TEM$_{00}$ fiber laser emitting 94W at 977 nm

J. Boullet$^1$, Y. Zaouter$^{1,2}$, F. Salin$^3$ and E. Cormier$^1$

$^1$ CELIA, Université Bordeaux 1, France
$^2$ Amplitude Systèmes, Pessac, France
$^3$Eolite Systems, 11 Avenue Canteranne 33 600 Pessac, France
Outline

1. Introduction
2. Experimental setup
3. Results and simulations
4. Applications
Needs for high brightness sources emitting at 976 nm

✓ Optical pumping of Yb or Er doped material:
  Laser diodes: \textit{few W}
  VECSEL: \textit{mW}
  Yb-doped lasers: 1.4 W

✓ Blue sources at 488 nm for biology or telecom:
  Argon lasers
  Frequency doubled sources at 976 nm

\[\downarrow\]

No available sources in excess of 10 W

\[\rightarrow\]

\textbf{Yb-doped double clad fiber laser solutions for 100 W class sources}
Laser operation

Configuration 1

Yb-doped fiber

![Graph showing absorption and emission spectra with wavelengths λ_p = 976 nm and λ_s = 1030 nm]

\[ \lambda_p = 976 \text{ nm} \]

\[ \lambda_s = 1030 \text{ nm} \]
Laser operation

Configuration 1

Yb-doped fiber

Absorption

Emission

Configuration 2

Yb-doped fiber

Absorption

Emission

\[ \lambda_p = 976 \text{ nm} \]

\[ \lambda_s = 1030 \text{ nm} \]

\[ \lambda = 915 \text{ nm} \]

\[ \lambda = 976 \text{ nm} \]

\[ \lambda = 1030 \text{ nm} \]
Main issues

1. Transparency:

Bleaching is achieved if:

\[
\frac{n_{\text{trans}}^2}{\eta_{\text{Tot}}} = \frac{\sigma_{s}^{\text{abs}}}{\sigma_{s}^{\text{abs}} + \sigma_{s}^{\text{em}}} \approx 50\%
\]

for a pump intensity of:

\[
I_{p}^{\text{trans}} = \frac{h\nu_{p}}{\left(\frac{\sigma_{p}^{\text{abs}}}{\sigma_{s}^{\text{abs}}} - \sigma_{p}^{\text{em}}\right)\tau_{\text{fluo}}} \approx 30 \text{ kW/cm}^2
\]

2. Gain competition and induced losses:

\[
G_{1030} = 0.25 G_{976} + 0.72 \alpha_{p} \beta
\]

Large β will lead to negligible gain at 976 compared to 1030.

Invert 50% of the population
Achieve small β value
Induce losses > G_{1030}
Experimental setup

Rod type fiber:
Microstructured
Double clad Yb doped
80µm/200µm
Absorption: 10 dB/m
Length : 1.2 m

1 \( P_{\text{trans}} = 11 \text{ W} \)
2 \( \beta = 6.2, \text{ losses} = 60 \text{ dB} \)

Bouillet et al., OE 16, 17891 (2008)

E. Cormier ICUIL ,08 Tongli China
Results

Efficiency:

- Slope Efficiency = 48%
- $P_{\text{threshold}} = 18 \text{W}$

 Beam quality:
- $M^2 = 1.2$

 Spectrum:
- ASE suppression: 35 dB
- 977.5 nm peak intensity

Parasitic lasing suppression:
- Log scale intensity graph
**Simulations**

**Population inversion:**

![Graph showing population inversion]

- $n_{\text{trans}} = 0.5$
- $P_{\text{trans}} = 11 \text{W}$
- $L_{\text{abs (13dB)}} \approx 200 \text{cm}$

**Pump reinjection:**

![Graph showing pump reinjection]

- $60 \text{ W}$

**Losses at 1030 nm:**

![Graph showing losses at 1030 nm]

- Our experiment:
  - Cavity losses: 14 dB
  - Medium gain: $G_{976} = 7 \text{ dB per pass}$
  - Absorption: $\alpha = 11 \text{ dB}$
  - Geometry: $\beta = 6.2$

- $G_{1030} = 0.25 G_{976} + 0.72 \alpha \beta$

Boulet et al., OE **16**, 17891 (2008)
Conclusions

1. Demonstration of a ultra high power Yb fiber laser source
   a) Single mode TEM\(_{00}\) : \(M^2 = 1.2\)
   b) Zero line transition at 977 nm
   c) Output power : 94 W (pump power limited)
   d) Large core Yb-doped microstructured rod type fiber
   e) Very compact and simple setup

2. Analysis through numerical simulations
   a) Pump absorption and population inversion
   b) Pump recycling
   c) Influence of the core diameter
Outlooks

1. Applications
   a) Core pumping of Yb or Er doped fibers
   b) High fluence pumping of Yb doped bulk material
   c) High power high quality pumping of Yb doped bulk material
   d) Frequency conversion -> high power high brightness sources at 488 nm

2. Further studies
   a) Q-switch
   b) Single frequency
   c) Frequency doubling