Dynamic population gratings in highly doped erbium fibers

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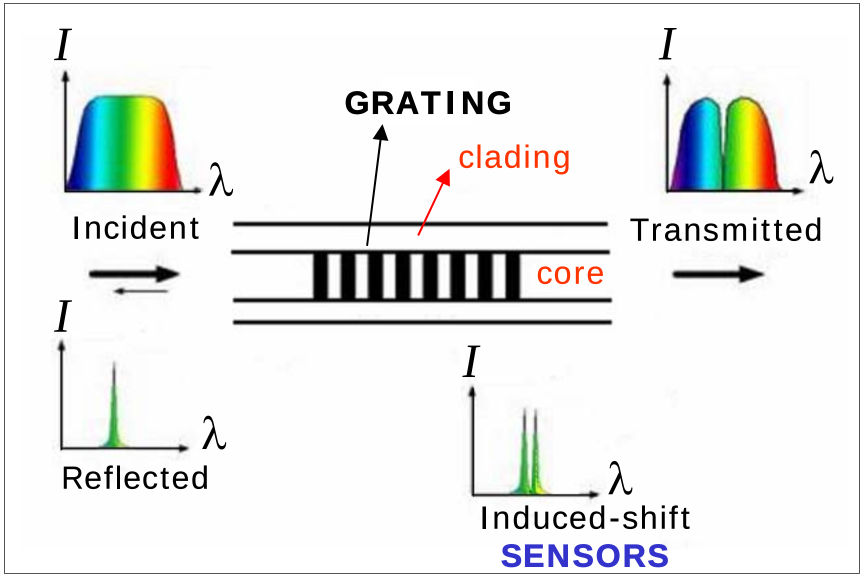
Previous works

Dynamic gratings recorded in Er-doped fiber amplifiers

Frisken, Opt. Lett. **17**, 1776 (1992)

TRANSIENT TUNABLE BRAGG REFLECTION GRATING IN AN EDF

- Long: Efficient thickness given by fiber length ➔ Narrow-band filter ~ 16 MHz
- Tunable: Grating wavelength controlled by the recording wavelength
- Transient: Grating disappear after removal of the recording waves

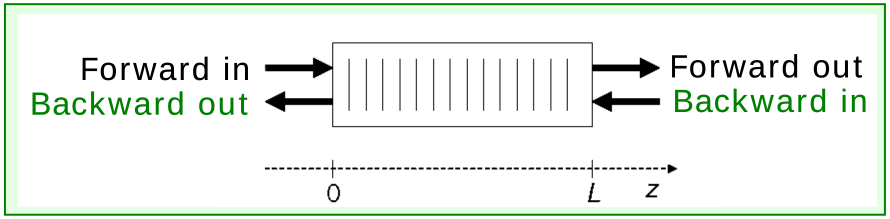


Fundamental works: Nonlinear optical properties, wave mixing (Review Stepanov, 2008)

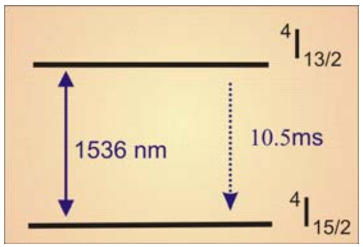
Applications:

- Single frequency fiber lasers (Horowitz et al. 1994, Cheng et al 1995)
- Tunable narrow-band filters (Frisken 1992, Feuer 1998, Havstad et al 1999)
- Fiber sensors, adaptive interferometers (Stepanov et al. 2004, Fan et al. 2005)

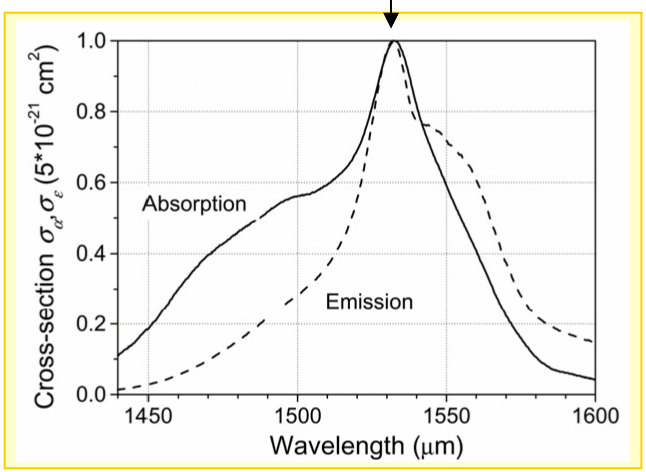
How to generate a dynamic population grating?

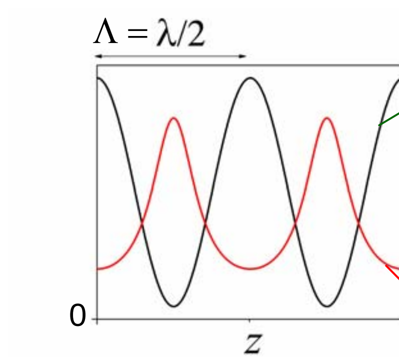


Recording wavelength



λ = 1536 nm





Interference pattern

$$I = I_F + I_B + 2\sqrt{I_F I_B}\cos(Kz)$$

$$K = \frac{2\pi}{\Lambda}$$

Absorption Grating

$$\alpha = \frac{\alpha_0}{1 + \dfrac{I}{I_{sat}}}$$

→ Linear absorp. coeff.

→ Absorp. saturation

SATURABLE ABSORBER

Motivation:

Generate dynamic gratings in shorter devices by increasing ion concentration

Objective

Optimize the efficiency of the dynamic gratings recorded in highly doped Er fibers

Fiber code	Peak absorption (dB/m)	Ions density (m^{-3})	α_0 (m^{-1})
Er20	20 ± 2	1.6×10^{25}	3.8
Er30	30 ± 3	2.1×10^{25}	5.0
Er40	40 ± 4	2.7×10^{25}	6.4
Er80	80 ± 8	6.3×10^{25}	15.0

Er20, Er30, Er40: HIGHLY DOPED FIBERS

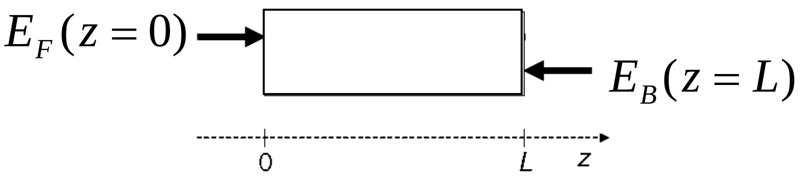
Er80: ULTRA-HIGHLY DOPED FIBER

Manufactured by Liekki

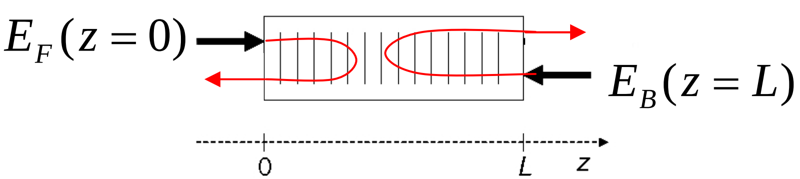
MFD @ 1550nm = 6.5 ± 0.5 μm
Cladding = 125 ± 2 μm
Coating = 245 ± 15 μm
NA =0.2 ± 0.02

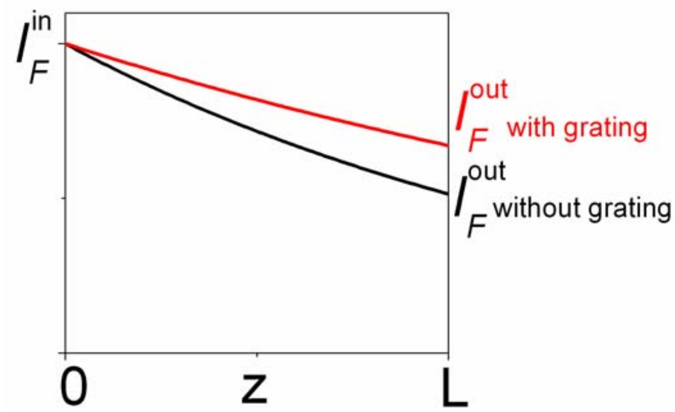
How to characterize the dynamic grating?

Incoherent waves: NO GRATING



Coherent waves: GRATING





The diffracted waves
add in phase to
the transmitted waves

⇒

The grating increase
the transmitted signals

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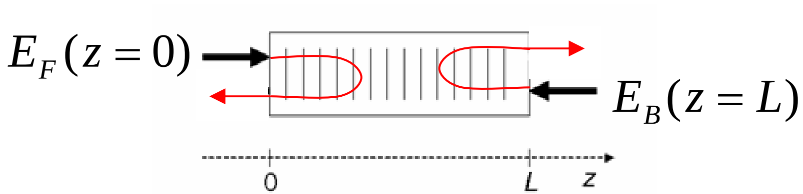
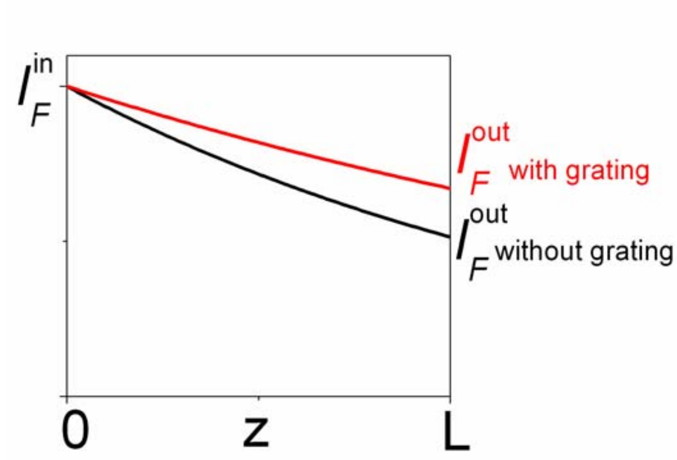
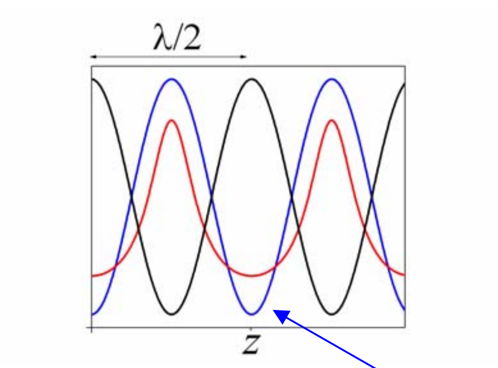
How to characterize the dynamic grating?

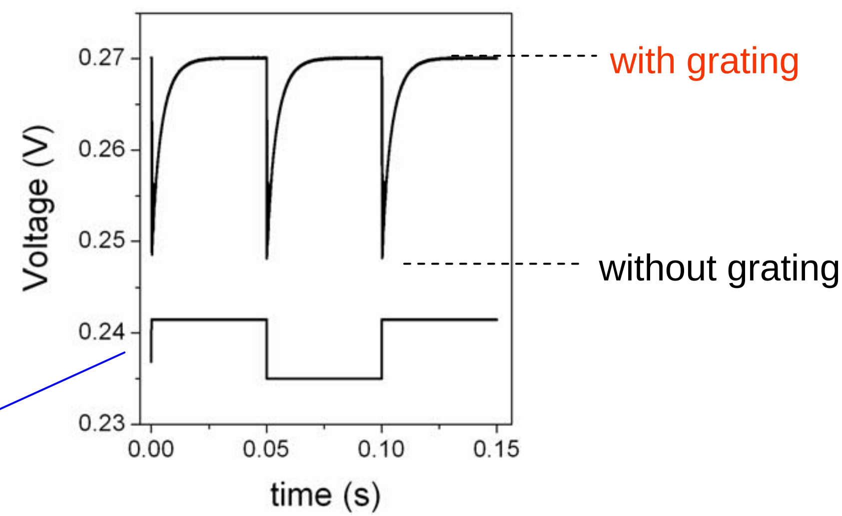
Coherent waves: GRATING





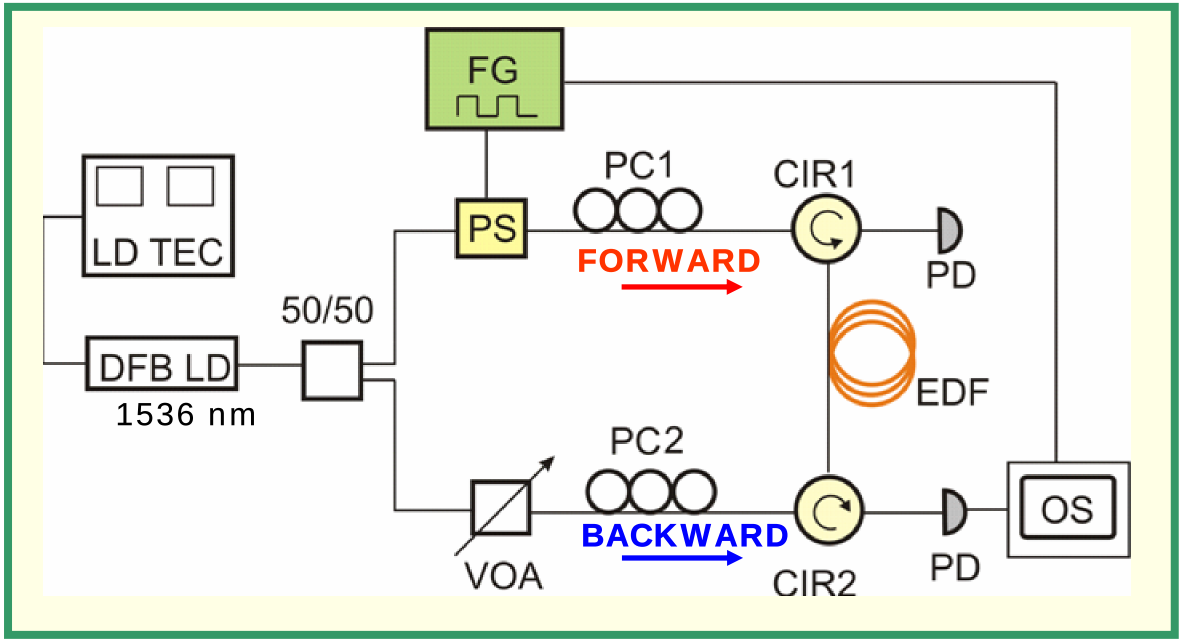
Grating formation time ➔ τ_g <10 ms



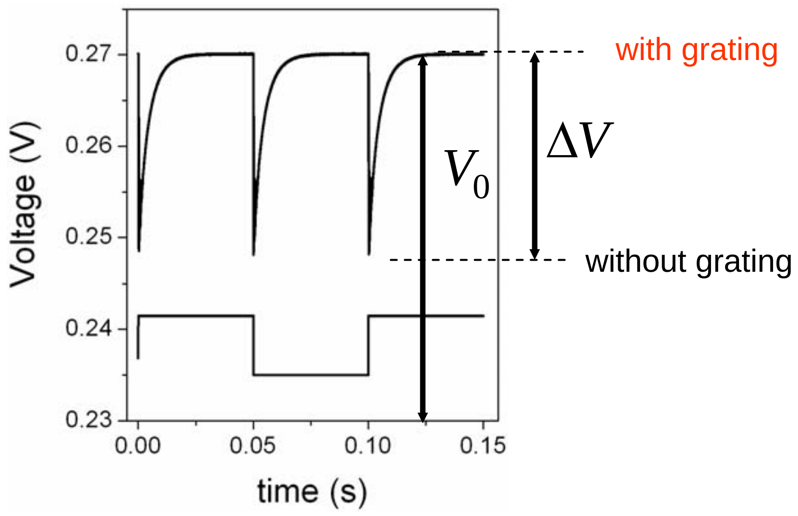


Square phase modulation

Experimental setup: transient TWM



Relative amplitude = $\frac{\Delta V}{V_0}$



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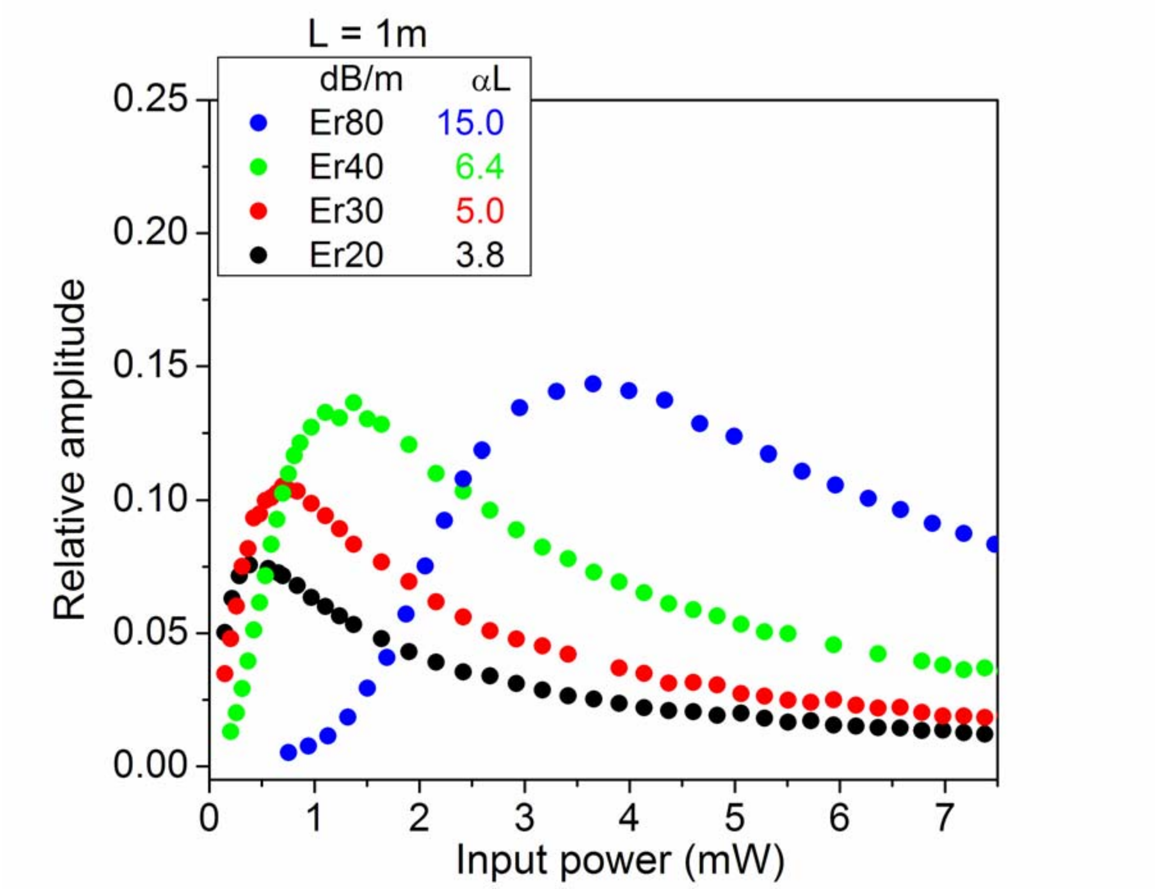
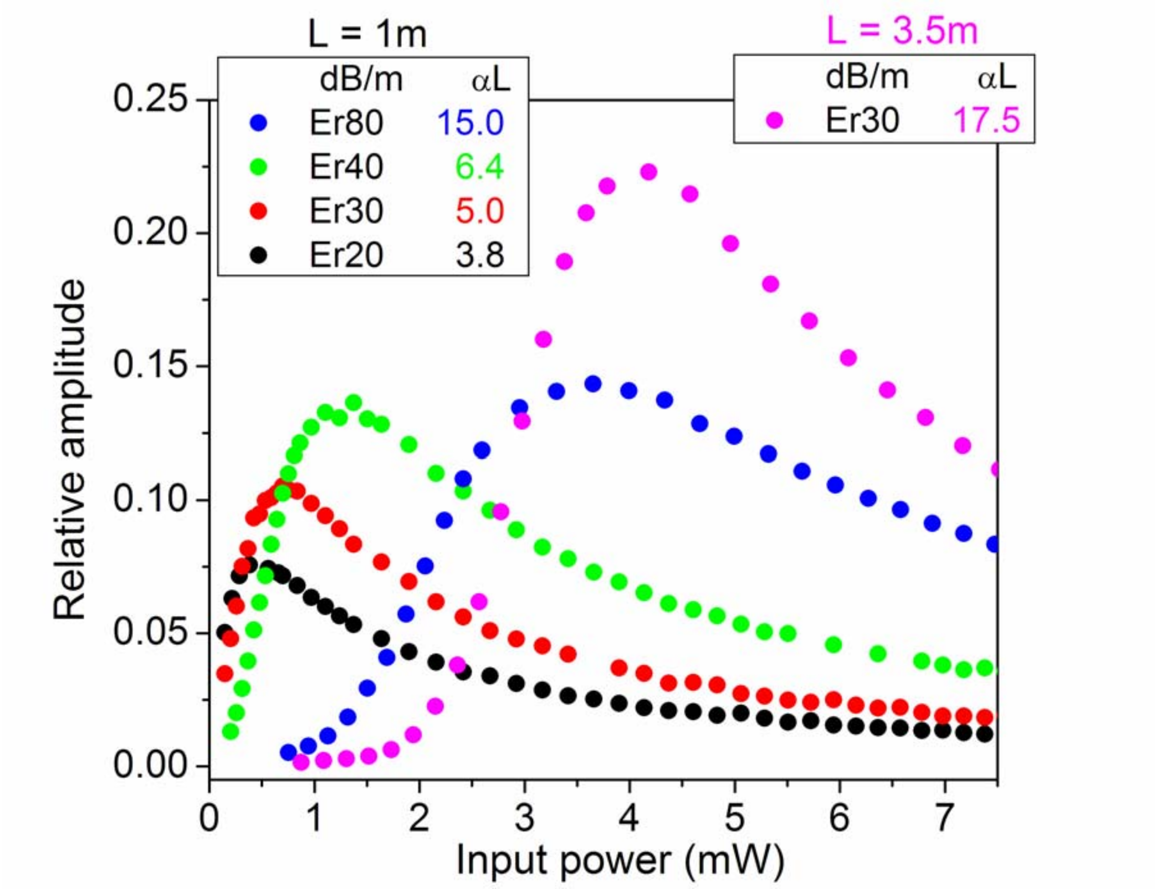
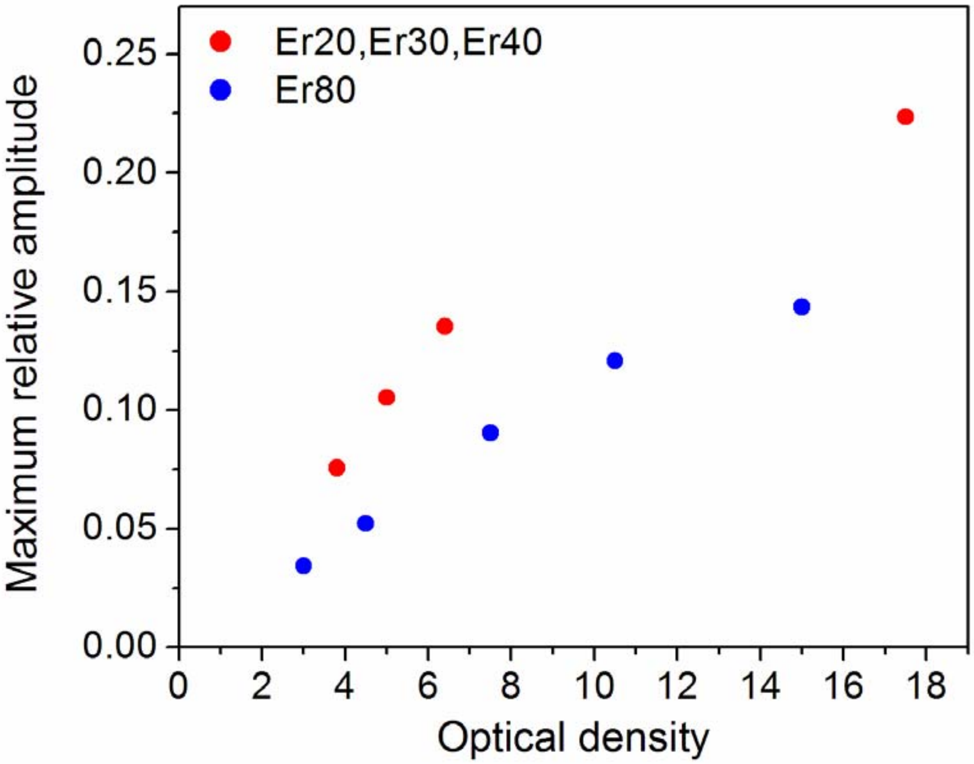
Experimental results: transient TWM

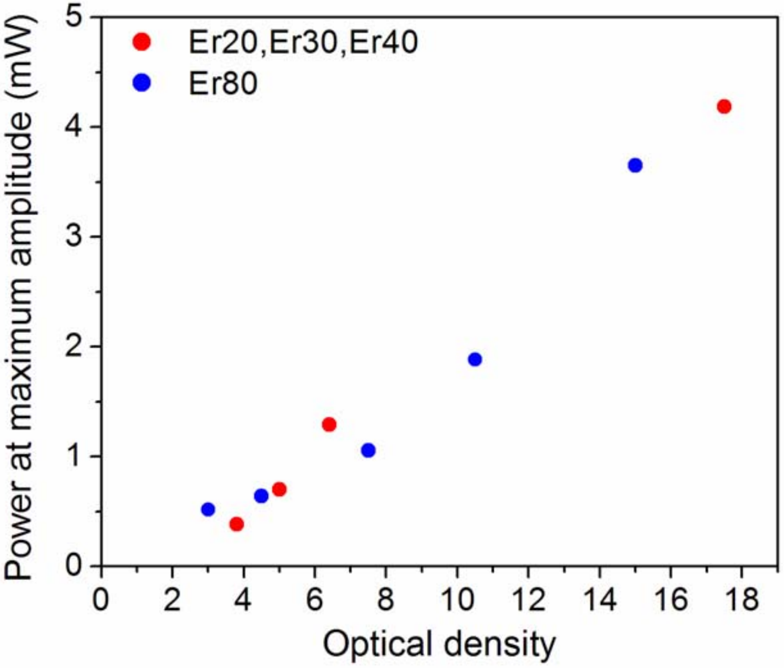


Experimental results: transient TWM



Experimental results: transient TWM





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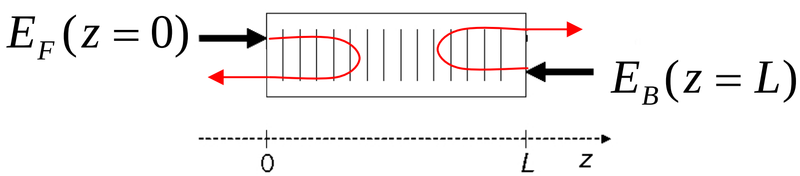
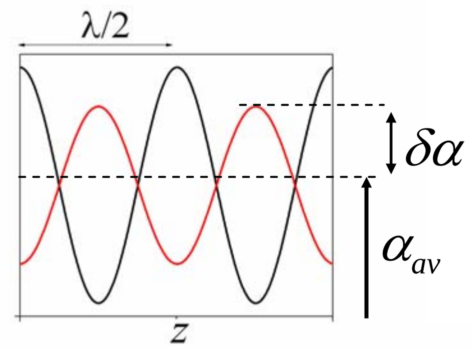
Simulations:

Interference pattern
$$I = I_1 + I_2 + 2m\sqrt{I_1 I_2}\cdot\cos(Kz)$$

Optical absorption
$$\alpha = \frac{\alpha_0}{1+\dfrac{I}{I_{sat}}} \Rightarrow \boxed{\alpha \approx \alpha_{av} - \delta\alpha\cdot\cos(Kz)}$$



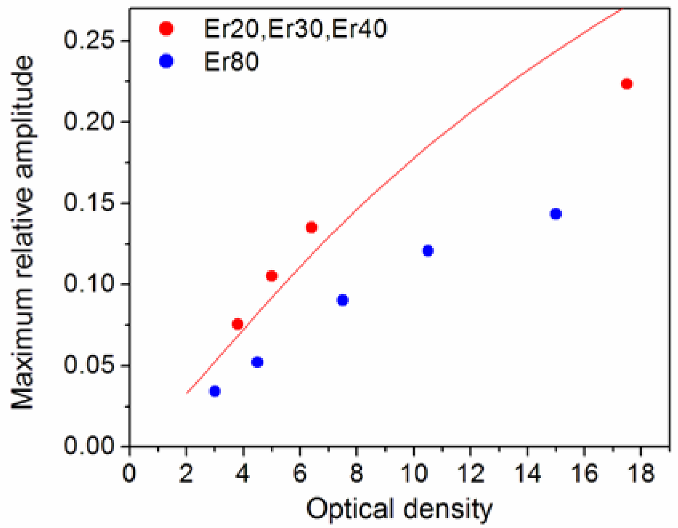


Nonlinear coupled wave equations

$$\frac{\partial E_F}{\partial z} = -\frac{\alpha_{av}}{2}E_F + \frac{\delta\alpha}{4}E_B$$
$$\frac{\partial E_B}{\partial z} = \frac{\alpha_{av}}{2}E_B - \frac{\delta\alpha}{4}E_F$$

Stepanov, J. Phys. D: Appl. Phys. ***41*** *(2008)*

Numerically solved →



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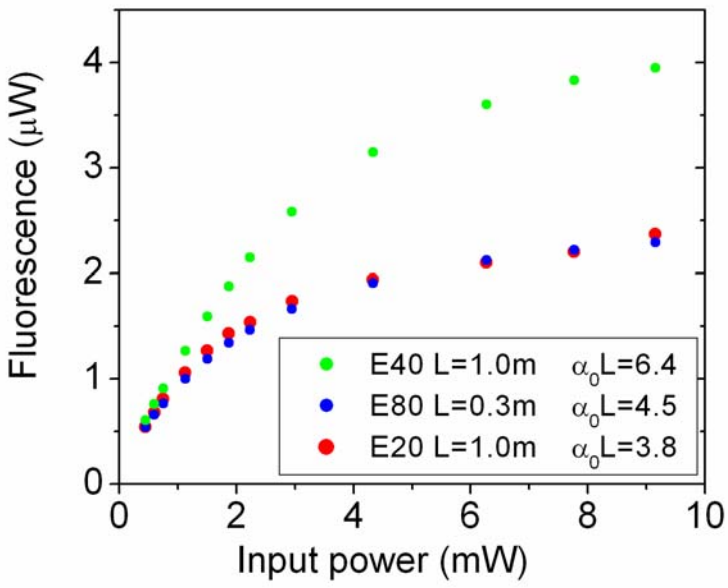
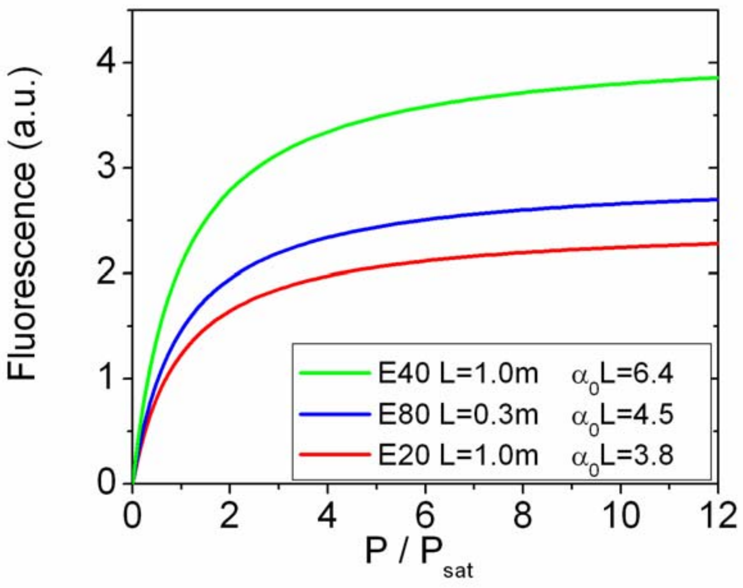
Simulations:





Quenching in the fluorescence
for the more highly doped fiber Er80

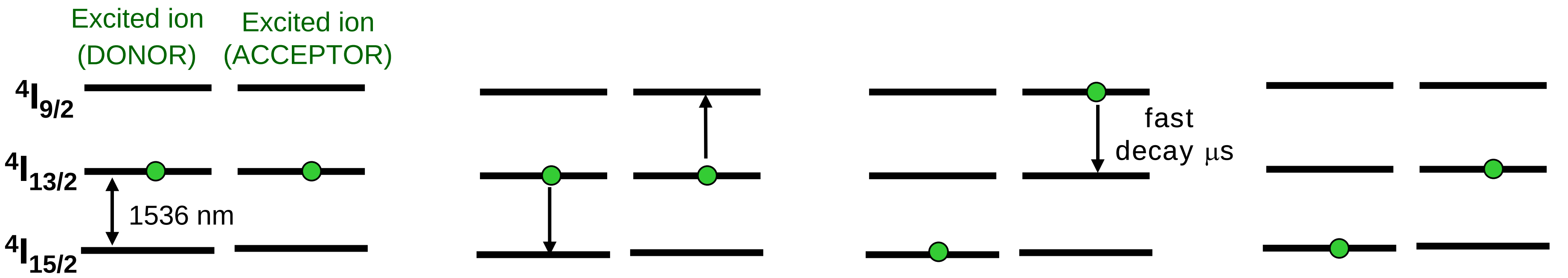
⇩

Inhomogeneous cooperative upconversion
PAIR-INDUCED QUENCHING (PIQ)

Li et al, J. Mod. Opt. ***55*** *447 (2008)*

Simulations: PIQ effect at high ion concentration

Li et al, J. Mod. Opt. ***55*** *447 (2008)*



PIQ ➔ One excited ion is lost

$$N_T = N_i + 2N_p$$

N_i: Number of isolated ions

N_p: Number of ion pairs

$$\kappa = \frac{N_p}{N_T}$$

FRACTION OF ION PAIRS

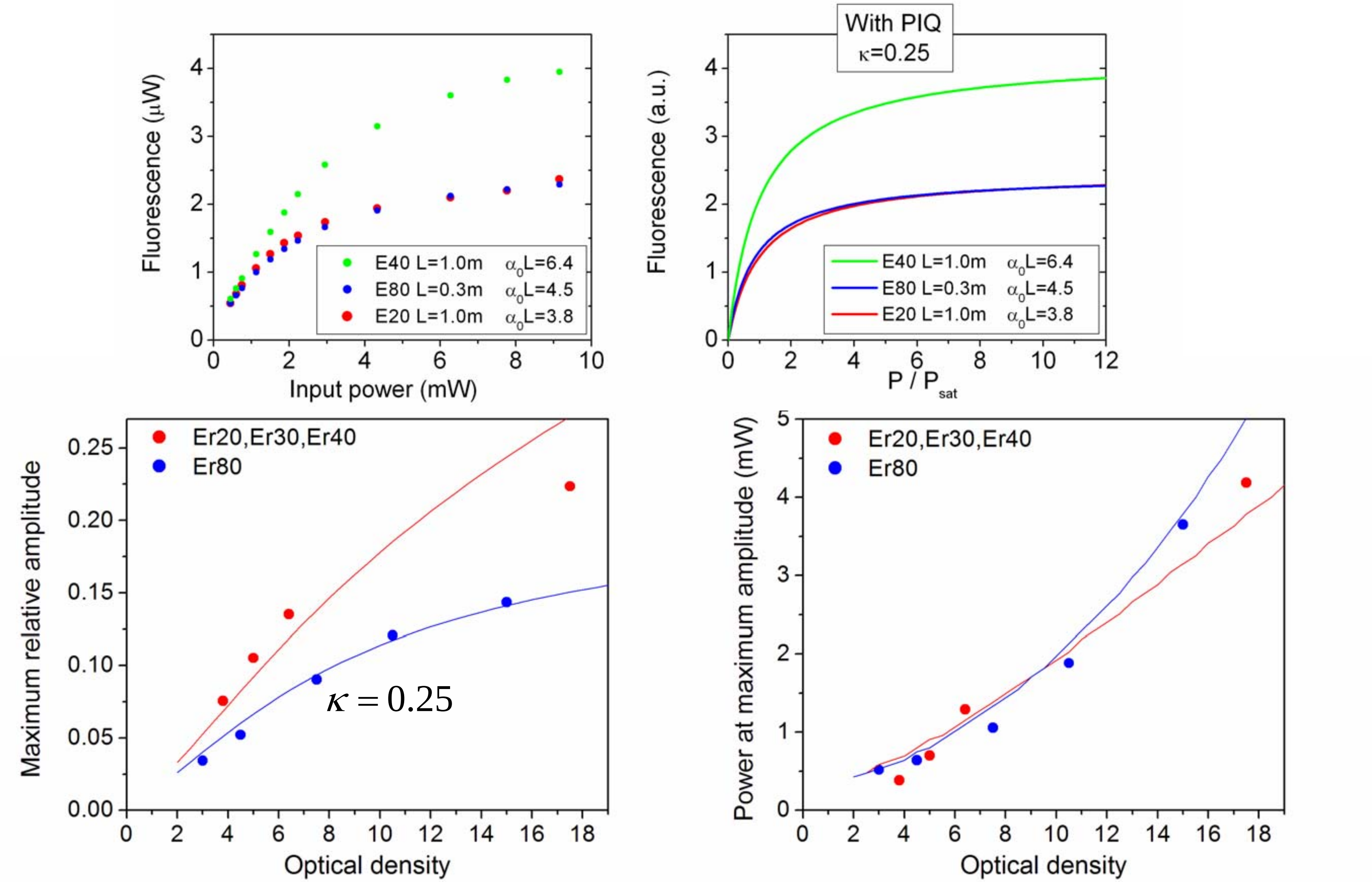
$$\alpha = \frac{\alpha_0(1-2\kappa)}{1+\frac{I}{I_{sat}}} + \frac{\alpha_0 2\kappa\left(1+\frac{I}{2I_{sat}}\right)}{1+\frac{3}{2}\frac{I}{I_{sat}}}$$

Isolated ions — Paired ions

Simulations: PIQ effect at high ion concentration

Li et al, J. Mod. Opt. ***55*** *447 (2008)*

Estimation of the number of ion pairs



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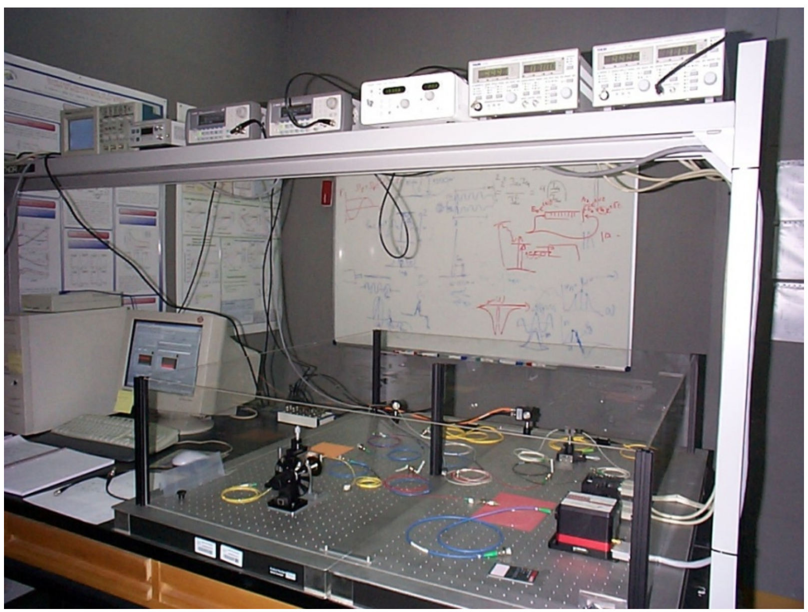
Conclusions

- Grating efficiency increases with optical density

- At very high ion densities (~ 6 x 10^{25} ions /m^3), cooperative upconversion processes (PIQ) that occurs between closely locate erbium ions decrease the grating efficiency.

Thank you for your attention!!



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