Picosecond, 115 mJ Energy, 200 Hz Repetition Rate Cryogenic Yb:YAG Bulk-amplifier

M. Hemmer¹,²
F. Reichert¹,², K. Zapata¹,², M. Smrz³, A.-L. Calendron¹,², H. Çankaya¹,², K-H. Hong⁴, F. X. Kärtner¹,²,⁴, and L. E. Zapata¹,²

¹Center for Free-Electron Laser Science, Hamburg, Germany
²Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany
³Hilase Center, Dolni Brezany, Czech republic
⁴Research Lab of Electronics, Massachusetts Institute of Technology, USA

12th May 2015
Cryogenic technology can scale energy and repetition rate simultaneously & simplify current architecture.
BASIC MATERIAL PROPERTIES AT CRYO TEMPERATURE

This all looks very promising—onto experimental demonstration...

- Higher cross section $\rightarrow$ higher gain
  - $G_{4\text{pass}} = 2$, 4 passes
  - $G_{\text{cryo}} = 8$, 4 passes
  $\rightarrow G_{4\text{pass}} = 4100$

- Saturation fluence is reduced at cryo
  - $1.8 \text{ J/cm}^2$ at saturation
  - $\sim \text{few J/cm}^2$

- At cryo temp Yb:YAG turns 4-level

- Simultaneous increased of thermal conductivity and reduction of $dn/dT$

- Expansion coefficient simultaneously reduces
  $\rightarrow$ reduced wavefront distortions

ROBUST, COMPACT, 4-PASS LAYOUT

- Seed operates at 1 kHz with up to 4 mJ energy, 2 ns stretched pulses
- KD*P Pockels cell operated in ¼ wave voltage
- Yb:YAG crystal: 1% doped, 2.5 cm thick, 3 mm undoped YAG cap
115 mJ, 200 Hz, EXCELLENT BEAM PROFILE
HIGH GAIN, HIGH ENERGY

- Optimization possible with in-band seeding
- 5 ps TL pulse duration – compressibility of seed has been demonstrated

Robust setup yields over 2 order of magnitude gain
Further energy scaling ?...
High gain in thin-disk requires mitigating transverse ASE buildup

Model driven design of ASE mitigation is experimentally validated
Implementation in a multi-pass amplifier...

Zapata et al., Opt. Lett., accepted for publication
MULTI-PASS CRYOGENIC THIN-DISK AMPLIFIER

- 6 or 12 pass design
- Strict relay imaging to control propagation in the amplifier
- Built-in spatial filtering to smooth out output profile
- Equipped with similar pump module as previously with 2 kW average/peak power
**160 mJ, 100 Hz, NEAR DIFFRACTION LIMITED PROFILE**

- **In-band** seeding with 20 mJ energy from previous bulk amplifier
- Saturation reached for ~20 mJ seed energy and 2.5% duty cycle
- Increasing duty cycle results in onset of transverse ASE build up

**Further energy scaling toward the Joule level is underway**
SCALING REPETITION RATE – 100 kHz

MODIFICATIONS TO ORIGINAL SETUP FOR AVERAGE POWER HANDLING

- Similar layout as 100 Hz setup – 4 pass polarization switched amplifier
- Splitting of pump power on two crystals to facilitate high average power operation
SCALING REPETITION RATE – 100 kHz OPERATION

- Excellent output spatial profile – **no evidence of thermal effects**
- Rollover at ~60 W – currently under investigation
- Spectral gain narrowing is similar to low repetition rate configuration

**Preliminary results** – readily illustrates versatility of cryo cooled amplifier
CONCLUSION & REMARKS

Demonstration of simple 100 mJ class amplifiers

• Demonstration of robust, low-cost, bulk amplifier
  115 mJ, 200 Hz, 5 ps TL duration, near diffraction limit
  spatial profile

• Demonstration of a robust, high gain, cryo cooled thin disk amplifier
  160 mJ, 100 Hz, 5 ps TL pulse duration, near diffraction limit
  spatial profile

• Experimental demonstration of a robust, high gain, 100 kHz amplifier
  0.6 mJ, 100 kHz, 5 ps TL pulse duration, near diffraction limit
  spatial profile

• These sources make ideal pump laser for OPCPAs!