The High Power FEL Development at JLab

George Neil for the FEL Team

With congratulations to Kwang-Je Kim on his retirement

3/15/2019
Jefferson Lab’s CEBAF accelerator was the first major project built using superconducting SRF technology and was based on pioneering work by Stanford, Cornell and others.

*It was 10 years in planning, took 5 more years to build and cost ~$600M in 1990-1995.*

JLab’s Linear Accelerator
Superconducting cavities are assembled in Class 10 cleanroom

Surface electric fields are high during acceleration so any internal contamination leads to field emission.

Eliminate this during assembly and seal the cavity.
I told George he should use the CEBAF linac for an FEL. Maybe KEK should try it, too.
Parallel tracks: Designs, Proposals and the Hunt for $

1990: “Applied Research and Technology “ grant from VA’s CIT
1991: First Design for standalone kilowatt class IR-UV FEL
1994: Submitted to DOE/DOC for $25m with $10m of partner $ (didn’t make the cut ~ 0.1% of proposals funded)
1995: Project reviewed by NASA for DOE
   Sec. O’Leary: “great project, a model for the nation” “...good luck in finding the money”...
1995: With help from NPS and VA Congressional delegation, $10M in FY 96 appropriation to Navy Research
IR Demo Project Launched (1996)

- 1 kW IR FEL using spare cryomodule parts donated by DOE-NP
- Multipurpose FEL Facility and User Labs built with VA funds
- Cliffhanger: delayed federal funds due to FY96 shut-down; federal funds arrived shortly before VA funds disappeared
- Construction project compressed to 18 months (including 14 reviews)
JLab’s first FEL: IR Demo: 1996-2001

- 2 - 8 microns at > 1 kW average power
- sub-picosecond pulse length
- up to 75 MHz rep rate
- 3-40 keV sub picosecond x-rays
So why doesn’t LANL use energy recovery with an SRF linac like Jefferson Lab?
Energy Recovery Works

RF Power Draw vs Beam Current

Power (kW/cavity)

- Beam Off
- 1.1 mA No Recovery
- 1.0 mA ER
- 2.4 mA ER
- 3 mA ER
- 3.5 mA ER

- Energy Recovery Off
- Energy Recovery On
Attempts to Demonstrate ERLs

Over 50 years of attempts, the three JLab FEL drivers are the only CW ERLs to achieve "break-even" i.e., the beam power exceeded the installed linac RF drive:

- Chalk River (pulsed copper)
- Bates (pulsed copper)
- Novosibirsk (CW copper, but with much more RF drive than beam power, even including wall losses)
- HEPL (pulsed only)
- CEBAF FET (source and beam loss limited to low power)
- IR Demo (5 mA x 45 MeV > 200 kW; only 40 kW installed in linac)
- CEBAF-ER (source and beam loss limited to low power)
- IR Upgrade (8.5 mA x 150 MeV = 1.25 MW; only 120 kW installed in linac)
- ALICE (pulsed only - due to SRF issues)
- UV Demo (2.5 mA x 135 MeV = 335 kW; only 120 kW installed in linac...)
- BNL ERL (failed)
- KEK cERL (beam loss limited to 1 mA -> below or barely at breakeven)
- S-DALINAC, ERL just started up at Darmstadt
Predicted Optimum Lasing Performance vs. Experiment for IR Demo

The graph shows the comparison between predicted and achieved laser power performance based on wavelength. The x-axis represents the wavelength in micrometers (µm), while the y-axis indicates laser power in watts (W).

- **Fundamental Lasing** is represented by a red line.
- **Third Harmonic Lasing** is depicted by a dashed blue line.
- **Achieved Power** is shown by red bars at specific wavelengths.

The graph visually illustrates the theoretical predictions compared to the experimental results, highlighting discrepancies and areas of improvement.
Simultaneous production of 3 µm, THz, and 10 keV X-ray femtosecond pulses

- 800 fsec pulses at 37.4 MHz
- Synchronized to <psec levels (same beam!)
- All three wavelengths at world class fluxes

3 micron lasing >1 kW

10 keV X-ray > 10^5 ph/sec/0.1% BW

THz pulses, ~50 W total power
FEL Team celebrating the “kilowatt prize”
So George, why don’t you get a UV undulator and lase at shorter wavelengths? The rest of these guys won’t know what hit them.
But I can’t afford another undulator

FEL Prize winners
JLab’s IR/UV 4th Generation Light Source

E = 120 MeV
135 pC pulses @ 75 MHz

20 μJ/pulse in 250–700 nm UV-VIS
120 μJ/pulse in 1-10 μm IR
1 μJ/pulse in THz

UV system first lasing
August 19, 2010
IR power record still holds
Jlab FEL Program Accomplishments

FEL Physics and Technology (6 different FELs have operated in the facility)

• First demonstration of high power lasing in an ERL
• Highest average output power in a tunable laser (14.3 kW)
• First demonstration of 2nd and 5th harmonic lasing
• High average power in the UV (150 W)
• Continuous tuning of a CW laser over two octaves of wavelength change
• Highest average THz power emitted in any accelerator
• Demonstration of off-axis Thompson backscattering in an FEL
• Demonstration of inverse tapered operation in an FEL
• Operation of a FEL with cryogenic mirrors
FEL Facility User Lab

- Microfabrication
- Surface Physics
- FEL Development Propagation (Future)
- Photochemistry/Photophysics
- Metals
- Multi-purpose Polymers

6600 ft² User Labs
40'x240' FEL Vault
Sampling of FEL User Results

• Spectroscopy
  • H-Si (Luepke, CWM)
  • Amide-I in myoglobin (Austin, Princeton)
  • Dark Matter search (Baker, Yale; Boyce, JLab; Milner, Fisher, MIT)
  • THz studies at high power (Klopf, Williams, JLab)

• Ablation
  • Resonant PLD of polymers – (Kelley, CWM; Haglund, Vanderbilt)
  • Non-resonant, high quality magnetic/SC films – (Reilly, CWM; Shinn, JLab)

• Micro/nano-fabrication
  • C-nanotubes – (Jordan, JLab; Smith, NASA)
  • UV/visible micro structuring of glasses (Helvajian, Aerospace Corp.)

• Surface processing
  • Laser nitriding of metals (Schaff, Göttingen)
  • Laser amorphization of metals (Kessel, Dominion Power)

• Biomedical
  • Selective photothermolysis of lipid rich tissues (Anderson, MGH)
Nanotubes at the JLab FEL

Penn State
College of William and Mary
NASA LaRC

Led to spin-off company now producing the world’s only pure commercial Boron Nitride nanotubes: BNNT LLC
Infrared absorption spectra of water (solid line) and human fat (dotted line), noting approximate wavelengths of fat absorption maxima.

Collaboration with MGH

Selective Photoablation of Lipid-Rich Tissues:


Led to laser treatment of adult acne in clinical setting
Some of the JLab FEL Team who made all this possible
What to do in retirement?
Join me at Burning Man?

Courtesy www.doublehelixart.com
See us at GLEAM2019
Madison WI               Aug.24-Oct.26
Backups
Superconducting cryomodules

- Cryomodule
- RF Waveguides
- Helium return line
- Electron beamline
Recirculation Pi Bend transport > 10% energy spread
JLab IR/UV Mirror Cassette works to very high power

Conflat seals to achieve vacuum rating.

Deformable mirrors correct thermal distortion

Access ports for installation or replacement of components.

Mirrors on translation stage to change wavelength ranges

Access ports for Survey and Alignment Team and diagnostics.
Control Room (familiar shot)