Multi-kW High Beam Quality CW Laser for Space Debris Manoeuvring

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The Right Laser for Space Debris Manoeuver

Active debris manoeuver with laser technologies:

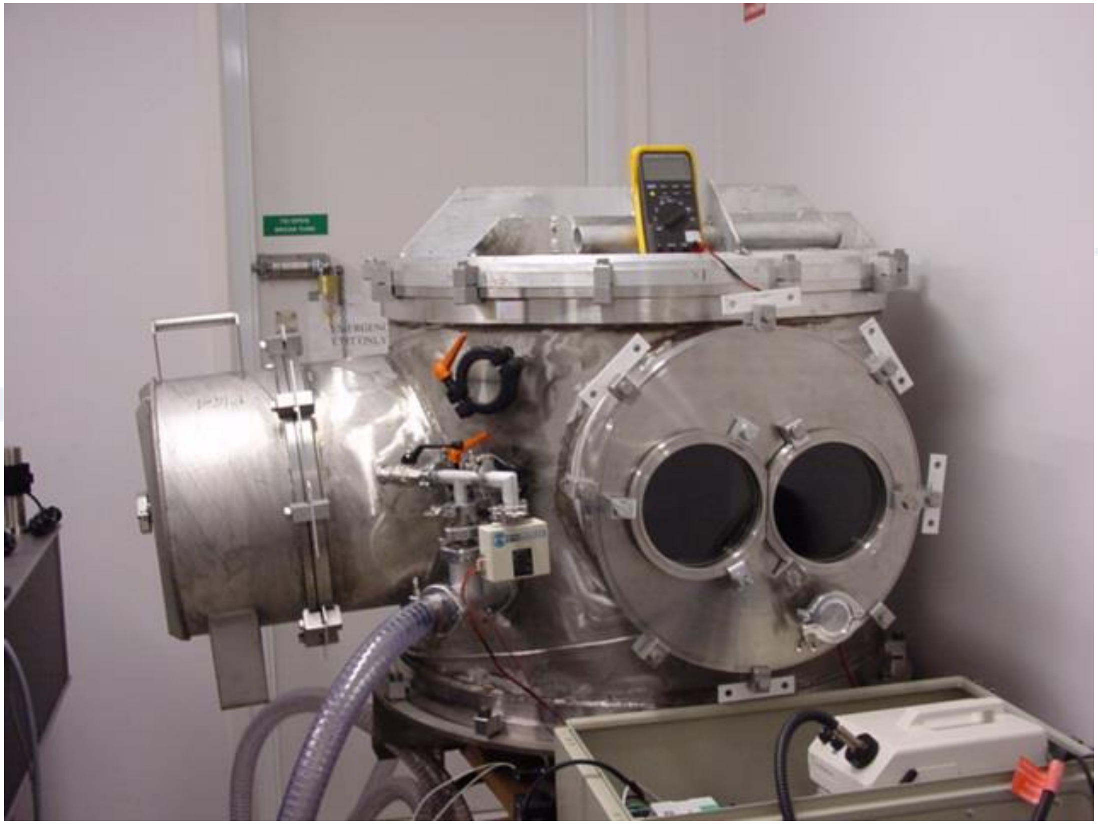
- Pulsed Laser – ablation
- CW Laser – photon pressure

Their physical process and mechanism are different

- Ablation – power density needs to be above ablation threshold
- Photon pressure – momentum transfer

Space Debris Manoeuver With Laser Technologies

Since 2001 investigations on different laser formats, wavelengths, output power, pulse energy, pulse width and their influence on Momentum Coupling Coefficient in air and vacuum have been conducted at EOS.



Laser Ablation Experiment – hit by single pulses

An aluminum/titanium alloy target placed in vacuum chamber, hit by laser beam with single pico-second (ps) pulse

Laser Ablation Experiment – hit by special pulse format

The same aluminum/titanium alloy target placed in vacuum chamber, hit by the laser beam with special pulse format

Space Debris Manoeuver Through Laser Ablation

	Ablation Threshold in Air	Ablation Threshold in Vacuum
Laser pulses with 3.5 ns pulse width	952 mJ/cm^2	1145 mJ/cm^2
Laser pulses with 33 ps pulse width	175 mJ/cm^2	276 mJ/cm^2

1. The ablation thresholds are higher in vacuum than in the air
2. For nano-second pulses much higher energy density is required to generate laser ablation

	Ablation Threshold in Vacuum
Conventional laser with 33 ps pulse width	276 mJ/cm^2
Laser with special pulse format	136 mJ/cm^2

- A laser with special pulse format which can generate efficient laser ablation at much lower energy density identified by EOS in 2003. The ablation threshold is much lower than that of conventional single pulse

Space Debris Manoeuver Through Laser Ablation

- ORION – 20 kJ, 40 ns laser, unrealistic

- The lower ablation thresholds have a profound influence on the design and development of laser systems that are practical to construct and capable of generating laser ablation threshold energy densities

- The laser system with this special pulse format has become realistic and practical (hundreds of Joule) to construct but still quite big so VERY EXPENSIVE.

Space Debris Manoeuver Through Photon Pressure

- Use photon pressure as propulsion
- Photon pressure is a result of the photon momentum. If a piece of debris absorbs or reflects incoming photons, the momentum transferred leads to a small but noticeable force, F

$$F/A = C_r \times I/c$$

A: the illuminated cross section

I: the intensity of the radiation

C_r: the radiation pressure coefficient of the object

c: the speed of light

Space Debris Manoeuver Through Photon Pressure

- The intensity that can be delivered to the target is proportional to the laser power and inversely proportional to the laser wavelength.
- The beam quality describes how well the laser beam can be focused over long distances, critical for targeting small debris objects.

Key requirements on major laser specifications:

Laser power: the higher the better

Wavelength: the shorter the better

Beam quality: good M^2 value, close to 1

A baseline system for Space Debris Manoeuver Through Photon Pressure

Laser should be technologically practical and financially realistic

Laser power: > 5 KW

Wavelength: ~1 µm (Nd:YAG - 1.064 µm, Yb:YAG - 1.03 µm)

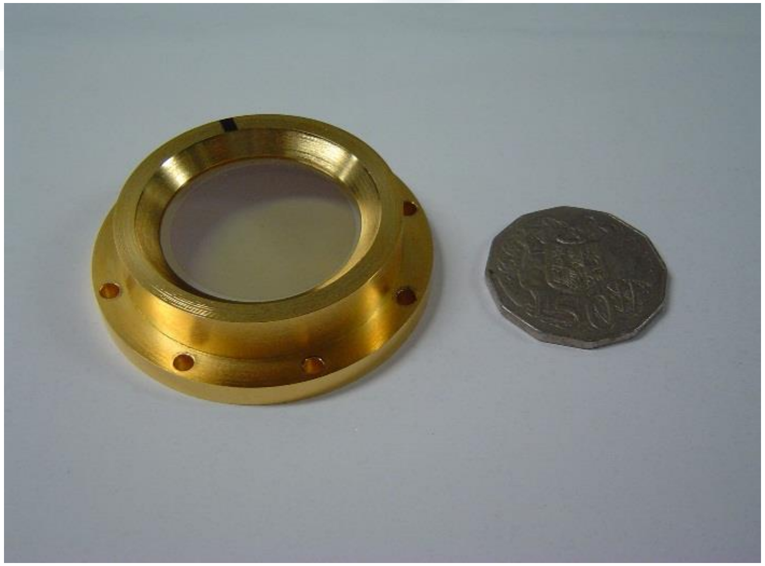
Beam quality: $M^2 \sim 1.2$

Adaptive optics system with artificial laser guide star is required to counter the negative effect of atmospheric turbulence on the laser beam quality

Available High Power CW Lasers

Thin disk laser

- Multi-mode laser oscillator using 45 mm diameter (35 mm clear aperture) thin disks – these were and still are the largest thin disks in the world
- Wavelength: 1.03 µm
- > 4000 W average output power - 2008



Fiber laser

High Power Fiber Laser Technologies

Now ~10 kW single mode fiber lasers are commercially available

- Simple, turn key solution
- Expensive at ~$144/W
- If fails, it fails completely and there will be no any output power

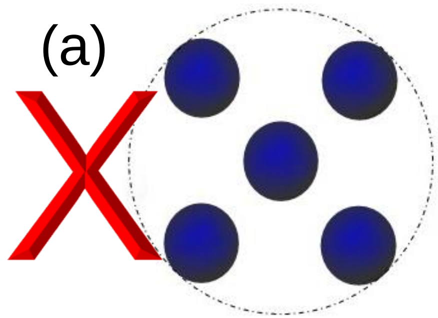
Multi-beam combination [combine outputs from several (n) low power fiber sources together, including:

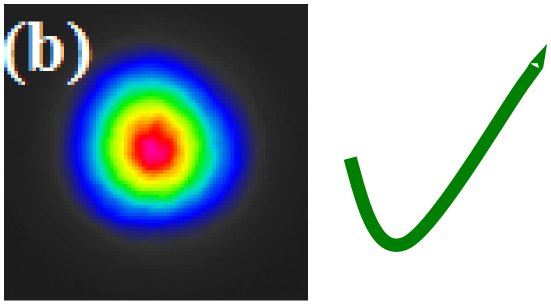
(a) Spatial Beam Combination

(b) Spectral or Wavelength Beam Combination

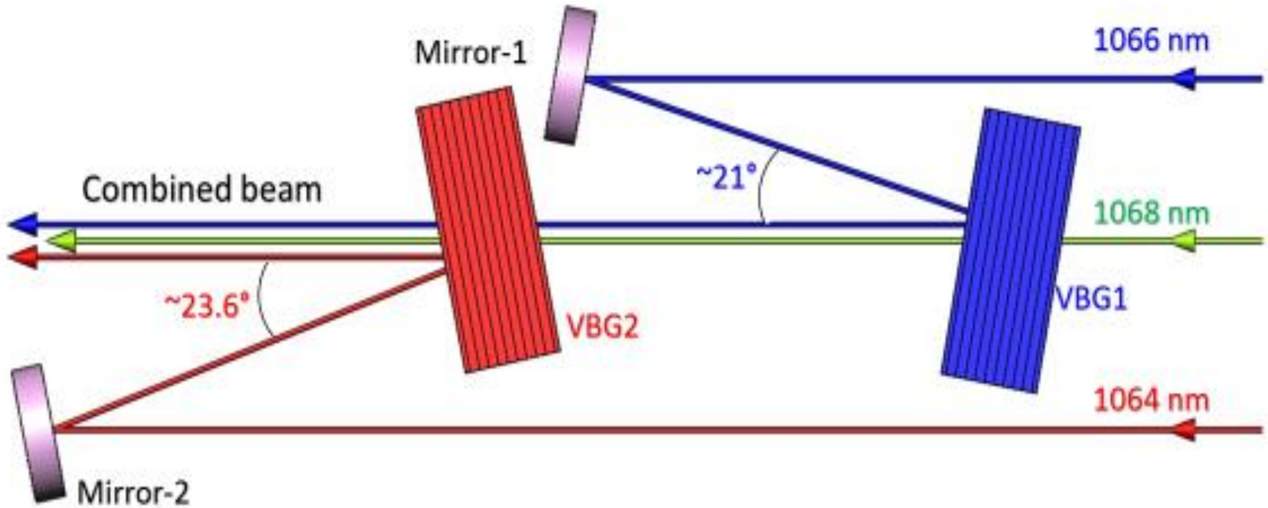
(c) Coherent Beam Combination

- Cheaper at ~$110/W
- Modular solution so if one fails we still have (n-1)/n output power.
- The power can be increased gradually by combining 3, 4 and more low power sources





Scheme to Combine Multi-beams With Different Wavelengths Using Volume Bragg Gratings



Key Elements Required for WBC - 1

Volume Bragg Grating (VBG) is a kind of ultra-narrowband, wavelength-selection filter

Dimensions	**25 x 25 mm**
Wavelength range	**1055 – 1070 nm**
Angle of incidence	**~ 15°**
Diffraction efficiency	**≥ 97%**
Spectral linewidth	**~ 0.8 nm**

Key Elements Required for WBC - 2

Low power source - fiber amplifier (YAM-2000-SM)

Output power	**2000 W**
Input wavelength range	**1055 – 1070 nm**
Input linewidth	**25 GHz**
Output beam quality	**1.07 (Typical), 1.1 (Max)**

2-phase Approach

Phase-1

Achieve 8 kW output power through multi-beam combination scheme

Phase-2

Achieve ~15 kW through combining 8 kW laser beam with the output beams from other multi-kilo-Watt laser sources, such as another fiber laser or thin disk laser

Fiber Amplifier Input Wavelength

– determined by the gain wavelength region of the fiber amplifier

1055 – 1070 nm

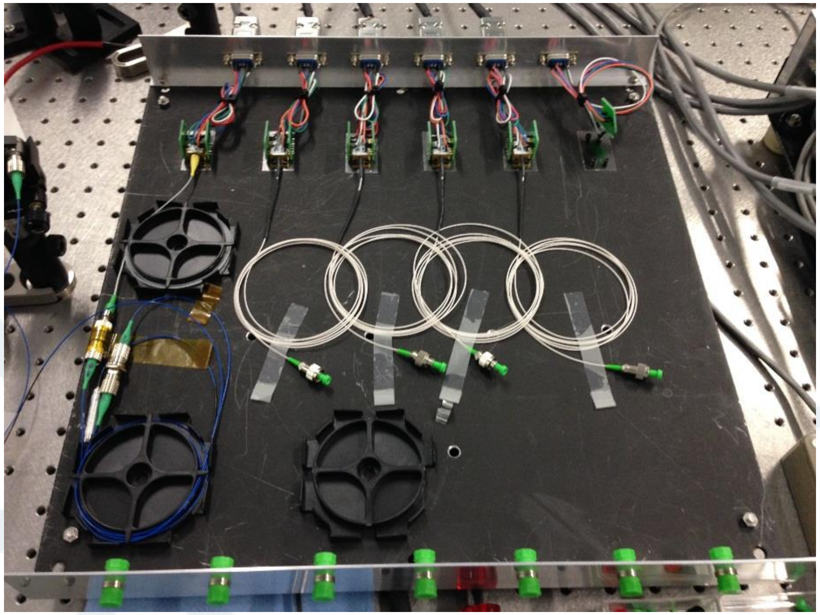
Seed Oscillator Output Wavelengths

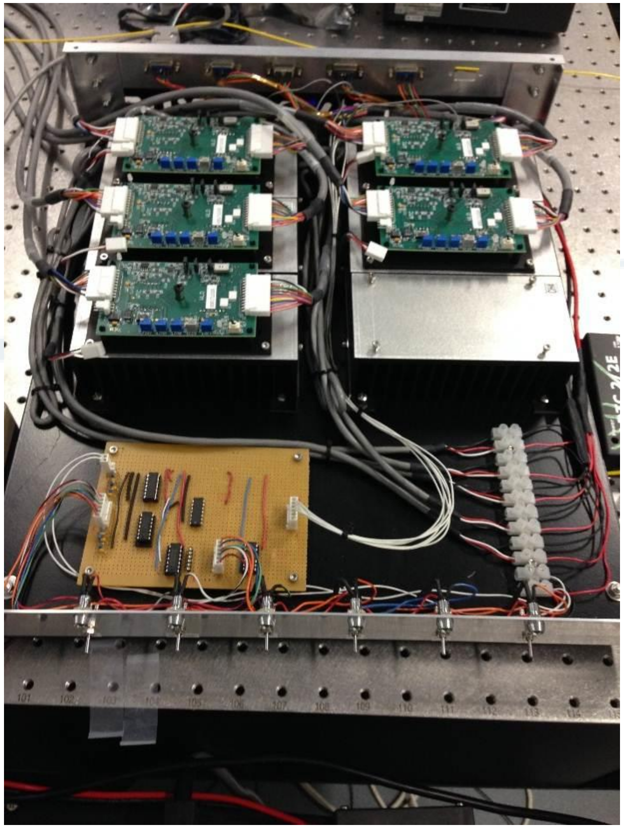
- Channel-1: 1064 nm
- Channel-2: 1062 nm
- Channel-3: 1060 nm
- Channel-4: 1058 nm

Output Spectral Linewidth – determined by the spectral linewidth of the VBG

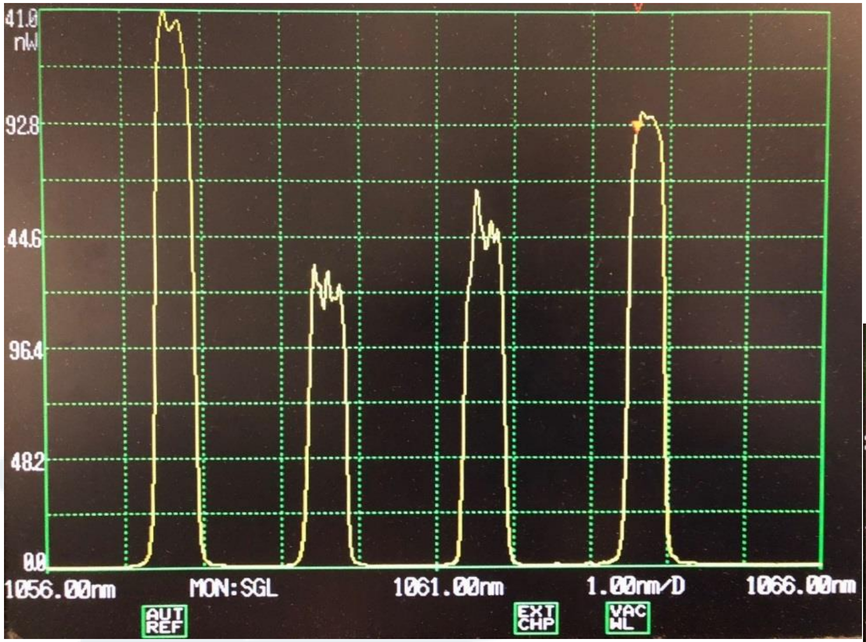
Narrower than 0.8 nm

Fiber Based Seed Oscillator and Power Supply

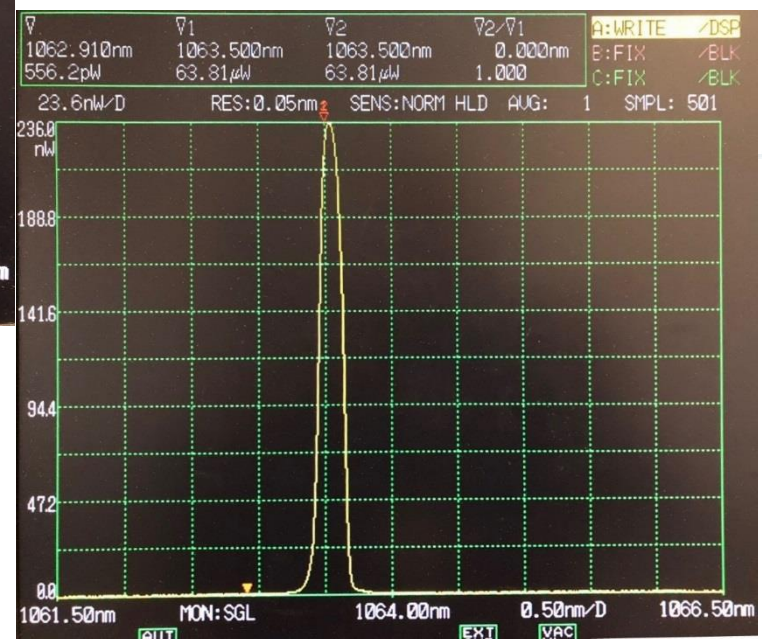




Output Wavelengths and Spectral Linewidth of Seed Oscillator



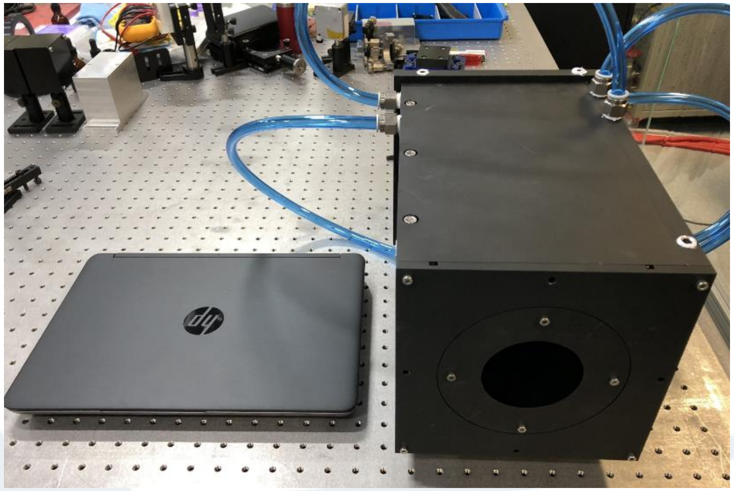
Output power of seed oscillator: ~10 mW



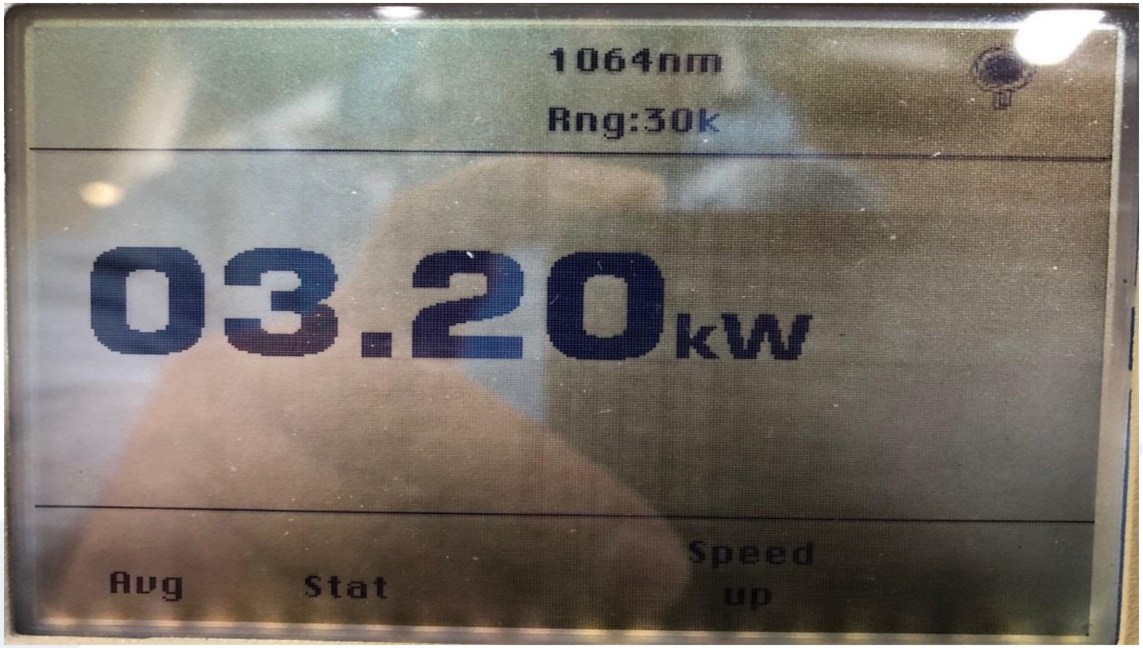
Spectral Linewidth: 0.05 - 0.2 nm

Seed Oscillator, Fiber Amplifier, Power Supplies and Cooling Systems

Liquid Cooled Beam Dump & Power Meter



2-beam Combined Single Mode Output Power : **3200 W** Obtained



Beam combination efficiency:

- Spectral linewidth of seed laser
- VBG temperature

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Thanks for your attention