Monolithic solid-state lasers for spaceflight

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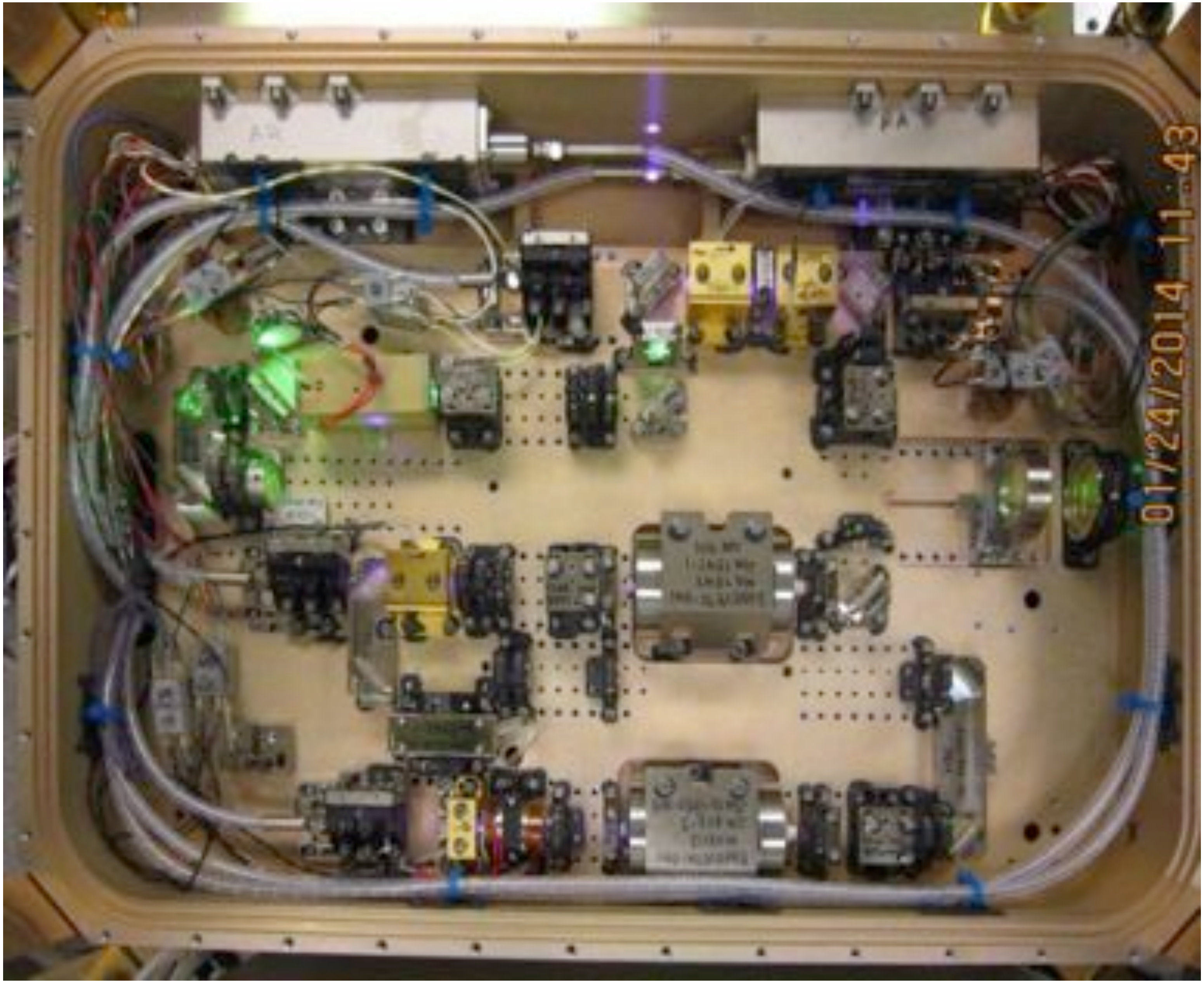
ATLAS laser – is there a "better" way?



Definition

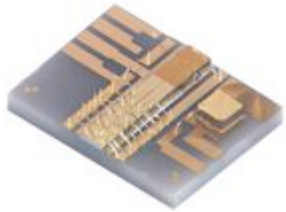
- Monolithic - cast as a single piece OR constituting an undifferentiated and often rigid whole

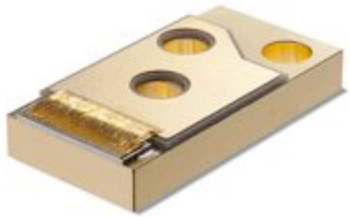
Monolithic laser advantages

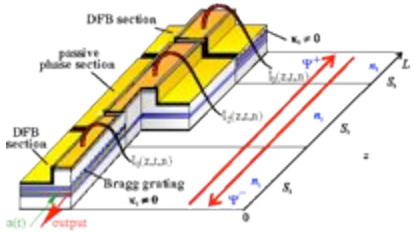
Parameters	Single element monolithic laser and multi-element laser array
Spectral	DFB/DBR helps with spectral narrowing, spectral stability and single frequency operation.
Spatial	Thermal lens and passive q-switching provides soft aperturing to ensure high beam quality
Temporal	Short cavity means short optical pulses
Energy/Power	Design to produce 50 μJ; also per design to produce 8.4 kHz - average power ~0.42W
Repetition Rate	Pump power driven, also affected by Yb concentration, need iterative processes to optimize concentration for gain and rep rate
Passive QS	Discrete SA element or co-dope with Yb in PTR, no high voltages as in Active QS
Coatings	Bragg mirrors serve as high reflector and output coupler, no coating except for AR to minimize Fresnel reflection for pump and lasing wavelength, avoid the issue of optical damage to coating.
Nonlinear Effects	No detrimental nonlinear effects
Reliability	Use highly fiber coupled pump lasers used in telecom industry. Multiple lasers mean losing one laser can still do majority of science - built in redundancy.
Pump configuration	Fiber coupled pumps for compact and robust design. Using microlens array for coupling pump light into laser array.
Laser Cavity	Closed cavity immunes to contamination inside laser cavity, which usually has the highest fluence. Monolithic design to minimize number of components.
Pointing Stability	End gratings formed the lasing axis, thermal lensing and soft aperturing from PQS provides additional pointing stability
Alignment Sensitivity	Monolithic design means robustness. No to low misalignment concerns with laser resonator.
Thermal Control	Will examine the use of embedding loop heat pipes (LHP) or microchannel cooler(MCC) into the laser array for efficient thermal management. LHP has been used successfully in spaceflight lasers and MCC has been used extensively in packaging of high power semiconductor laser arrays

Monolithic Lasers in Use Today

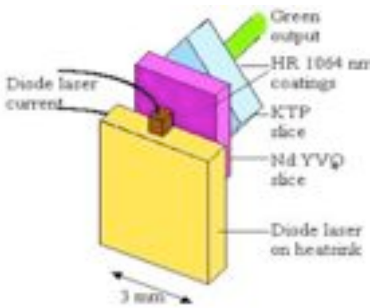
Semiconductor Lasers

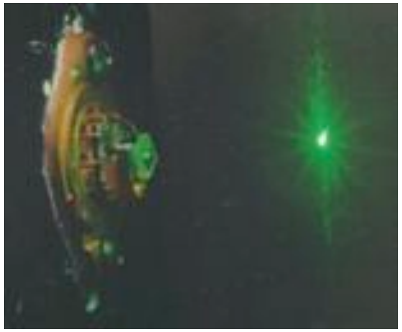




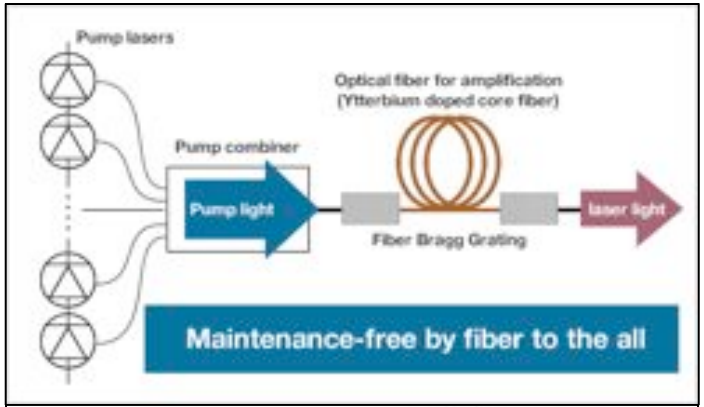


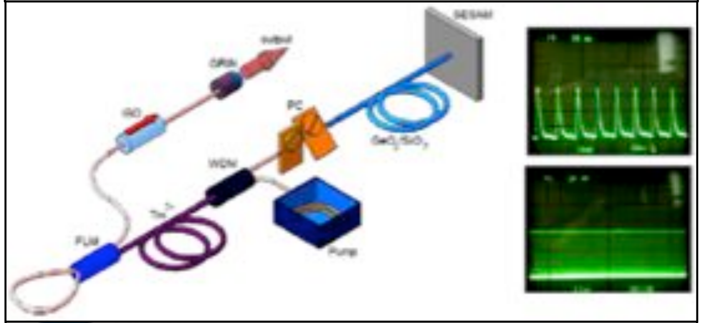
Microchip (Solid State) laser

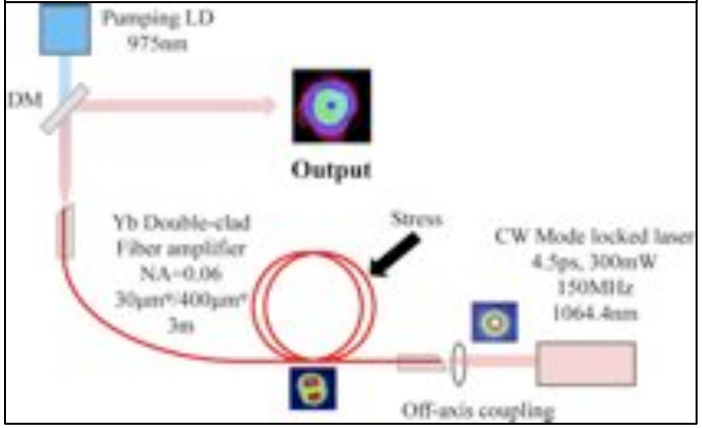




Fiber Lasers







Non-Planar Ring Oscillator (NPRO)

(T. Kane, R. Byer – Stanford U. -1984)

February 1985 / Vol. 10, No. 2 / OPTICS LETTERS 63

Monolithic, unidirectional single-mode Nd:YAG ring laser

Thomas J. Kane and Robert L. Byer

Ginzton Laboratory, Stanford University, Stanford, California 94305

Received October 1, 1984; accepted November 28, 1984

We have built a nonplanar ring oscillator with the resonator contained entirely within a Nd:YAG crystal. When the oscillator was placed in a magnetic field, unidirectional oscillation was obtained with a pump-limited, single-axial-mode output of 163 mW.

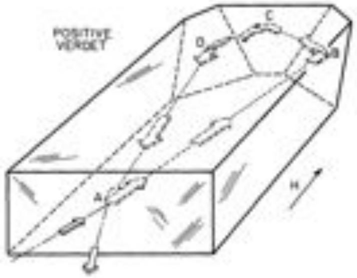


Fig. 1. The MISER laser design. Polarization selection takes place at the curved, partially transmitting face (point A). At points B, C, and D, total internal reflection occurs. A magnetic field *H* is applied to establish unidirectional oscillation. Magnetic rotation takes place along segments *AB* and *DA*. The focused pump laser beam enters the crystal at point A, and the output beam emerges at the same point.

1020 OPTICS LETTERS / Vol. 20, No. 9 / May 1, 1995

Single-frequency *Q*-switched ring laser with an antiresonant Fabry–Perot saturable absorber

B. Braun and U. Keller

Ultrafast Laser Physics, Institute of Quantum Electronics, Swiss Federal Institute of Technology, ETH Hönggerberg-HPT, CH-8093 Zürich, Switzerland

Received January 3, 1995

We passively *Q* switched a monolithic Nd:YAG ring laser [monolithic isolated single-mode end-pumped ring laser (MISER)] using an evanescent-wave coupled antiresonant Fabry–Perot saturable absorber. Single-frequency, 0.7-μJ pulses with a pulse width below 100 ns at an ≈1-MHz repetition rate are demonstrated. Pulse width and repetition rate can be varied by changing the distance and thus the coupling strength between the crystal and the absorber.

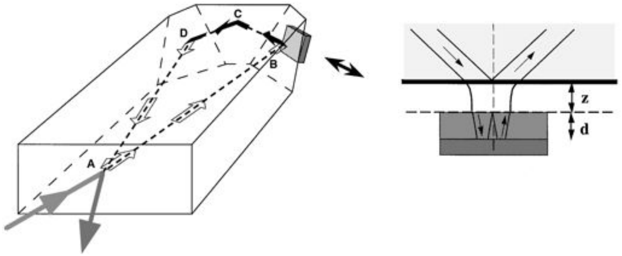


Fig. 1. Layout of the MISER with an A-FPSA coupled to a total-internal-reflection point and (at the right) a schematic of the interface between the MISER and the A-FPSA.

Continuous-Wave (CW) Single-Frequency IR Laser

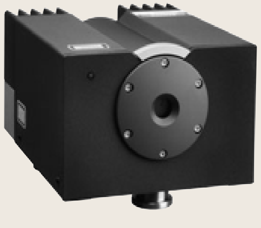
NPRO® 125/126 Series

JDSU

Key Features

- 1319 or 1064 nm outputs available
- Fiber-coupled output
- Proven nonplanar ring oscillator (NPRO) design
- Superior power stability
- Narrow linewidth
- Tunability
- Ease of use
- Ideal for OEM applications

COHERENT.



Features

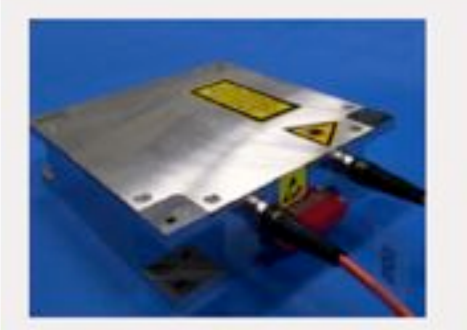
- Non-planar ring oscillator (NPRO) technology for ultra-stable operations
- Diffusion bonded, quasi monolithic cavity for ultra-stable emission
- Q-switched operation with Cr^{4+}:YAG saturable absorber crystal
- Low noise control electronics
- User-installed, turn-key operation

250 mW, 50 μJ at 5 kHz

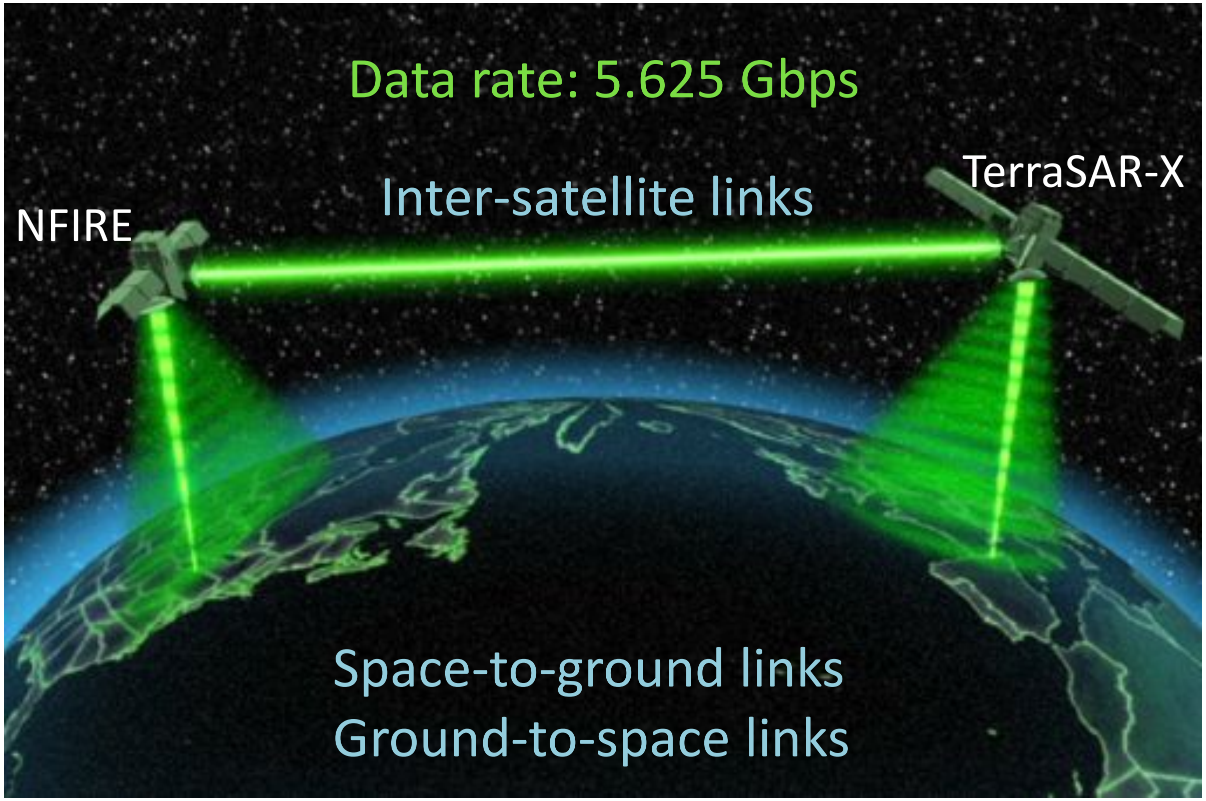
Space-qualified NPRO – Tesat Inc. - Germany
Flown on joint USA-German
Laser communication NFIRE (USA-DoD) to TerraSAR-X (Germany) (2008)

Tesat Inc.

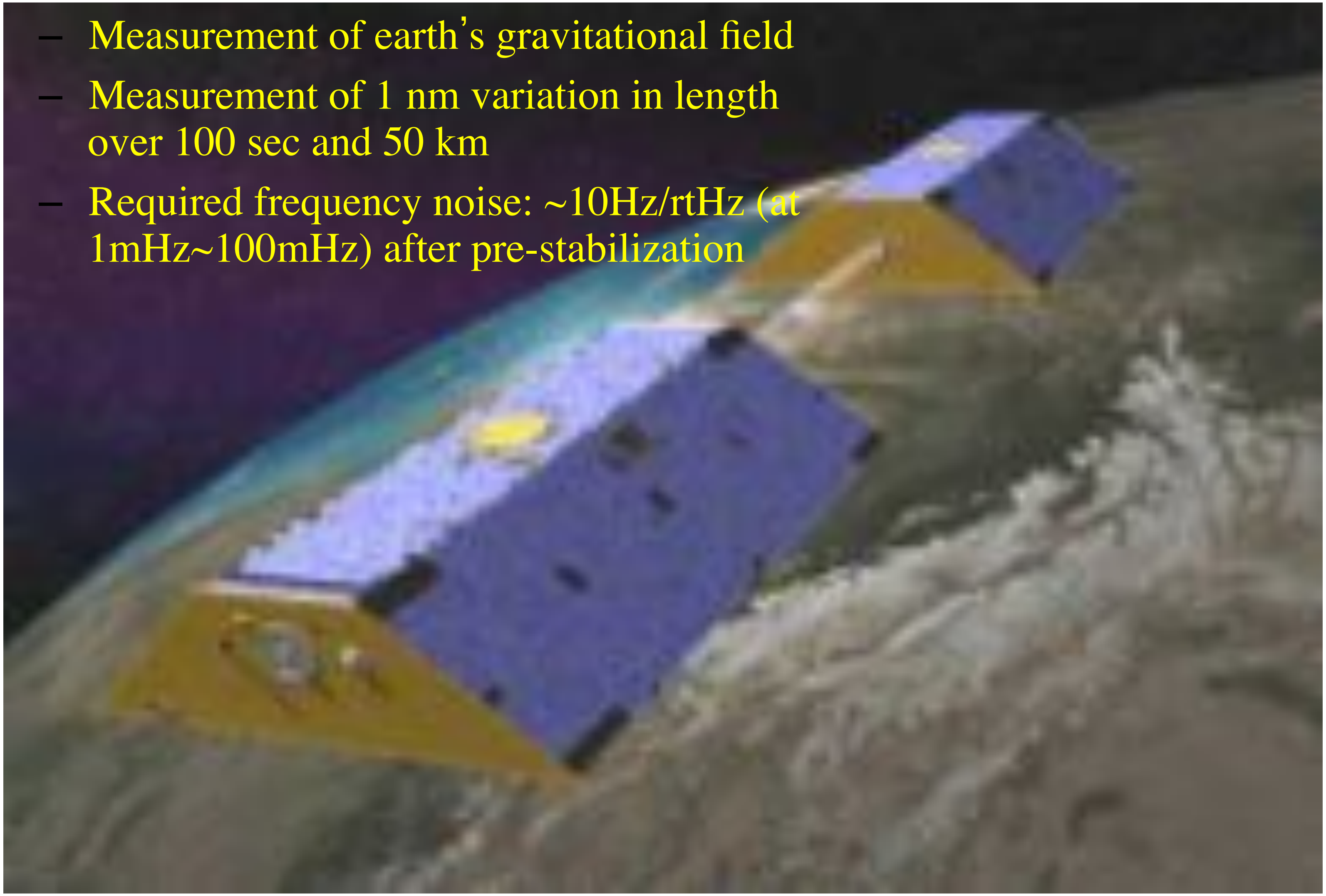
space-qualifie



W Yb fiber amplifier



GRACE follow-on (Gravity Recovery And Climate Experiment) NASA-JPL



- Measurement of earth's gravitational field
- Measurement of 1 nm variation in length over 100 sec and 50 km
- Required frequency noise: ~10Hz/rtHz (at 1mHz~100mHz) after pre-stabilization

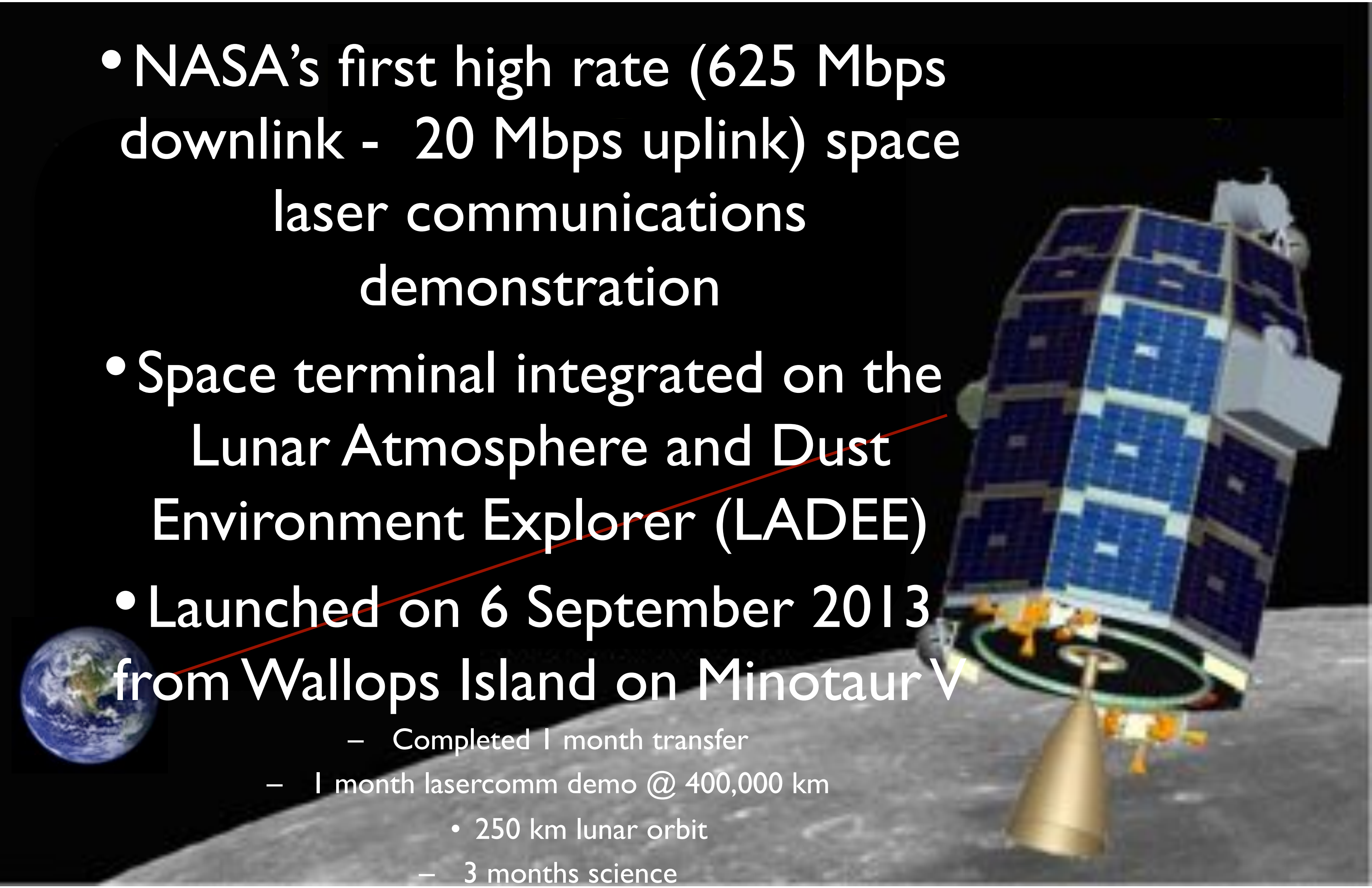
GRACE-FO Laser (Baseline)

- Non-planar ring oscillator (NPRO) Nd:YAG laser provides tunability for locking to cavity
  - Laser wavelength adjusted by changing dimensions of YAG crystal using PZT glued to crystal and thermal adjustment
- Space-qualified NPRO laser available from Tesat Spacecom

NPRO laser head

Laser pump diode assembly

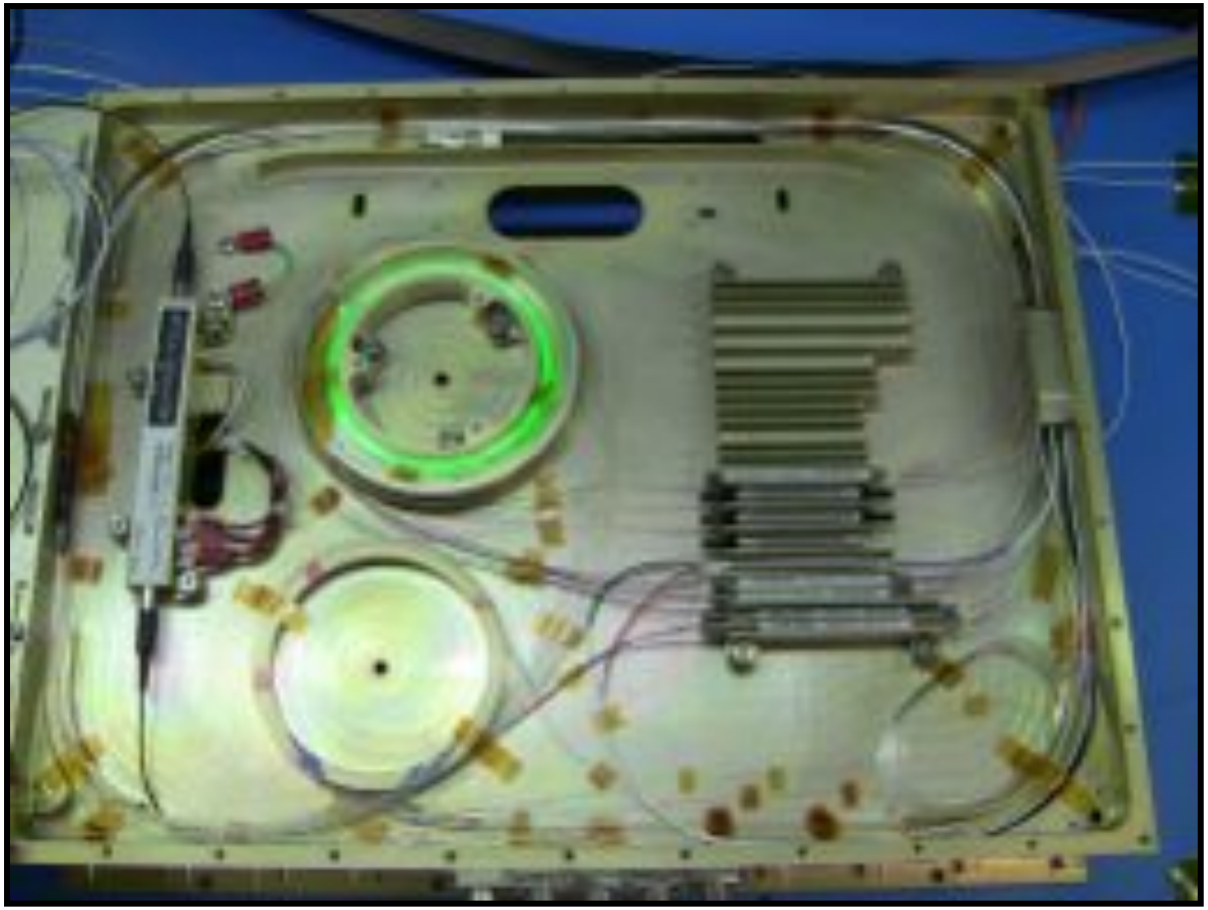
Lunar Laser Communications Demonstration (LLCD)



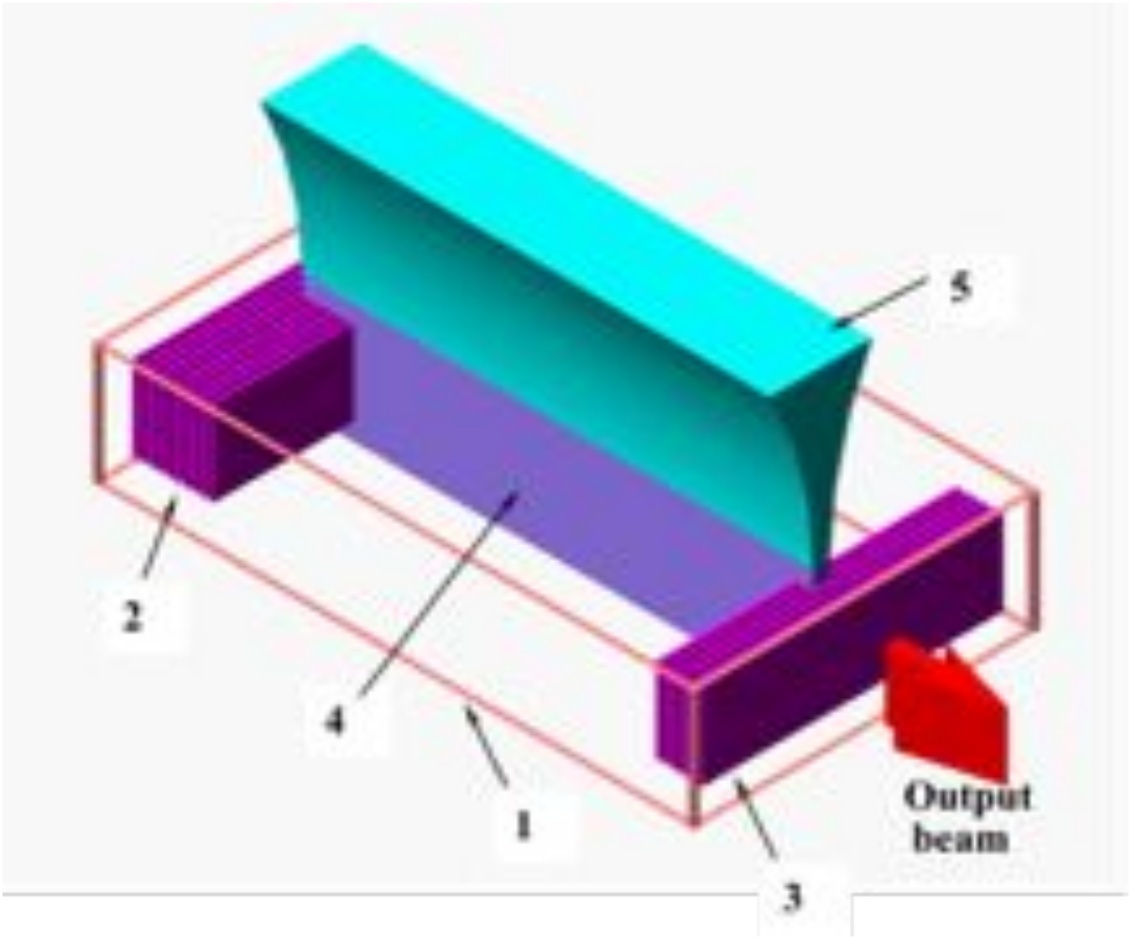
- NASA’s first high rate (625 Mbps downlink - 20 Mbps uplink) space laser communications demonstration
- Space terminal integrated on the Lunar Atmosphere and Dust Environment Explorer (LADEE)
- Launched on 6 September 2013 from Wallops Island on Minotaur V
  - Completed 1 month transfer
  - 1 month lasercomm demo @ 400,000 km
    - 250 km lunar orbit
  - 3 months science

LLCD diode oscillator/fiber amplifier MOPA laser transmitter

(built by MIT-LL)

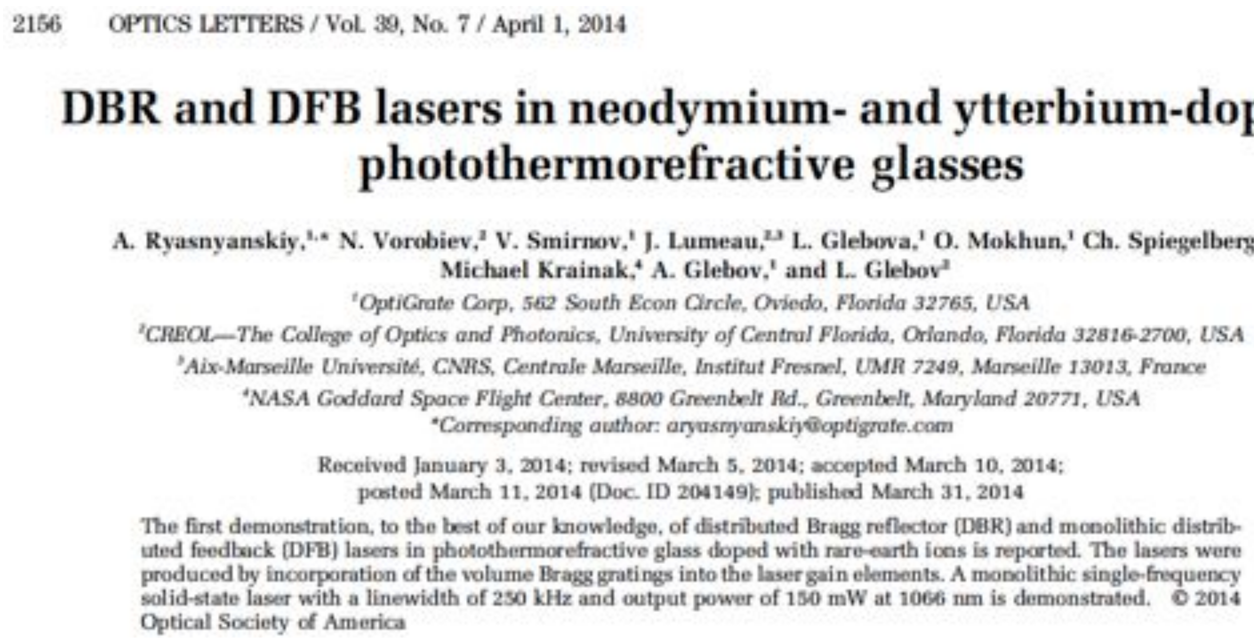


Solid state monolithic laser with Volume Bragg Grating mirrors



Possible geometry of a monolithic solid state laser in PTR glass doped with rare earth ions. 1 - rear-earth doped PTR-glass wafer; 2 – high efficiency VBG as a feedback coupler; 3 – low efficiency VBG as an output coupler; 4 - pumped volume in active PTR-medium; 5 - pumping beam from LD bars.

Monolithic Yb:glass CW solid state laser



2156 OPTICS LETTERS / Vol. 39, No. 7 / April 1, 2014

DBR and DFB lasers in neodymium- and ytterbium-doped photothermorefractive glasses

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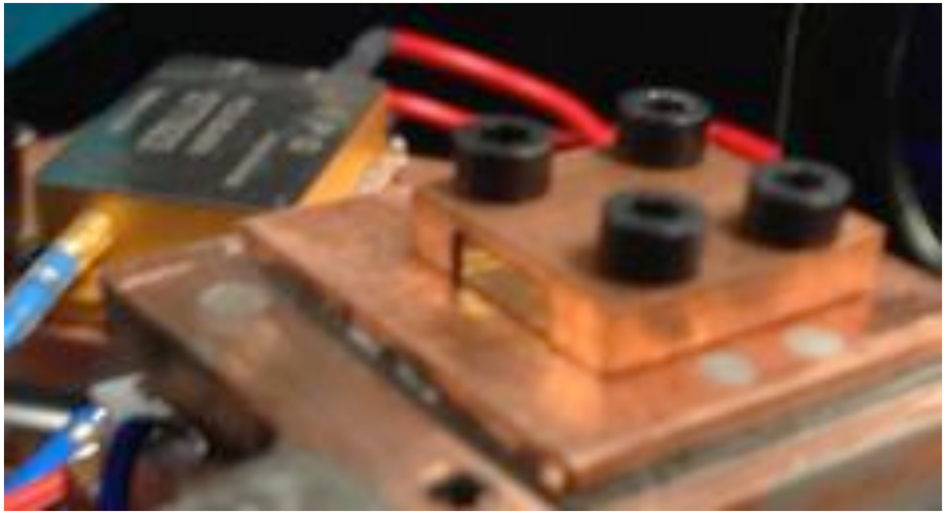
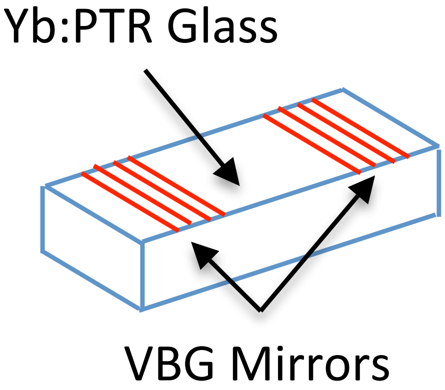
The first demonstration, to the best of our knowledge, of distributed Bragg reflector (DBR) and monolithic distributed feedback (DFB) lasers in photothermorefractive glass doped with rare-earth ions is reported. The lasers were produced by incorporation of the volume Bragg gratings into the laser gain elements. A monolithic single-frequency solid-state laser with a linewidth of 250 kHz and output power of 150 mW at 1066 nm is demonstrated. © 2014 Optical Society of America





Yb:PTR Glass

VBG Mirrors

Making lasers with a laser

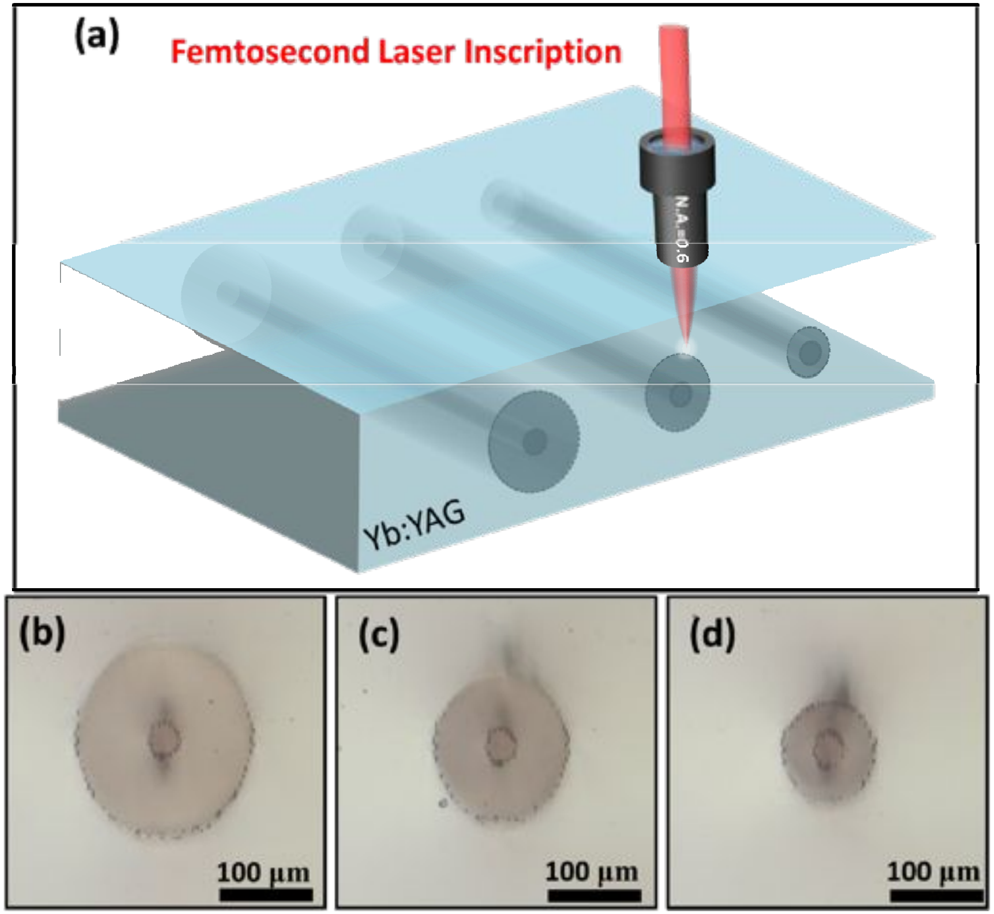
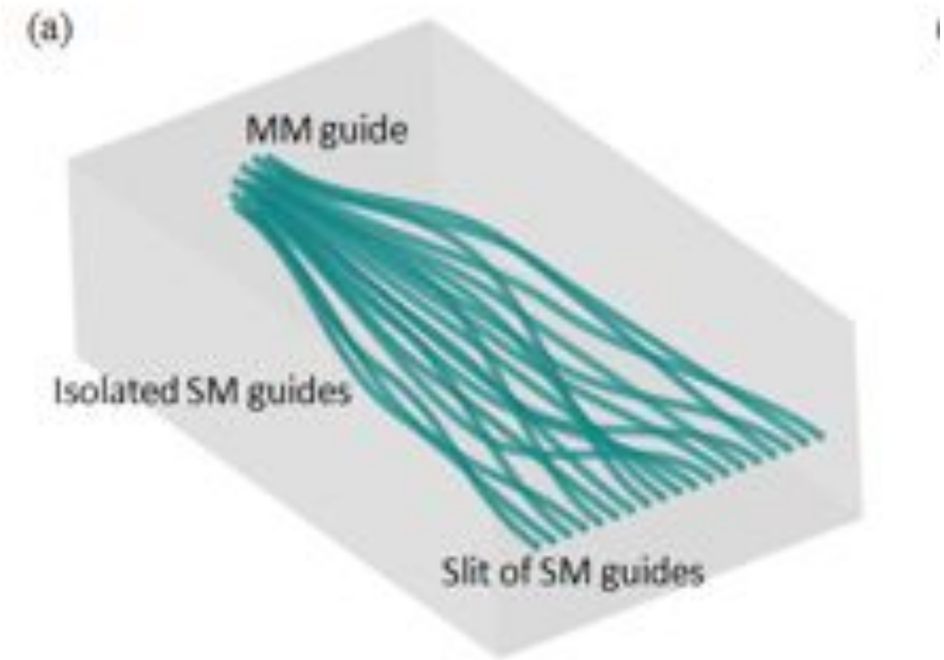


Fig. 1. (a) Schematic of fs-laser inscription process in Yb:YAG ceramics for the double cladding waveguides, and their cross sectional microscope images, which consist of tubular central structures with 30 µm diameter, and concentric larger size tubular claddings with diameters of (b) 200, (c) 150 and (d) 100 µm, respectively.

1 May 2013 | Vol. 3, No. 5 | DOI:10.1364/OME.3.000645 | OPTICAL MATERIALS EXPRESS 647

Double clad monolithic laser
Proposed pumping scheme with photonic lantern



4 November 2013 | Vol. 21, No. 22 | DOI:10.1364/OE.21.027197 | OPTICS EXPRESS 27197

Making lasers with a laser - Pulsed laser (SEmiconductor Saturable Absorber Mirror – SESAM)

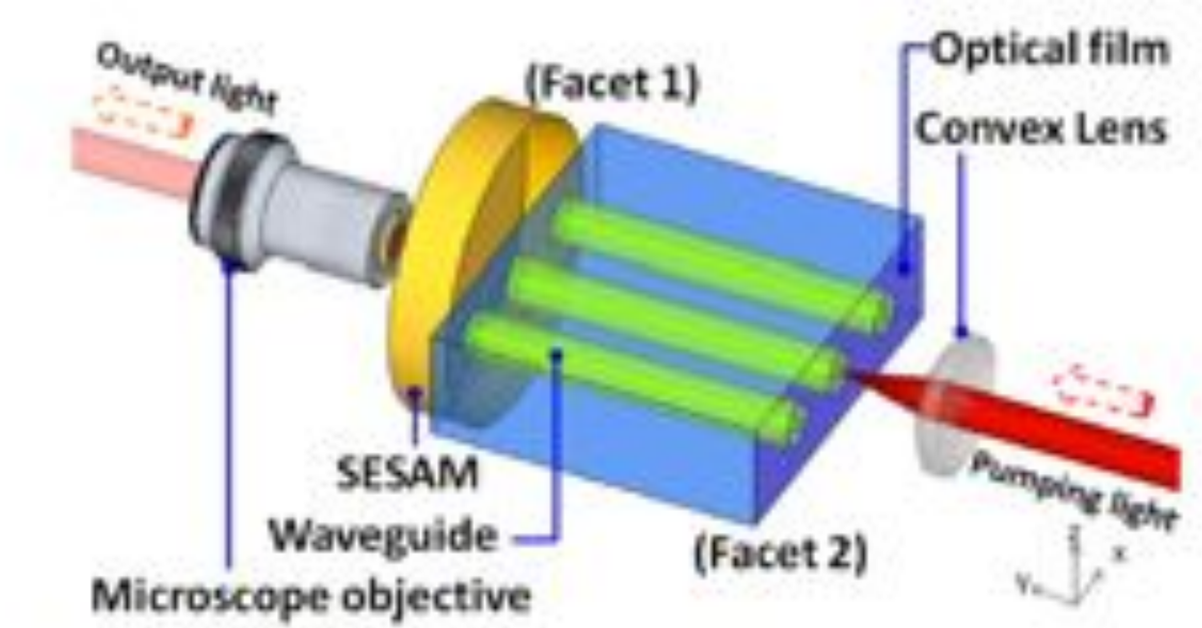
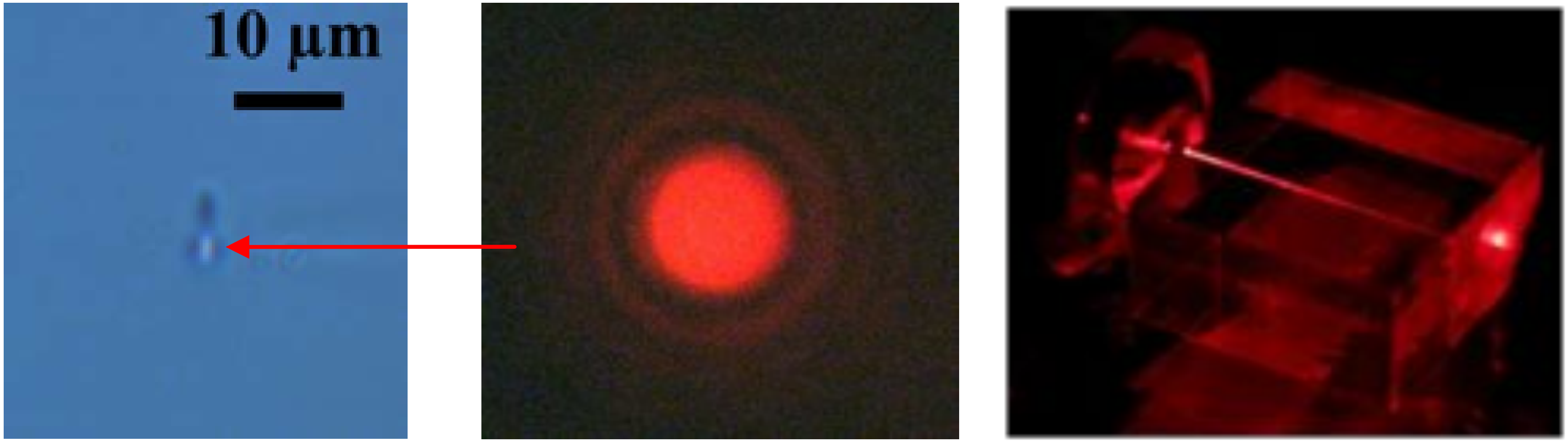


Fig. 2. Schematic plot of the experimental setup for the pulsed laser generation in the double-cladding Nd:YAG ceramic waveguides.

Directly written optical waveguides - Results

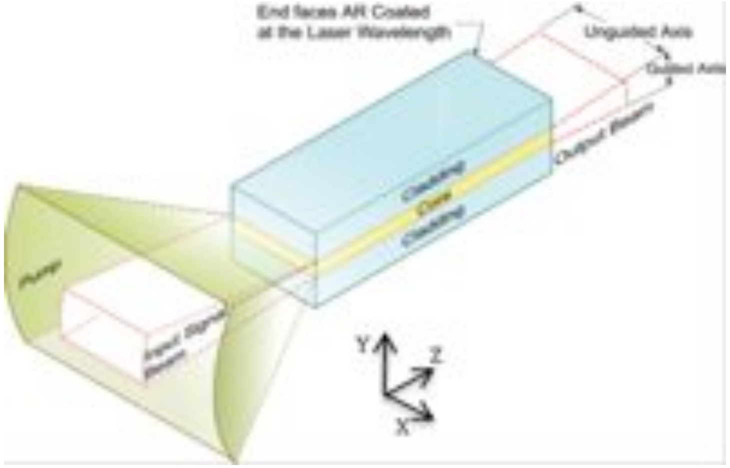
Figure 3. Optical microscope images of cross sections (left) and top views (right) of the fused silica waveguides written with different pulse energies (F_{ave} is 80.4 kJ/cm^2,54.3 kJ/cm^2 and 45.7 kJ/cm^2 from top to bottom) and constant writing speed of 0.5 mm/s. Arrows indicate the laser beam incident direction or writing direction.

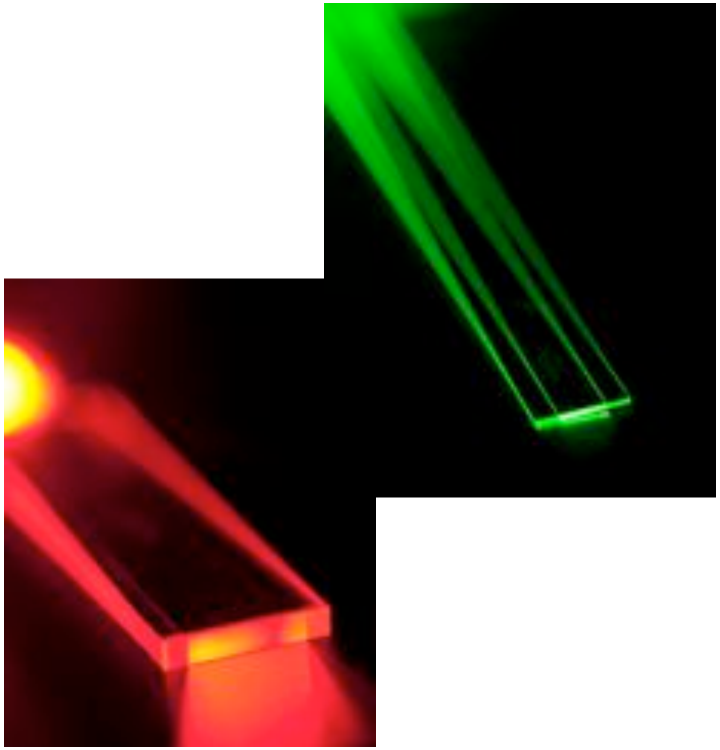


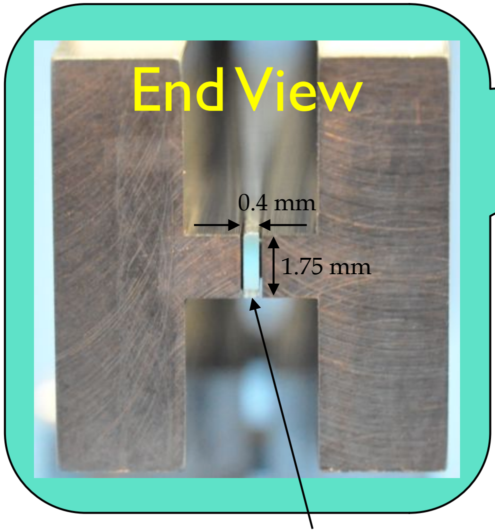
(a) (b) (c)

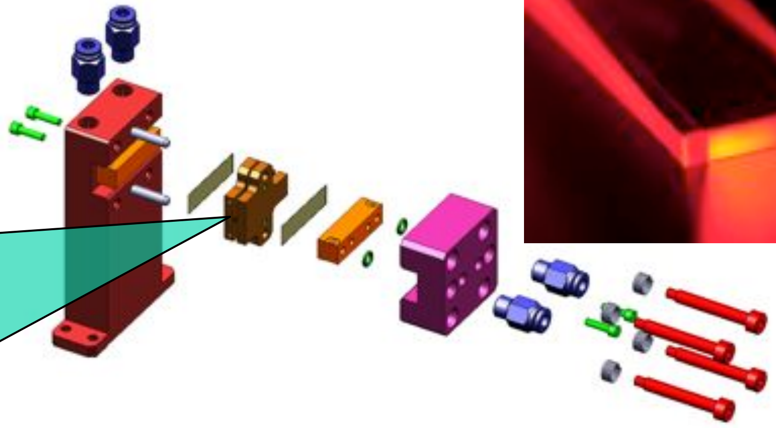
Figure 5. (a) Optical microscope view of cross section fs-written borosilicate glass waveguide (F_{ave}=478 J/cm^2 with 10 mm/s); (b) Near-field mode profile of 650 nm red laser beam of the same waveguide as (a); (c) Camera view of red laser beam coupling of fs written waveguide (F_{ave}=56.5 kJ/cm^2 with 0.1 mm/s).

Planar Waveguide Amplifier for Power Scaling









35 mm long laser amplifier for a 16 W laser at IR
(~9 W in green – same as ATLAS laser)

Yb:YAG waveguide core, 40 μm thick, sandwiched by undoped YAG

Conclusions

- Traditional discrete component laser transmitters
  - Large amount of optics and opto-mechanical parts
  - Open cavity: more susceptible to contaminations
  - Sensitive to misalignment
- Monolithic laser
  - Single component cavity
  - Closed cavity – less susceptible to contaminations
  - Insensitive to misalignment
  - Approach 1: “Bulk” monolithic laser
    - Volume Bragg Grating with doped glass monolithic laser
    - VBG recorded in glass using interference fringes
  - Approach 2: Waveguide monolithic laser
    - Use femtosecond laser as tool to generate waveguides and gratings;
    - Directly written waveguide and gratings
- NASA needs US industry and University help in developing robust, monolithic high power lasers for future space laser instruments