

COST MP0702 –WG3

Near and Mid Infrared Photonic Crystal Fiber Lasers

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Scope & short description:

Near and Mid Infrared Photonic Crystal Fiber Lasers constitute a strategic topic for potential UE fund requests. To his aim, an exercise which could be considered a theoretical feasibility investigation of peculiar innovative multi-wavelength sources to be fabricated as demonstrators in perspective European projects is proposed.

The main goal of the exercise/project is to design a continuous-wave photonic crystal fiber (PCF) laser made of erbium-doped chalcogenide glass. In particular, due to the comparable lifetime of the $^4I_{13/2}$, $^4I_{11/2}$ and $^4I_{9/2}$ erbium energy levels, we propose a cascade lasing scheme to obtain simultaneous emissions at the wavelengths close to 1500, 2700 and 4500 nm, by means of three suitable couples of mirrors and the same (single) input pump at the wavelength close to 800 nm (direct pumping into the level $^4I_{9/2}$). This scheme could be useful to develop high efficiency and high-beam-quality compact near and mid-infrared (mid-IR) oscillators with single-mode output powers for applications in spectroscopy, remote sensing, infrared countermeasures, laser surgery, high-efficiency pump sources for longer-wavelength oscillators, and a variety of chemical and biological sensors.

The exercise is a step towards full understanding the effect of the PCF geometrical properties, mirrors reflectivity and erbium concentration on the characteristics of the laser output at the three considered wavelength. In addition, it is very interesting to investigate the effect of depopulation of the $^4I_{11/2}$ energy level, induced by a suitable oscillation at $\lambda \approx 2.7 \mu\text{m}$, because it could improve the laser efficiency at the other two wavelengths.

Definition of the structure

The proposed chalcogenide PCF consists of three rings of air holes arranged in a triangular lattice having hole-to-hole distance $\Lambda = 8 \mu\text{m}$, hole diameter $d = 3.2 \mu\text{m}$ and a fiber diameter $D = 2R = 125 \mu\text{m}$. (see fig. 1).

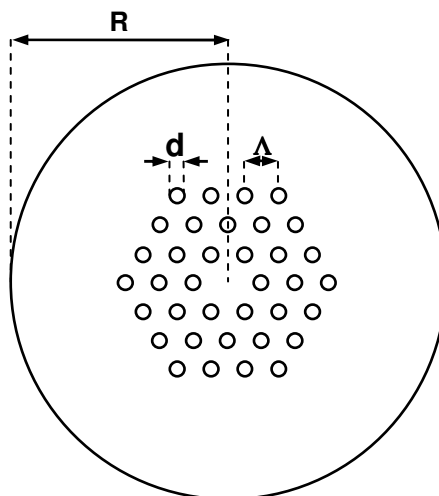


Fig. 1: Sketch of the chalcogenide photonic crystal fiber

The refractive index wavelength dispersion of the Ga₅Ge₂₀Sb₁₀S₆₅ chalcogenide glass can be expressed via the Sellmeier equation:

$$n^2(\lambda) = a + \frac{b\lambda^2}{\lambda^2 - c^2} + d\lambda^2$$

where λ is expressed in microns, the interpolating constants $a = 3.883$; $b = 1.164$, $c = 0.3552$ and $d = -0.02094$ have been optimized to match the measured values.

The Er³⁺ ion transitions among the energy levels are shown in Fig. 2

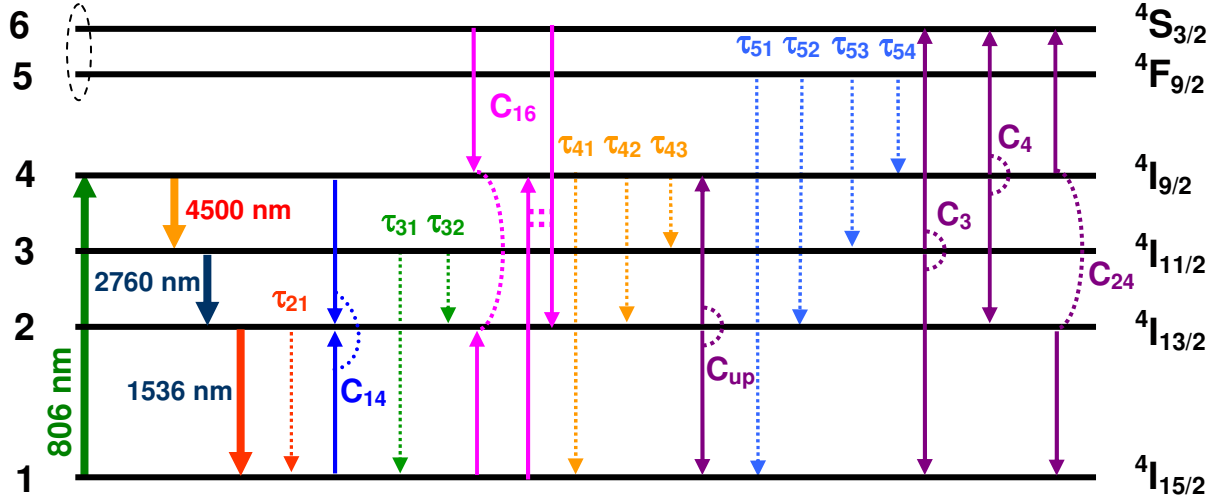


Fig. 2: Energy levels diagram of Er³⁺ ion transitions.

The spectroscopic details are presented in Tab. 1. The task is to compute the output power, threshold pump power and slope efficiency for each lasing wavelength versus fiber length,

Tab.1: spectroscopic details

Transitions	Wavelength λ (nm)	Transition Probability (%)	Ion Lifetime (ms)
$^4I_{13/2} \rightarrow ^4I_{15/2}$	1531.7	$\beta_{21}=100$	$\tau_{21}=1.83$
$^4I_{11/2} \rightarrow ^4I_{15/2}$	986.4	$\beta_{31}=86.28$	$\tau_{31}=1.37$
$^4I_{11/2} \rightarrow ^4I_{13/2}$	2770.7	$\beta_{32}=13.72$	$\tau_{32}=1.37$
$^4I_{9/2} \rightarrow ^4I_{15/2}$	810.0	$\beta_{41}=80.38$	$\tau_{41}=1.08$
$^4I_{9/2} \rightarrow ^4I_{13/2}$	1719.1	$\beta_{42}=18.82$	$\tau_{42}=1.08$
$^4I_{9/2} \rightarrow ^4I_{11/2}$	4529.4	$\beta_{43}=0.8$	$\tau_{43}=1.08$
$^4F_{9/2} \rightarrow ^4I_{15/2}$	662.7	$\beta_{51}=91.99$	$\tau_{51}=0.13$
$^4F_{9/2} \rightarrow ^4I_{13/2}$	1168.1	$\beta_{52}=4.32$	$\tau_{52}=0.13$
$^4F_{9/2} \rightarrow ^4I_{11/2}$	2019.4	$\beta_{53}=3.34$	$\tau_{53}=0.13$
$^4F_{9/2} \rightarrow ^4I_{9/2}$	3623.1	$\beta_{54}=0.35$	$\tau_{54}=0.13$
Wavelength λ (nm)	Emission cross section (m ²)	Absorption cross section (m ²)	
806		11.04×10^{-25}	
1536	15.8×10^{-25}	20×10^{-25}	
2760	14×10^{-25}		
4500	2.03×10^{-25}		
Ion-Ion interaction coefficient (m ³ /s)			
$^4I_{13/2} \rightarrow ^4I_{15/2} + ^4I_{9/2}$		$C_{up}=3 \times 10^{-23}$	

${}^4I_{11/2} \rightarrow {}^4I_{15/2} + {}^4S_{3/2}$	$C_3=2 \times 10^{-23}$
${}^4I_{9/2} \rightarrow {}^4I_{13/2} + {}^4S_{3/2}$	$C_4=2 \times 10^{-24}$
${}^4I_{9/2} + {}^4I_{13/2} \rightarrow {}^4I_{15/2} + {}^4S_{3/2}$	$C_{24}=5 \times 10^{-24}$
${}^4I_{9/2} + {}^4I_{15/2} \rightarrow {}^4I_{13/2}$	$C_{14}=5 \times 10^{-23}$
${}^4S_{3/2} + {}^4I_{15/2} \rightarrow {}^4I_{13/2} + {}^4I_{9/2}$	$C_{16}=5 \times 10^{-24}$
