0.7-0.8 (at 1.55µm)

➢Low waveguide losses (propagation and coupling)

Propagation losses of 2.6dB/cm at 1600nm



Good active material

➢As much Er^{3+} as possible (avoiding clustering)

Absorption losses of 6dB/cm

Thus, net gain is possible

➢Optimised Si-nc to Er^{3+} coupling to excite all the ions through indirect transfer without damaging the properties of Er^{3+}

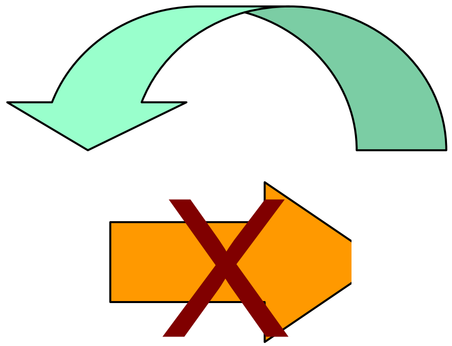
Issues to solve for getting a good active material

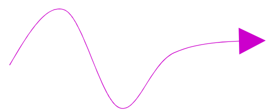
Si-nc + Er^{3+}

- Carrier absorption
- Auger deexcitation

- Non - radiative recombinations (low lifetime)
- Cooperative up-conversion

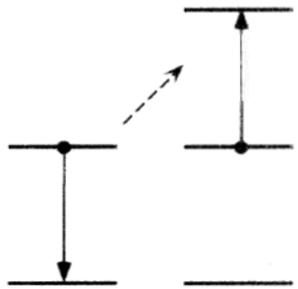
- Back-transfer
- Distance dependent interaction





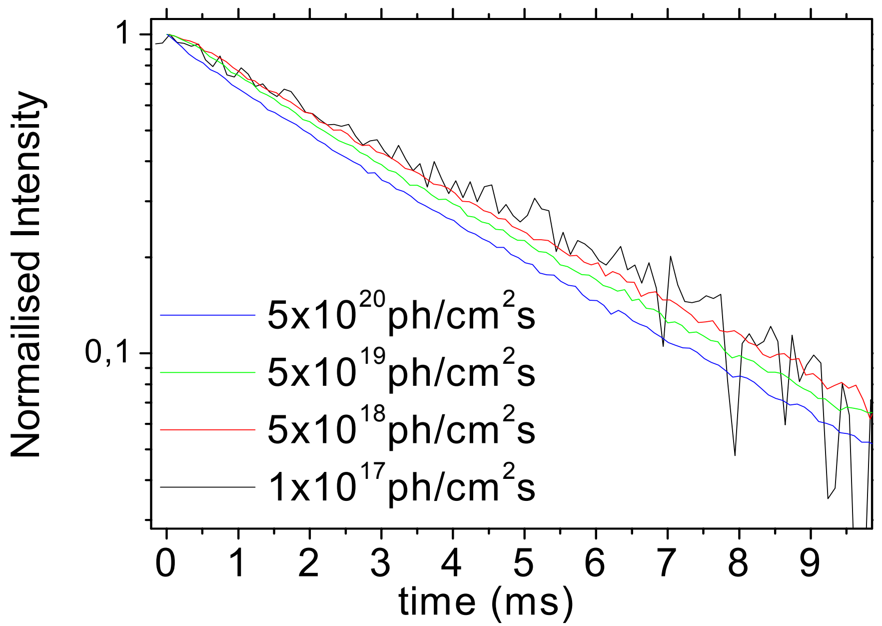
STARTING POINT…

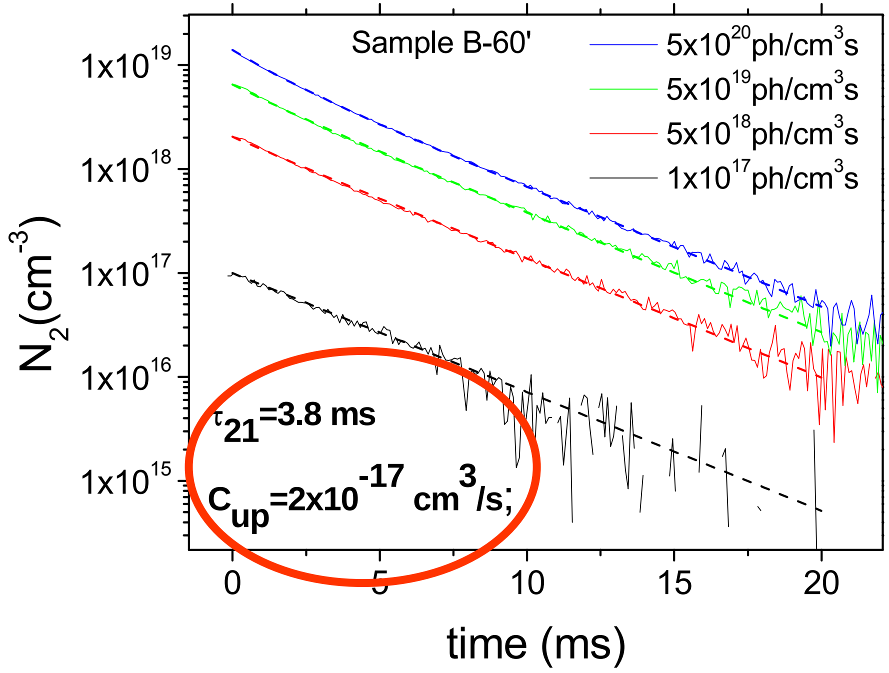
Total Lifetime and up-conversion



Quantitative measurements of the photon flux emitted from the samples
It is so possible to correlate the number of emitted photons with N_2

$$\frac{dN_2(t)}{dt} = -\frac{N_2(t)}{\tau_{21}} - C_{up} N_2(t)^2$$





Distance dependent interaction

σ_{eff} is decreasing with pump flux Φ

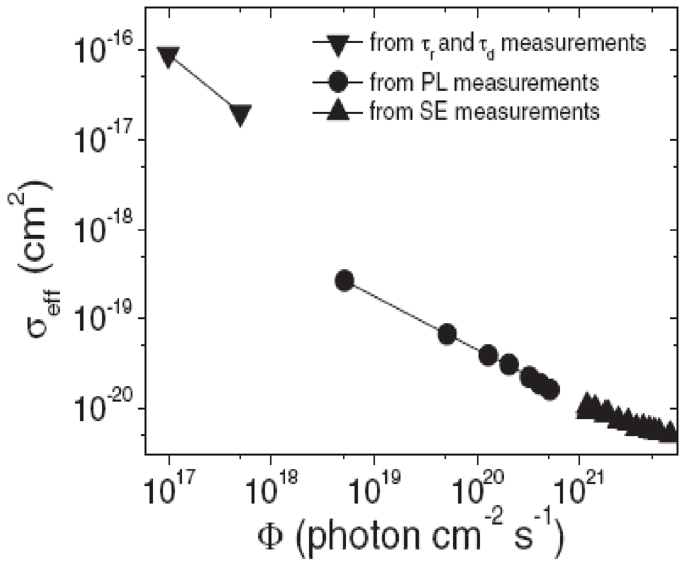
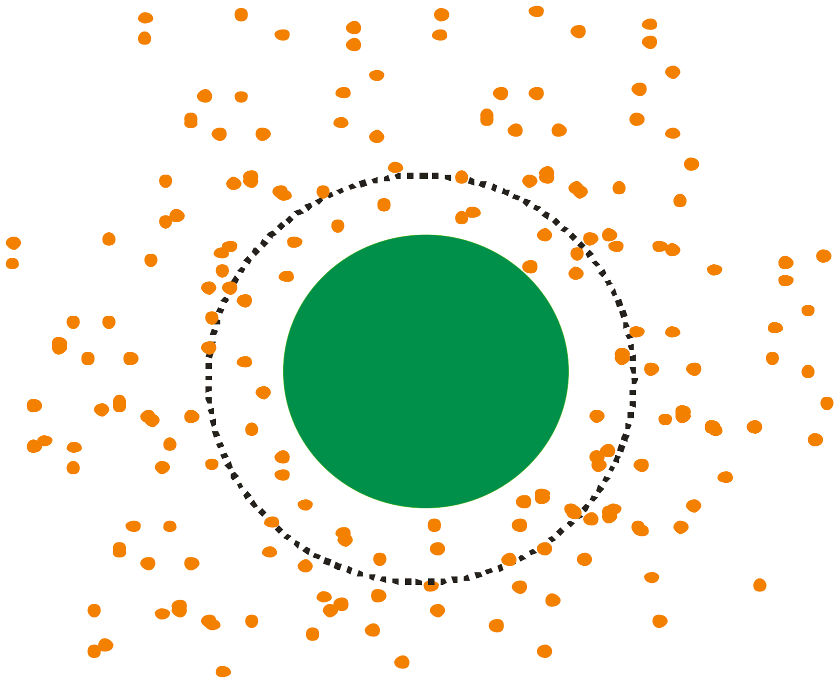


Fig. 9. Effective excitation cross-section of Er^{3+} as a function of the incident flux extracted from lifetime measurements (inverted triangles), from quantitative measurements of the density of excited Er^{3+} ions (circles) and from SE measurements (triangles). The pump wavelength is 488 nm, while the probe wavelength in the region of high pump photon flux was 1535 nm.

D. Navarro-Urrios et al., JJAP 46, 6626 (2007)

Distance dependent interaction



Er^{3+} ions near the Si-nc are efficiently coupled to them, whereas Er^{3+} ions far away behave more and more as Er^{3+} in SiO_2 that can be excited only directly.

Model for σ_{exc}

$$\sigma_{exc}(R) = \sigma_o e^{-\frac{R-R_{nc}}{R_o}} + \sigma_d$$

We consider that the first Er to be excited and therefore the strongest coupled would be the closest to the Si-nc

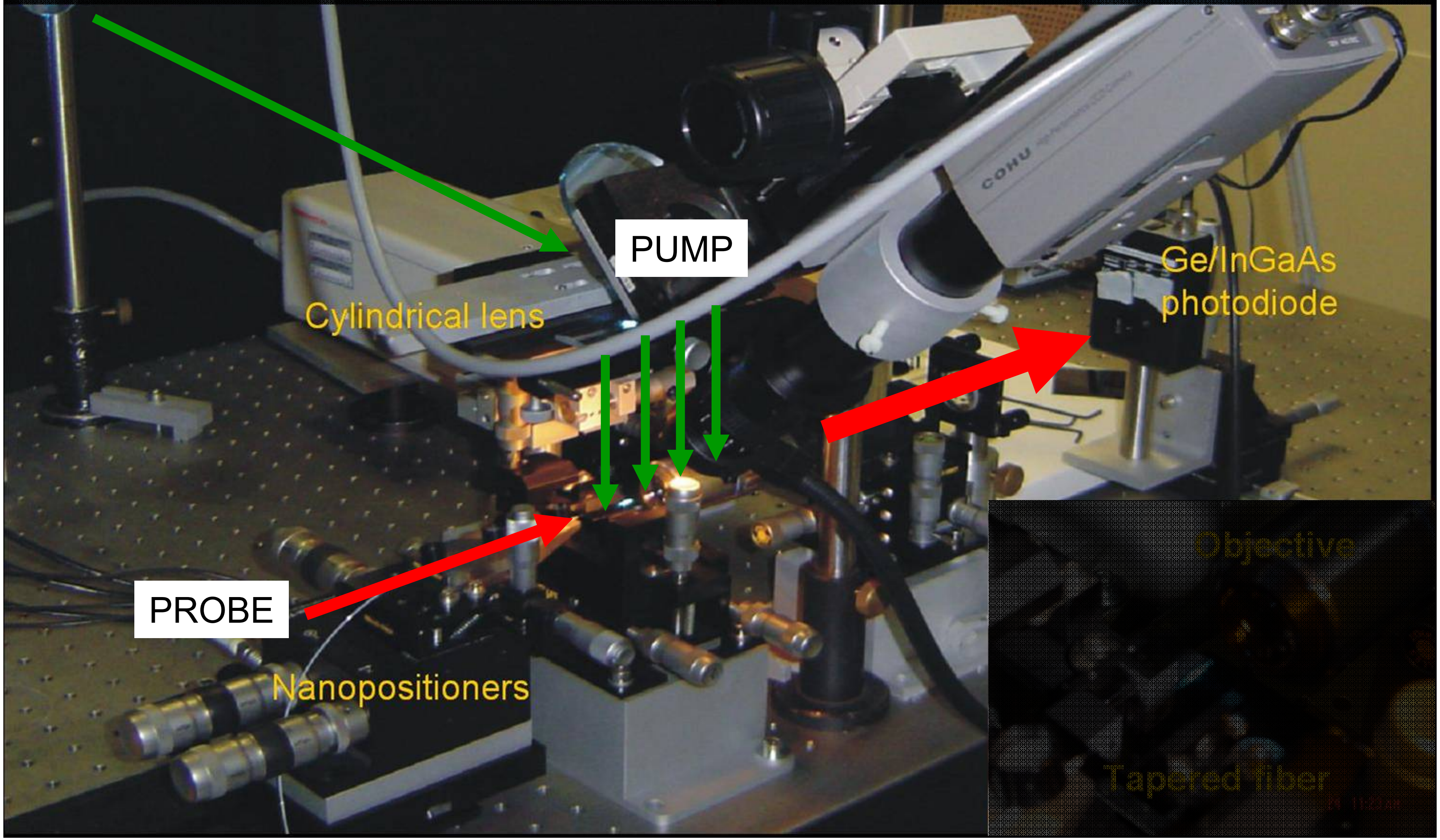
Garrido et al., APL 89, 163103 (2006)
Navarro-Urrios et al., JJAP 46, 6626 (2007)

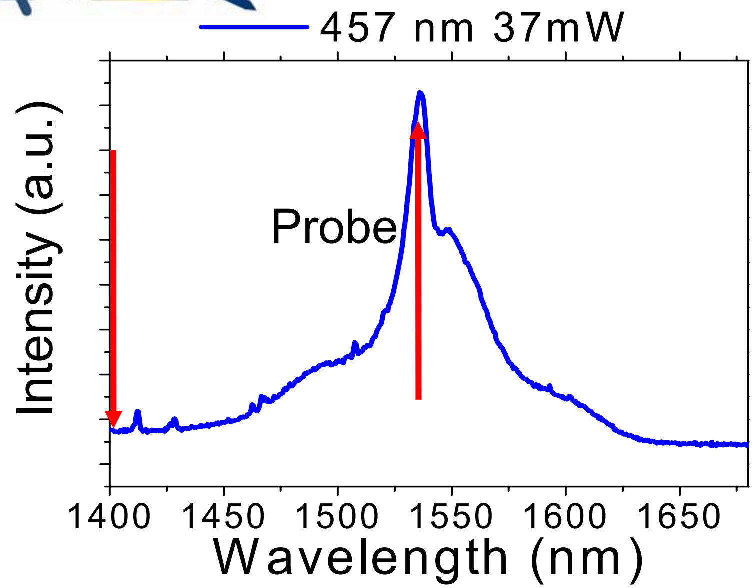
R_o=0.5 – 1nm

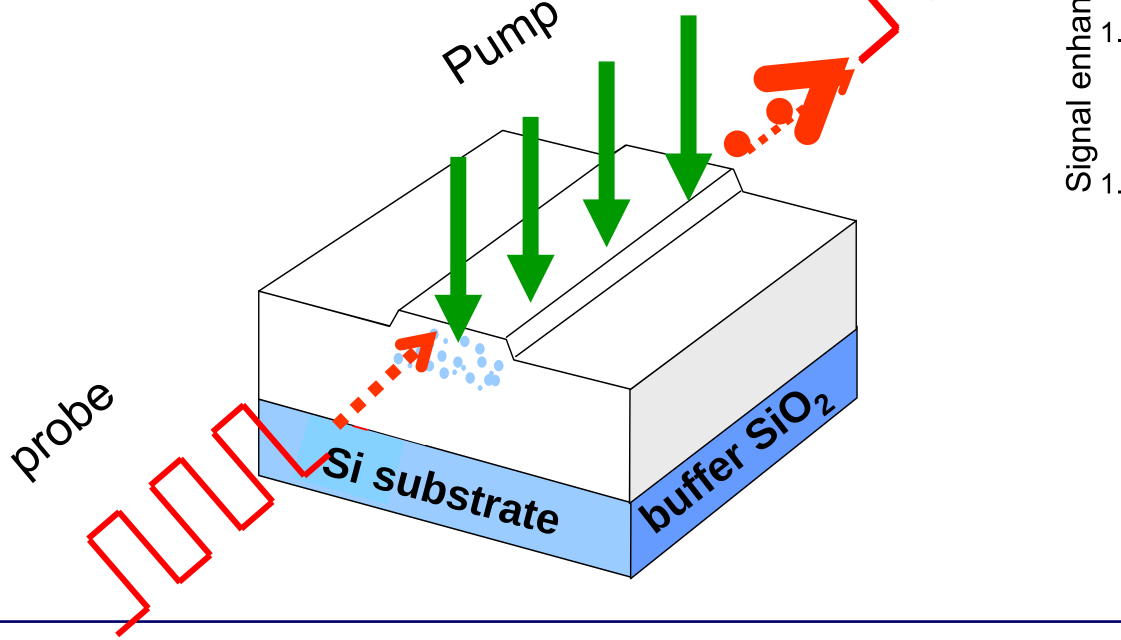
Short range interaction

Thus, we were able to excite only 2-3% of the whole erbium population trough transfer from Si-nc.

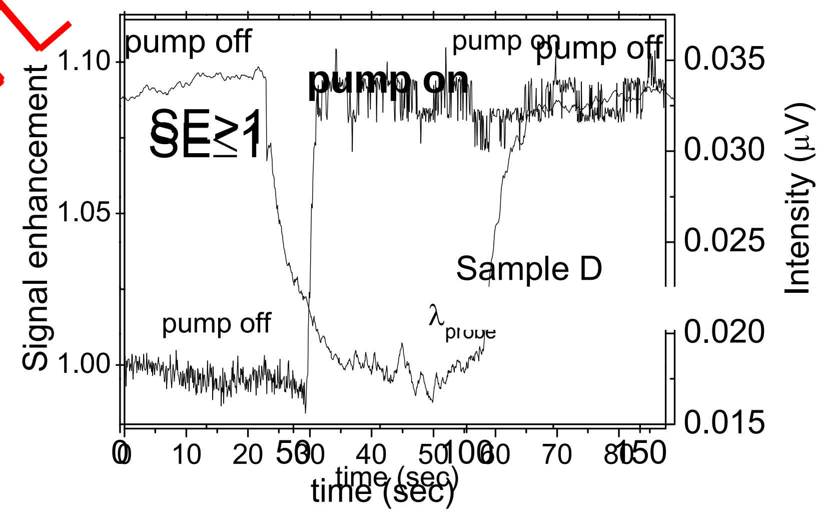
Signal enhancement
(Pump&Probe experimental setup)







Signal Enhancement!!
Carrier Absorption!!



α_{CA}=1dB/cm

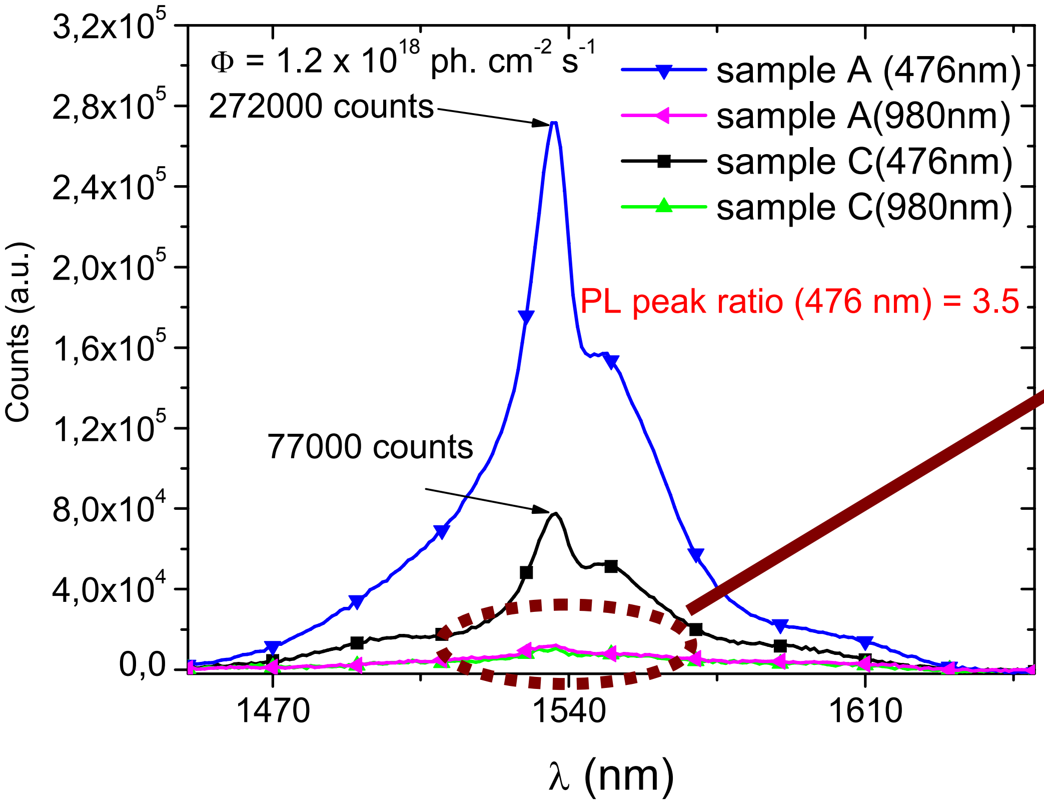
New run Sample Optimization
Deposition parameters

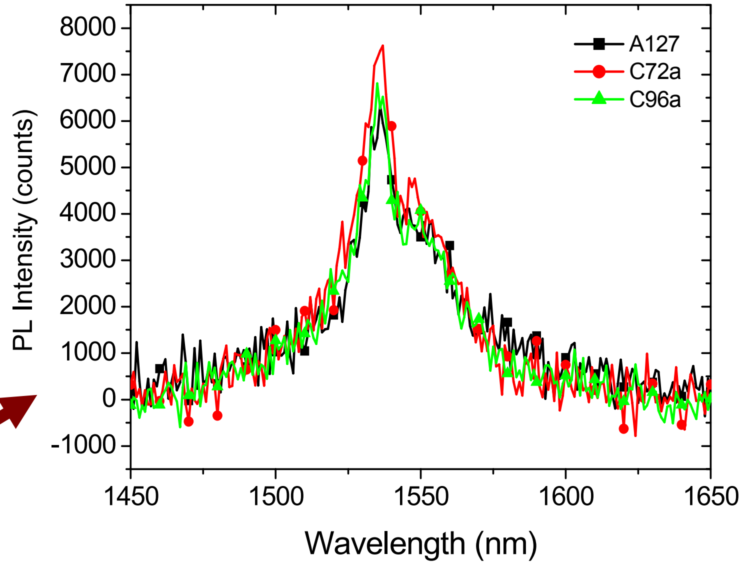
Figures of merit

- $^4I_{13/2} \rightarrow ^4I_{15/2}$ PL (@ 1535nm) under non-resonant pumping (476nm)
- $^4I_{13/2} \rightarrow ^4I_{15/2}$ lifetime
- Carrier absorption

Sample	Si excess [at %]	Er^{3+} conc [cm^{-3}]
A	5 ± 2	$3.4 \pm 0.2 \times 10^{20}$
C	8.5 ± 2.0	$4.0 \pm 0.4 \times 10^{20}$

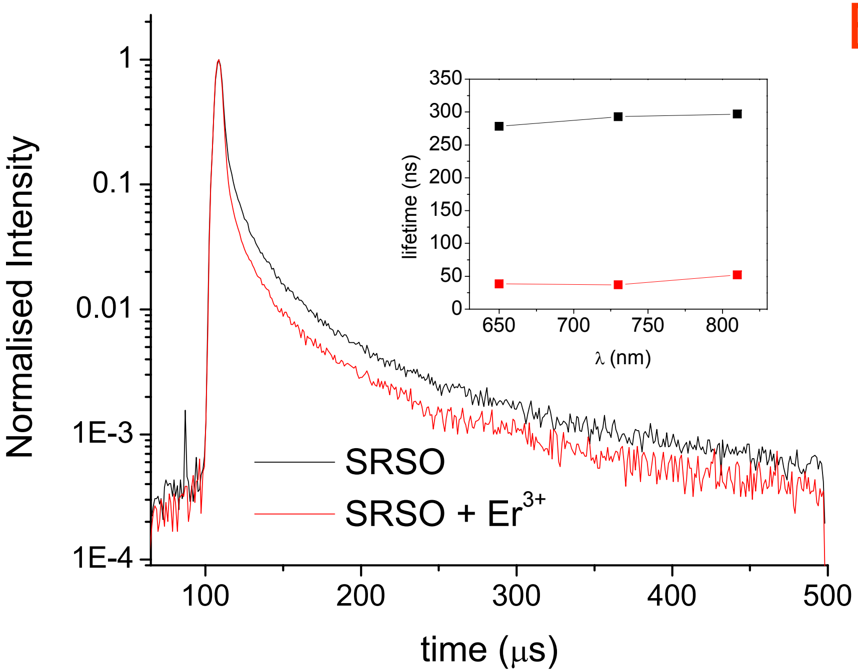
Optimization of the Si/Er ratio



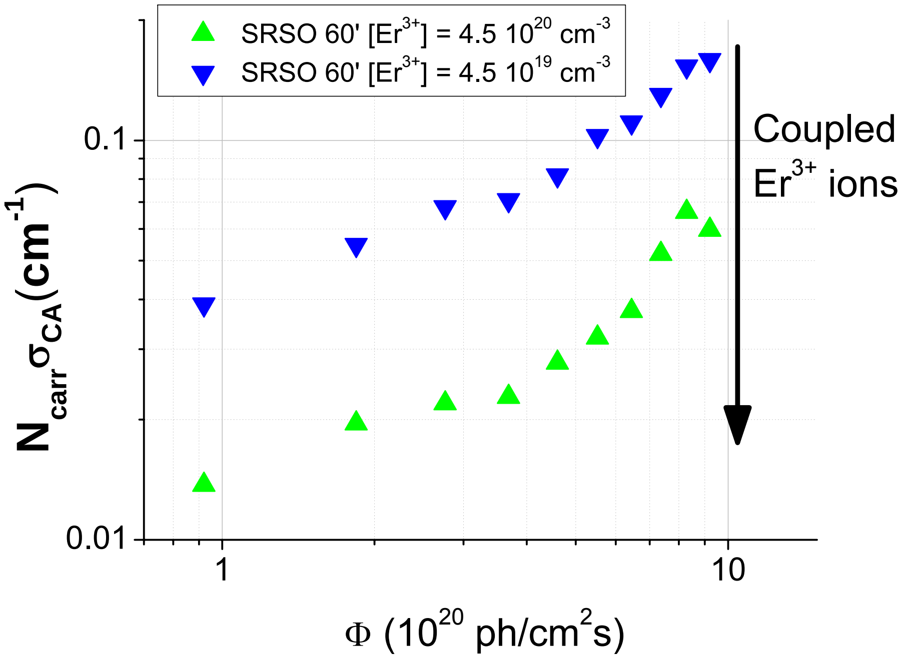


New run is much more intense than best sample of previous run when pumping indirectly, while direct pumping gives the same contribution

Optimization of the coupling: Minimising Si-nc decay time in presence of Er^{3+}

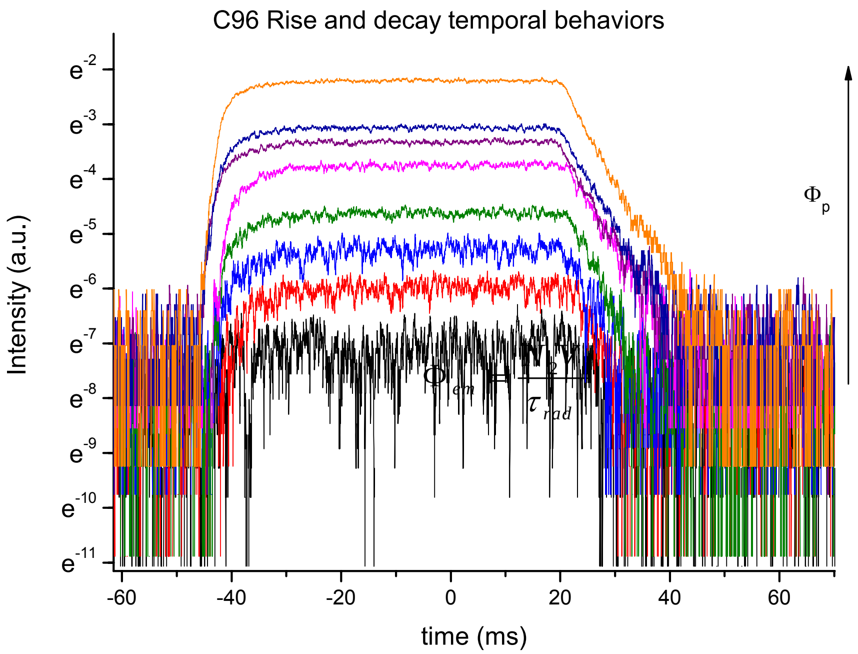


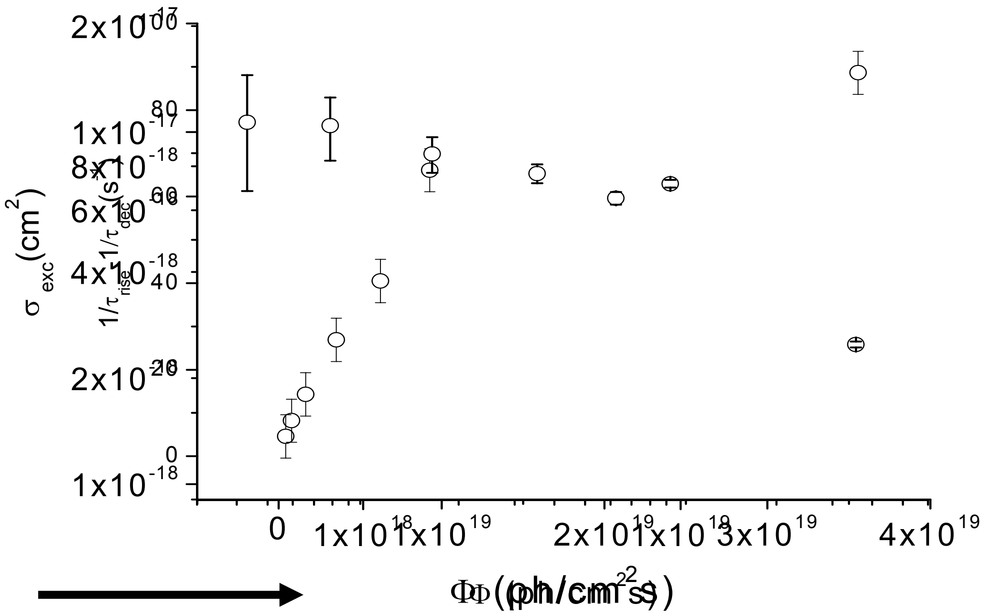
Bonus!!: Reduction of the CA losses



Optimization of the coupling: Quantification of the erbium coupled to the Si-nc

Lifetimes as a function of the pump photon flux:



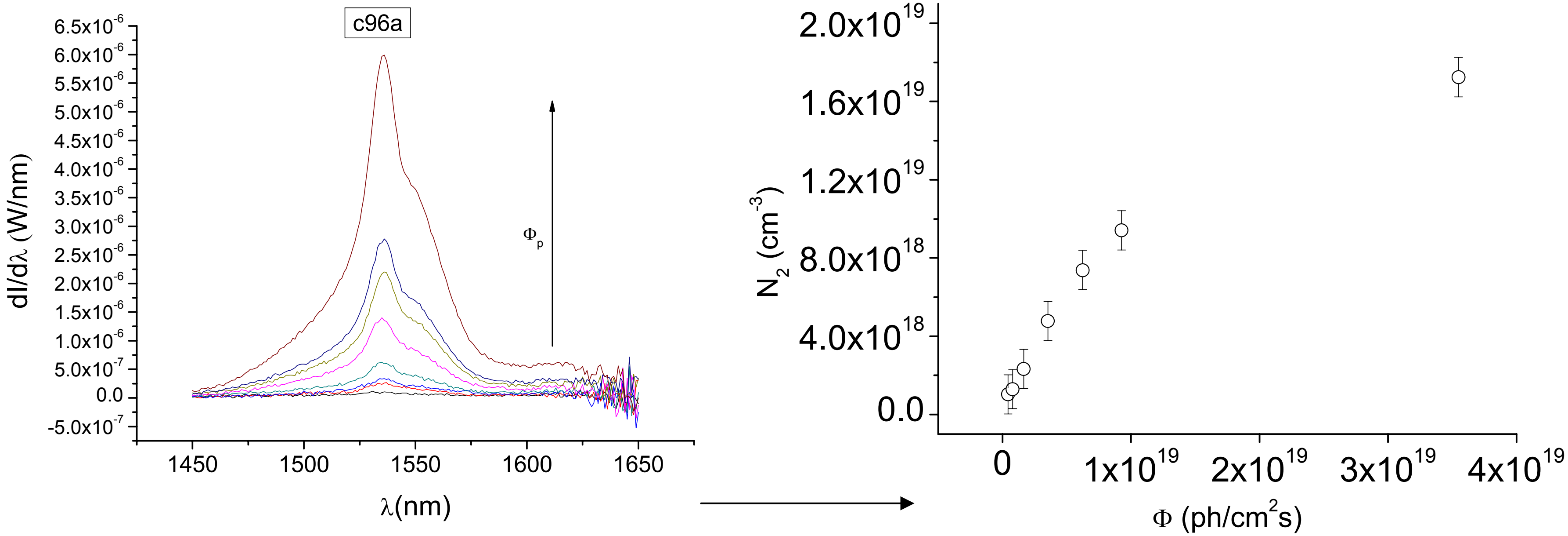


476nm pumping

$$\frac{1}{\tau_r} - \frac{1}{\tau_d} = \sigma_{eff}\Phi$$

Optimization of the coupling: Quantification of the erbium coupled to the Si-nc

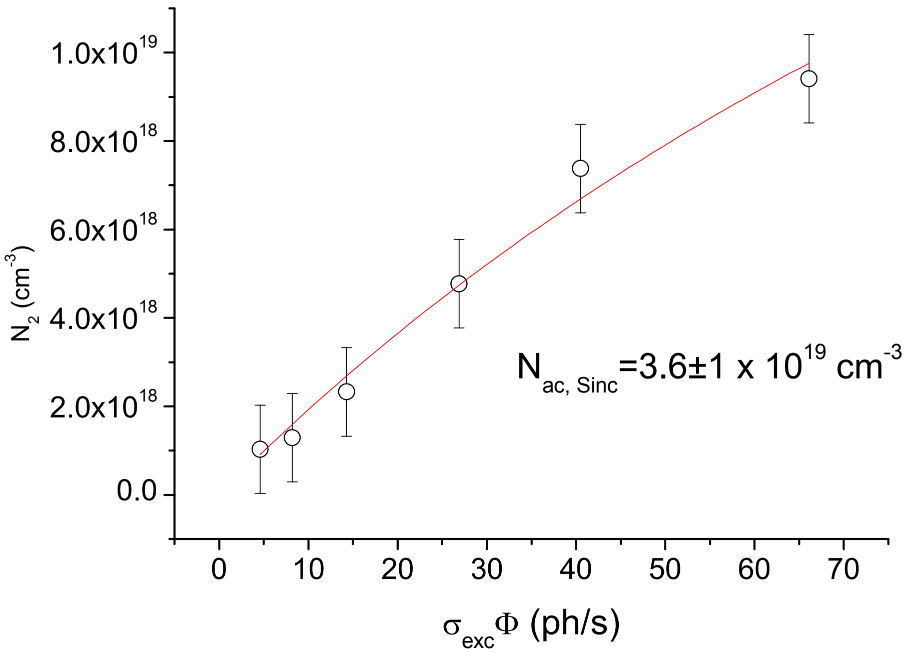
N_2 as a function of the pump photon flux:



$$\Phi_{em} = \frac{N_2 V}{\tau_{rad}}$$

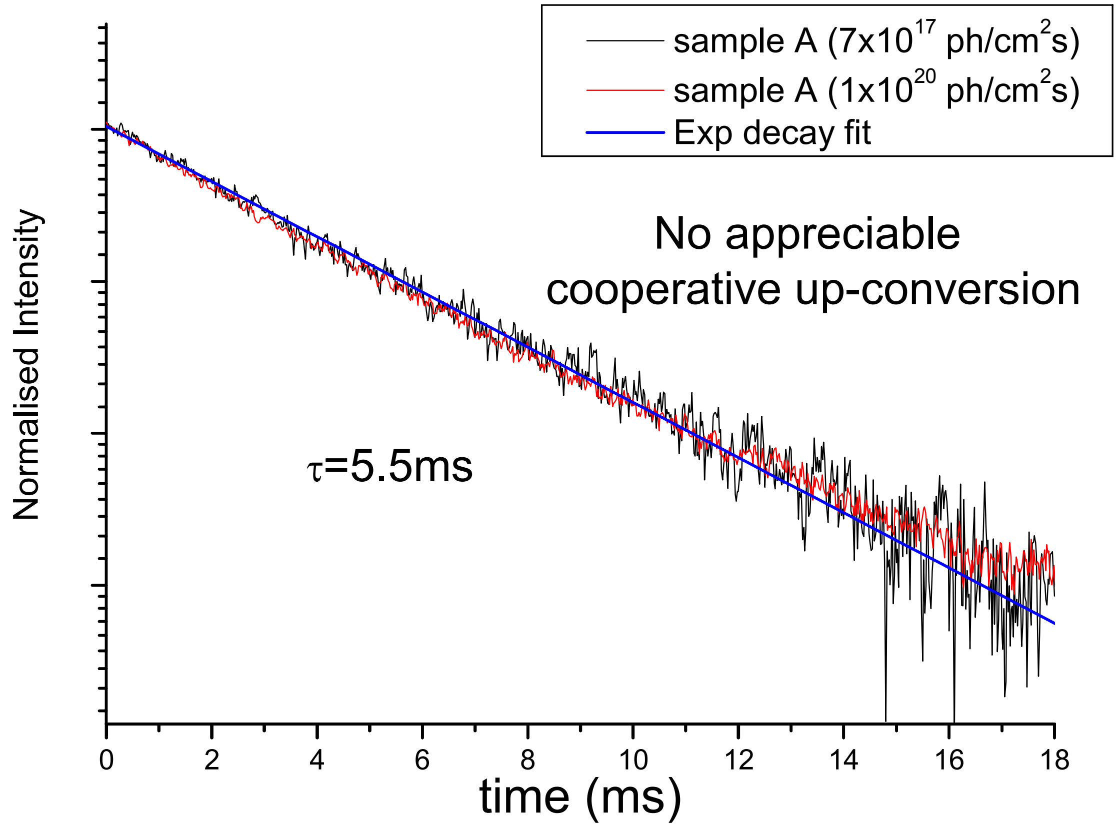
Quantification of the erbium coupled to the Si-nc

$$N_2 = N_{ac,Sinc} \frac{\sigma_{exc}\Phi}{\sigma_{exc}\Phi + 1/\tau_{PL}}$$



Around 23% of the optically active erbium.

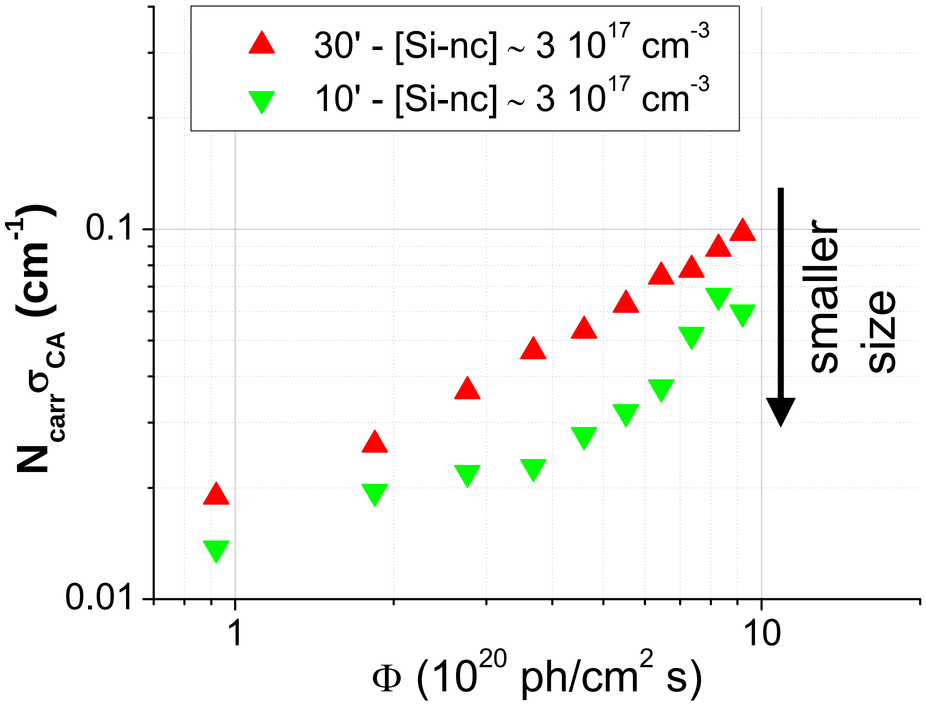
Cooperative up-conversion and total lifetime



We have increased the total PL lifetime to 5.5 ms and reduced the cooperative up-conversion to negligible values

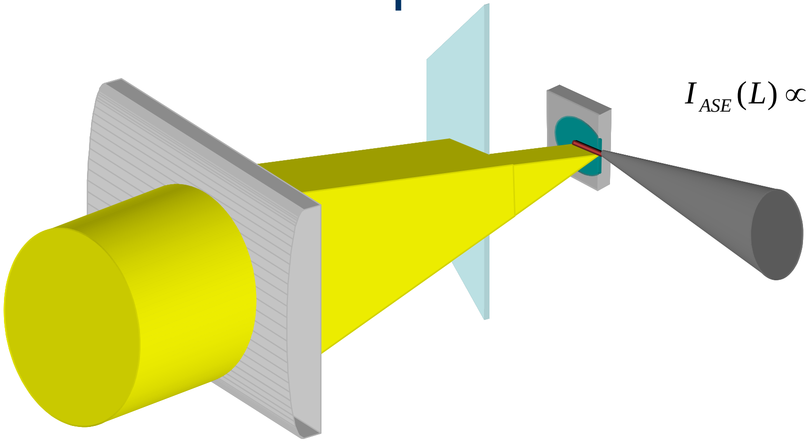
Minimizing Carrier Absorption

By engineering properly the Si-nc size and density it is possible to reduce the CA induced losses.



Minimizing Carrier Absorption

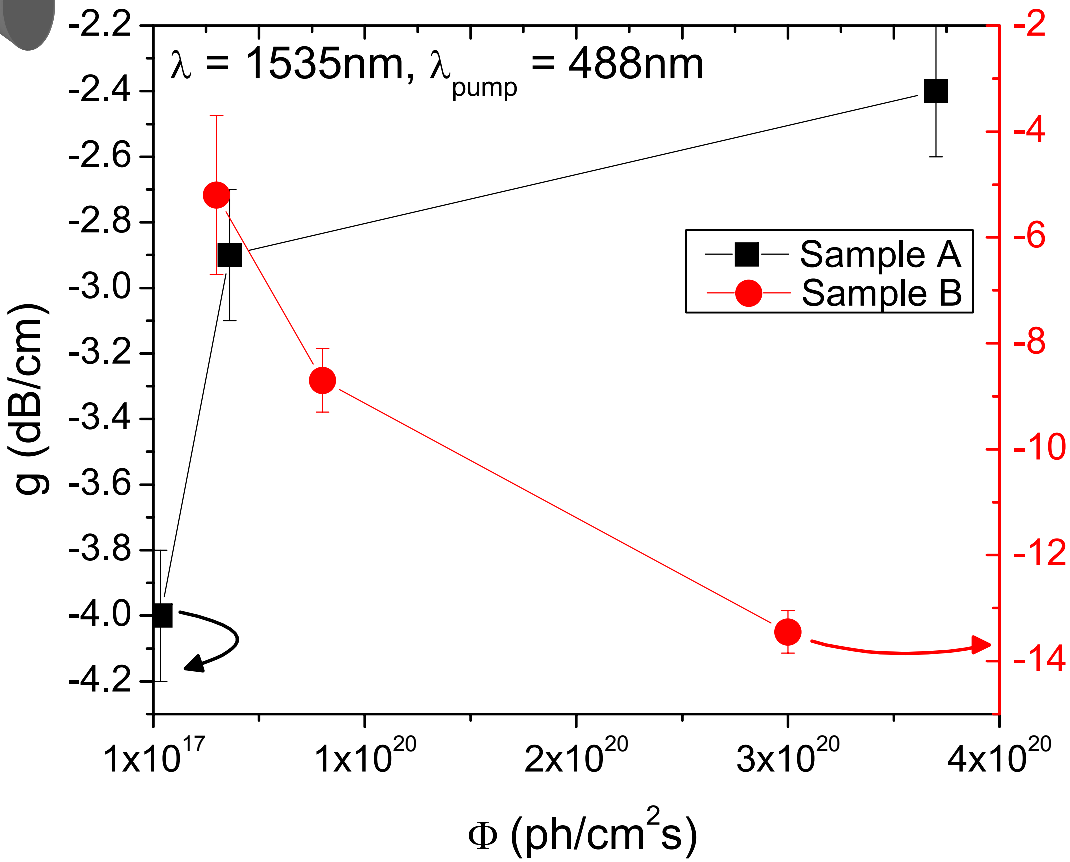
VSL technique



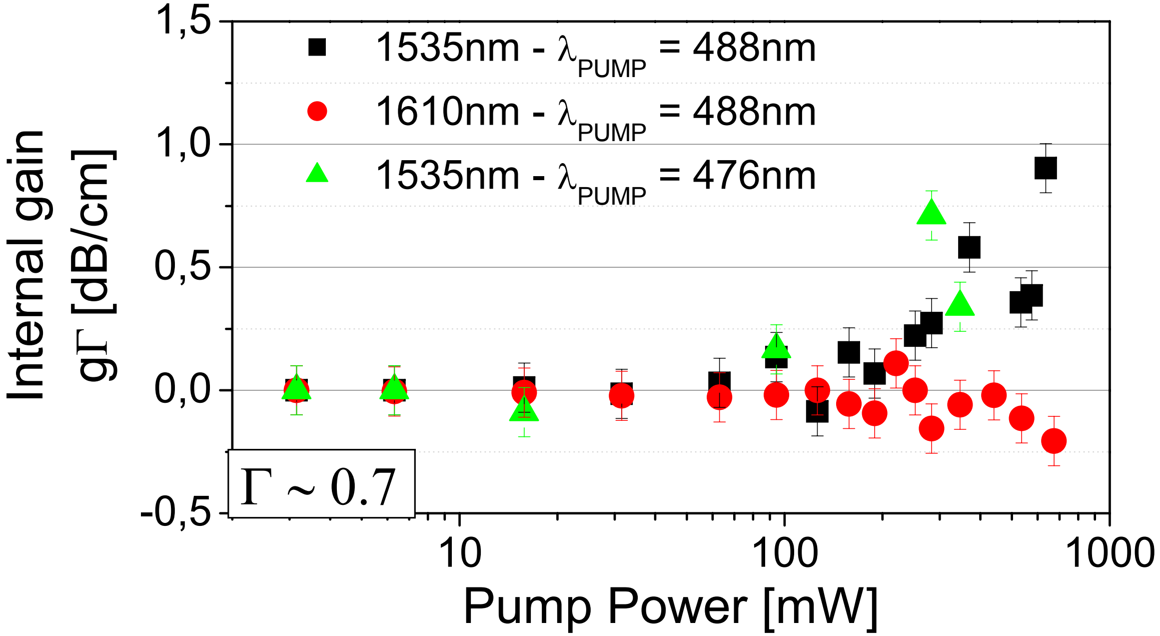
$$I_{ASE}(L) \propto \frac{1}{g}\exp(gL-1)$$

- In sample B the CA losses grow with pump power

- In sample A the CA losses has been reduced and a decreasing of the losses is measured



Pump & probe measurements



$$\frac{g}{\alpha} = \frac{\sigma_{em} N_2}{\sigma_{abs} N_{Er}} \approx \frac{N_2}{N_{Er}}$$

About 25% of Er excited via the Si-nc

Negligible carrier absorption

Comparison

Issue	Last run	New run
Total lifetime	3.8ms	**5.5ms**
Cooperative up-conversion	$2x10^{17}cm^3/s$	**Negligible**
Carrier absorption losses	0.9 dB/cm	**Negligible**
N_{Er} coupled to Si-nc	3%	**23%**

Conclusions

We have significantly improved our samples in terms of:

Total lifetime
Cooperative up-conversion
Carrier absorption losses
Concentration of ions coupled to Si-nc

But still it is not enough for achieving the minimum populationinversion needed to obtain **net optical gain** through indirect pumping (we are at 1dB/cm of internal gain).

We have to put most of the Er^{3+} in the close vicinity of a Si-nc

THANK YOU!