Near-Infrared Laser System for Dielectric Laser Acceleration Experiments at SINBAD

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IPAC21
**DLA experiments @ SINBAD (DESY)**

- **SINBAD:** Short Innovative Bunches and Accelerators at DESY
  → dedicated facility for Accelerator Research & Development

- **ARES (Accelerator Research Experiment at SINBAD)**

- DESY is part of the international **ACHIP**
  (Accelerator on a chip) collaboration, investigating Dielectric Laser Acceleration (DLA)

Electron acceleration on a DLA structure

1. Laser pulse
2. Half-cycle later

- At SINBAD, laser acceleration on relativistic electrons
- We here report on the NIR laser system

ACHIP experiment @ SINBAD

Two laser systems used: UV – Photoinjector + 2 μm IR laser for DLA experiments

Why operating at 2 μm?
- High damage threshold of dielectric materials
- Less distortion on electron bunch energy distribution (compared e.g. to 800 nm)
- Dielectric structures of suitable size can be produced

Challenges:
- Realize Laser system
- Beam delivery
- Synchronization + Timing
2050 nm Ho:fiber laser oscillator

- Constructed in-house for DLA-experiments
  - Holmium-doped gain fiber (emission at 2050 nm)
  - Synchronizable (control of repetition rate)
  - Nonlinear Amplifying Loop Mirror (NALM) used for mode-locking
- Features:
  - Long term stable
  - Optimized for seeding Ho:YLF amplifier

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
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<tbody>
<tr>
<td>Repetition rate</td>
<td>41.6 MHz</td>
</tr>
<tr>
<td>Pulse energy</td>
<td>170 pJ</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>1.3 ps</td>
</tr>
<tr>
<td>Wavelength</td>
<td>2050 nm</td>
</tr>
<tr>
<td>Spectral width</td>
<td>15 nm</td>
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</tbody>
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\[ \lambda_c = 2050 \text{ nm} \]
Ho:YLF Regenerative Amplifier at 2050 nm

- Regenerative amplifier with subsequent single-stage amplifier → **amplify pulses to mJ level**
- Intra-cavity **gain shaping** with etalon reduces the effect of gain-narrowing
  K. Murari et al., OL 41, 1114 (2016)
- Allows ~ 2 ps pulses → high peak fluence on DLA structures

<table>
<thead>
<tr>
<th></th>
<th>Original</th>
<th>Modified</th>
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<tbody>
<tr>
<td>$E_p$</td>
<td>2 mJ</td>
<td>2 mJ</td>
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<tr>
<td>$f_{\text{rep}}$</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$\tau_p$</td>
<td>3.6 ps</td>
<td>2.2 ps</td>
</tr>
<tr>
<td>$\tau_{\text{TL}}$</td>
<td>2.2 ps</td>
<td>1.25 ps</td>
</tr>
</tbody>
</table>

**Limitation for field gradient: damage threshold of DLA**


Gain Shaping with Etalon
Beam transport

- Laser light delivery via vacuum beamline with 4f relay imaging system
- Distance from source to target is ~31 m.
- Active beam stabilization system
Synchronization

- Both lasers (UV + 2 μm) are locked to the machine RF
- RF to optical synchronization:
  - photodiode signal is filtered and mixed with reference
  - Digital phase-locked loop using digital IQ demodulation
- Digital locking scheme allows time shift of laser pulses

2 μm oscillator locking performance

- In long-term operation jitter <50 fs (RMS)

2 μm beamline

- We identified pump laser intensity noise as major contribution to timing jitter → new low noise pump
- Optical synchronization: to improve the relative timing between electrons and the 2 μm laser, a balanced optical cross-correlator will be installed in Q2 2021
Summary and outlook

• We constructed/installed a synchronizable a 2 μm laser system for DLA experiments
  • Fiber oscillator
  • Regenerative Amplifier
  • Beam delivery over 30 m + active beam stabilization
• Synchronization to accelerator RF demonstrated
• First tests and integration into control system done
• Update to improve synchronization in progress (Q2/2021)
• DLA experiments are foreseen for Q3/2021

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