Industrial mJ-class all-fibered front end with spatially coherent top-hat beam output used as seeder for high power laser

Jean-François Gleyze$^1$, A. Perrin$^1$, Pierre Calvet$^{1,2}$, Pierre Gouriou$^{1,2}$, Florent Sco$^{1,2}$, Constance Valentin$^2$, Géraud Bouwmans$^2$, E. Lecren$^3$, and Emmanuel Hugonnot$^1$

$^1$Commissariat à l’Energie Atomique et aux Énergies Alternatives (Bordeaux)  
$^2$Laboratoire de Physique des Lasers, Atomes et Molécules, (Lille)  
$^3$IDIL Fibres optiques (Lannion)
1. Brief overview of LMJ facility status
2. phase 1: breadboard demonstration
3. Phase 2: Industrial version of mJ-class all fibered system
4. future improvements
Laser characteristics

- Glass Neodymium laser, frequency tripled: $\lambda = 0.35 \, \mu m$
- Laser energy ~ 1.5 MJ, Power ~ 400 TW
- Pulse duration: from 0.7 to 25 ns
- 2 x 2 cones irradiation: 33° & 49°

- 22 bundles of 8 beams lines (176 beams, 5 to 7 bundles per laser bay),
- 4 laser bay,
- a target bay,
- 1 specific beam line for the laser PETAL (PW class laser)
Experimental results

24.6 kJ

10.2 kJ

24.5 kJ

9.8 kJ
Delivers the initial laser pulse:

- 4 main oscillators, one per laser bay. OF technology,
  - spectrum control (1053 nm ±5pm, phase modulators)
- 44 pulse shaping systems (1 system per quad),
- 88 PreAmplifier Module (PAM), one PAM for 2 beams,
  - energy control (amplification from 1nJ to 1J),
  - spatial distribution control (spatial profile shaping system).
Outline

1. Brief overview of LMJ facility status
2. Phase 1: breadboard demonstration
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Fiber interest on front-ends:
compactness, reliability,
fiber geometry leading to high average powers...

Spectacular progress in the development of fiber lasers and amplifiers.

D.J. Richardson et al., JOSA B 27, 11 (2010)

Aim of this study?

Development of an fibered architecture to extend fibered components from the Seed to the PAM, with stringent requirements (ASE, OSNR, temporal distortion, non linear effects, polarization...), using commercial flexible fibers.

Fig. 4. Power evolution of cw double-clad fiber lasers with diffraction-limited beam quality over the past decade.
Currently:
- free-space amplification and spatial beam-shaping
- Difficult alignment
- Strong maintenance

In the future:
- Partially fibered PAM
- Compactness – no rod type (integration)
- Reliability

Our aims for a fibered PAM:
Stringent requirements:
- ASE, OSNR, Temporal and spatial shape,…
- Reduction of Non-linear effects (SPM, SBS, SRS,…)

phase 1: breadboard demonstration
Interests of fiber in the Pre-Amplifier Module (PAM)
phase 1: breadboard demonstration
Fibered laser – state of the art

Since 2010, few examples of publications for mJ class fibered laser

<table>
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<th>date</th>
<th>authors</th>
<th>pulse fwhm (ns)</th>
<th>energy per pulse (mJ)</th>
<th>spectral width (nm)</th>
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<td>0,26</td>
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</table>

these laser are non-LMJ compliant due to:

- Short pulse (spectrally wide) or very long pulse up to 500ns
- Use of Rod type fiber or multimode LMA fiber

Base of our system is: L Lago et al. Optics letters 36 (2011)

first demonstration of LMJ compliant, mJ-class frontend

- 10ns / 0,5mJ up to 1,5mJ / single frequency,
- linear polarization, single transverse mode, flexible fiber, free space launching, non linear effect at 1,5mJ
phase 1: breadboard demonstration
First demonstrator

L. Lago et al, Optics Letters 36, 734 (2011)

- 10ns / 0.5mJ up to 1.5mJ / single frequency,
- linear polarization, single Gaussian transverse mode, flexible fiber, free space launching

Possible improvements for this system:
- limitation of non linear effects,
- monolithic system for industrial use
=> top hat output beam
Main difficulty for LMJ fiber requirement are non-linear effects due to:

- Single frequency (<1MHz)
- Long pulse (up to 10ns)
- Gaussian spatial profile (= losses for spatial shaping)

**Push away the Non-linear effects**

Uniform beam could address not only LMJ or huge facilities but also:

- Laser marking, drilling, heating,…
- Laser – Biological tissues interactions inside the body
phase 1: breadboard demonstration
How to get a fundamental flattened mode with fiber

LP<sub>01</sub> classical fibre

LP<sub>01</sub> « top-hat » fibre

**multimode fibre:** Hayes, OE (2006)

**LMJ non compliant**

*Multimode => bad coherence = Poor 3w conversion*
Top-hat beam output

up-doped ring

Figure 1. Schematic diagram of the refractive index profile.

Design of Waveguide Refractive Index Profile to Obtain Flat Modal Field

A. K. Ghatak, I. C. Goyal and Rajeev Jindal
Department of Physics, Indian Institute of Technology Delhi

This crystal fiber with a flattened fundamental mode for the fiber lasers
Chun-can Wang *, Fan Zhang, Yu-chun Lu, Chu Liu, Rui Geng, Ti-gang Ning

Key Lab of All Optical Network & Advanced Telecommunication Network of EMC, Beijing Jiaotong University, Beijing 100044, China
Institute of Lightwave Technology, Beijing Jiaotong University, Beijing 100044, China

Low optical mode losses

mJ - project – Jeff Gleyze
Stack and draw method
Ge-doped ring by OVD
7 missing air holes
$A_{\text{eff}} = 320 \, \mu m^2$
MFD = 20 $\mu m$
phase 1: breadboard demonstration
Characterization of the passive top hat fiber

Loss: -0.23 dB/m

@500 nm  @1080 nm  @1010 nm  Offset de 20 µm
phase 1: breadboard demonstration
Integration of the fiber

- Splice loss: 0.65 dB
- Top-hat output

- Spatially monomode from 1010nm to 1080nm
- Reduce impact from misalignment
- Minimum radius curvature: 10cm
- Fibre OK for compact system
We develop specific calculation code.
phase 1: breadboard demonstration

Setup


- 10ns / 0.1mJ / single frequency,
- linear polarization, single transverse mode, flexible fiber, monolithic

73% more energy in the top of beam than Gaussian beam
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Phase 2: Industrial version optimized architecture
Phase 2: Industrial version
cabinet version

Thanks to this we have demonstrated:
- mJ scalable architecture
- possibility of shifting the wavelength from 1030 to 1064nm.
- interchangeability of the different racks with no compactness restriction
Phase 2: Industrial version
Temporal performances

Temporal shaping examples and performances
Rise/fall time <180ps
Temporal Extinction ratio: >50dB

28ns arbitrary waveform

Pulse duration: 300ps -> 30ns

Exemple Forme 10ns pré-compensée 100µJ

Dynamique de réglage accessible: 30dB avec extinction bruit à 50db
Phase 2: Industrial version
Spectrum and energy performances

Output from nJ seeder  
Output from 4µJ amplifier

*corrected by cycle: 10ns@10KHz Versus cw ASE
Phase 2: Industrial version
Spectrum and energy performances

Output from mJ amplifier @10ns
Ajout d’un filtre ASE entre µJ et mJ

Spectre injecté
Spectre sortie ~75µJ

Limitation RAMAN

OSNR ~57dB*

Spectre sortie ~100µJ

92µJ
Stabilité 1.5%rms

100µJ
Stabilité 3.8%rms
Phase 2: Industrial version
Spatial performances -

**Banc de mesure**

**Utilisation fibre « de transport » PM 16µm top hat**


**Profils spatiaux à 90µJ**

95cm de fibre optique
PM Top hat

25cm de fibre optique
PM Top hat
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Résumé

Nous avons réalisé une source entièrement fibrée :

- Totalement monolithique: plus de « passage » en faisceau libre
- Maintenable selon le concept URL LMJ (connecteurs et racks)

Nous avons démontré les performances suivantes:

- faisceau polarisé et monomode spatial
- 0.1mJ@10ns + mode plat pour une source mono-fréquence (modulation en phase)
- Une énergie jusqu’à 1 mJ@10ns en profil gaussien possible (extrapolation résultat breadboard)
- Durée des pulses programmable entre 0,3 et 30ns “carré” après amplification
- Un rapport signal/bruit maîtrisé >57db
- Des taux de répétition jusqu’à 10Khz
- Une adaptation en longueur d’onde importante 1010 à 1080nm
Future improvement


- Next industrial step could consist in further improving the compactness of the source
  - 3D technical drawing techniques will help to optimize the integration
  - Specifics electronics should be design

- Another way of improvement: Increasing energy
  - will be possible by the use of larger core yb doped top hat PM fiber
Thank you for your attention!