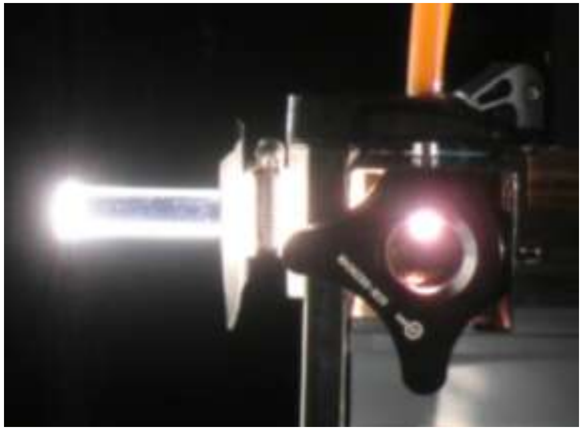
Improvement in solar-pumped Nd:YAG laser beam brightness



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PRESENTATION TOPICS:

1. SOLAR LASER APPLICATIONS
2. LASER BEAM BRIGHTNESS
3. STATE OF ART
4. SOLAR-PUMPED Nd:YAG LASER SYSTEM
5. EXPERIMENTAL RESULTS
6. CONCLUSIONS
7. PUBLICATIONS

1. SOLAR LASER APLICATIONS

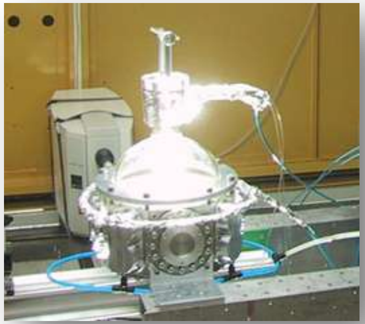
Solar-pumped lasers have gained an ever-increasing importance in recent years.

Compared to electrically powered lasers, solar laser is much **simpler** and more **reliable** due to the **complete elimination of the electrical power generation and conditioning equipments**.

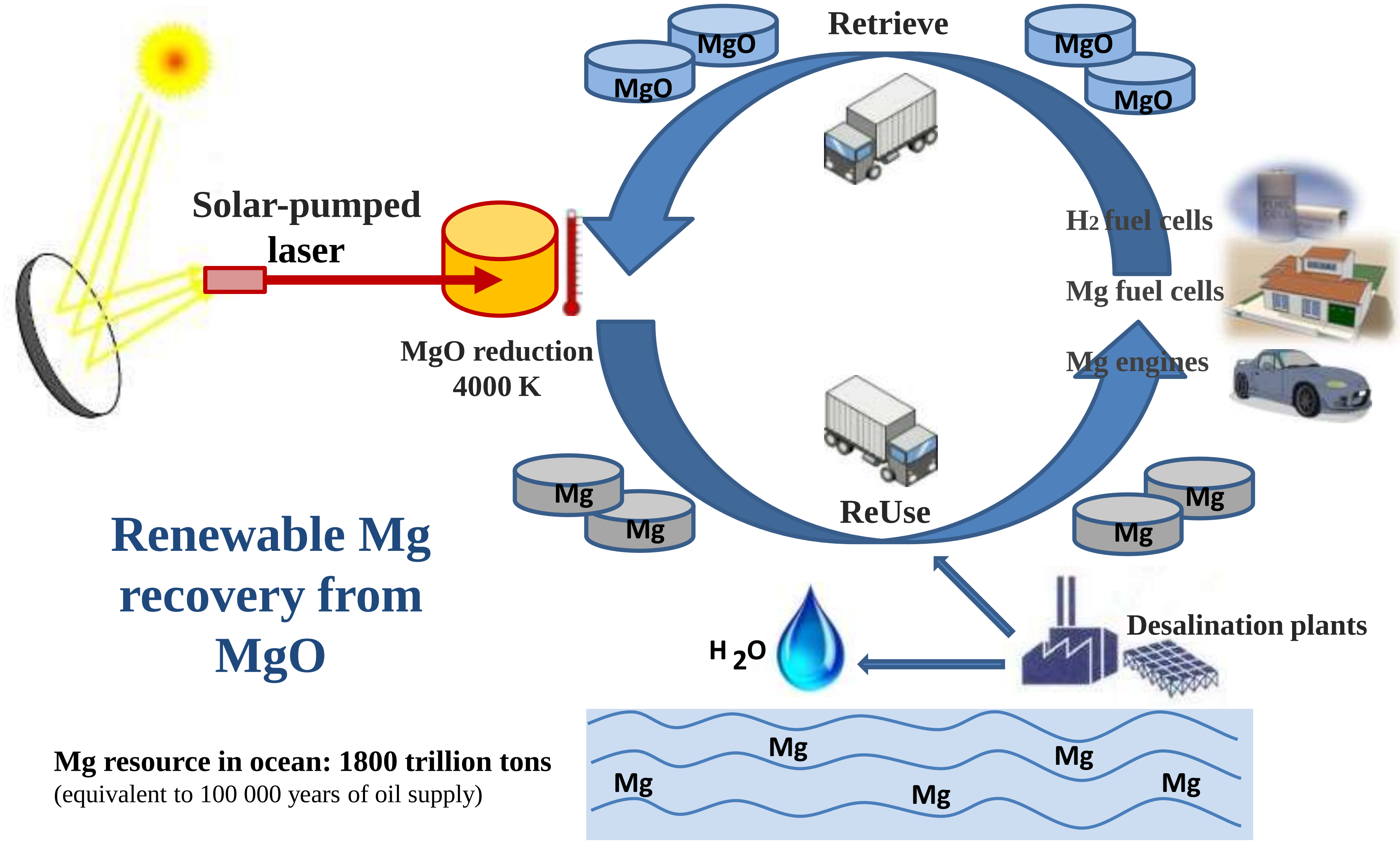
Space to earth power transmission

Free space laser communications

High-temperature material processing



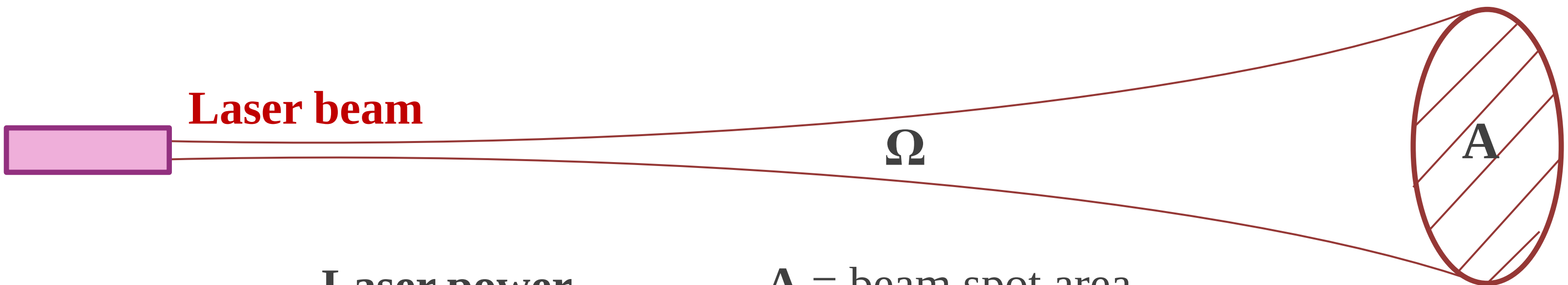
1. SOLAR LASER APLICATIONS



Renewable Mg recovery from MgO

Mg resource in ocean: 1800 trillion tons
(equivalent to 100 000 years of oil supply)

2. LASER BEAM BRIGHTNESS



$$\text{Brigthness} = \frac{\text{Laser power}}{A\,.\Omega}$$

A = beam spot area

Ω = solid angle divergence $\propto$ $(M_x.M_y)^2$

Beam quality factors

$$\text{Figure of merit B} = \frac{\text{Laser power}}{(M_x.M_y)^2}$$

✓ **Solar-pumped lasers with high beam brightness become hence very promising for tight focusing in magnesium reduction process.**

✓ Other energy cycles and renewable nano-materials production can also benefit from using solar-pumped lasers.

3. STATE OF ART

1964 The **first** cw 1 W **solar-pumped Nd:YAG laser** was reported by Young [1]

Since then researchers have been exploiting parabolic mirrors and Fresnel lenses systems to attain enough concentrated solar radiation at focal point and several pumping schemes have been proposed for enhancing solar laser output performance [2-6]:

1999 **6.7 W/m^2 collection efficiency** has been achieved in Weizmann Institute by pumping a Nd:YAG rod through **heliostat – parabolic mirror system** [6]

2007 The progress with **Fresnel lenses** and **chromium co-doped Cr:Nd:YAG ceramic laser medium** [9] has resulted in **18.7 W/m2 collection efficiency**, revealing a promising future for the renewable recovery of Mg from MgO [7].

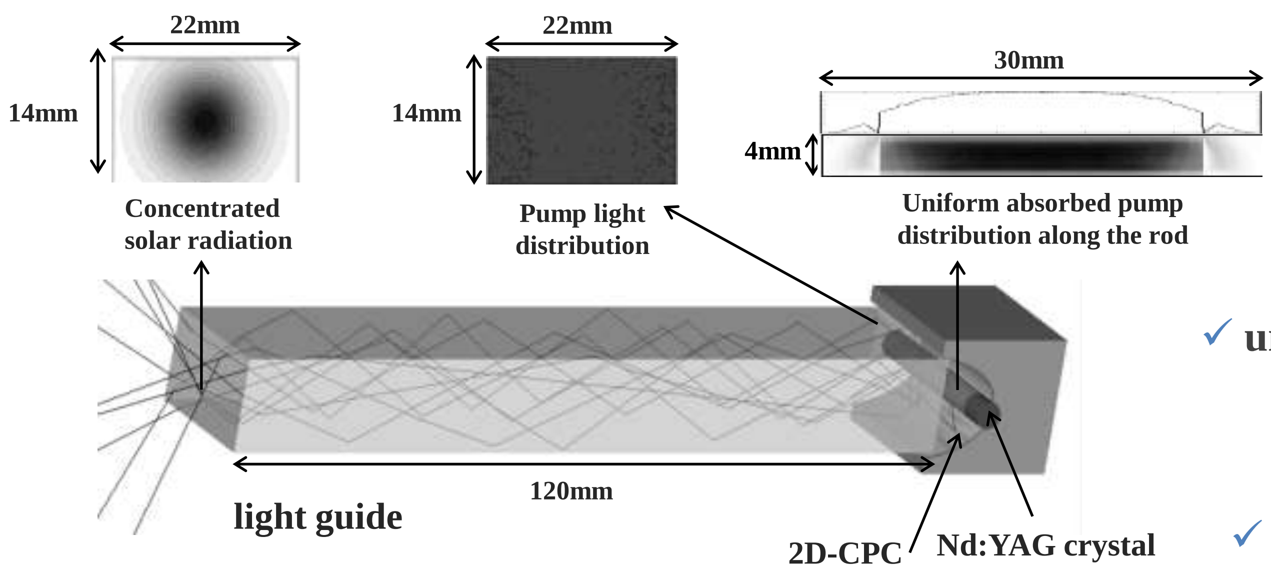
2011 **19.3 W/m^2 collection efficiency** has been reported in **FCT-UNL** by utilizing an economical **Fresnel lens** and the most-widely used **Nd:YAG single-crystal rod** [8].

2011 The **record collection efficiency for solar laser pumped through heliostat – parabolic mirror** was improved by us to **9.6 W/m^2** in 2011 at the PROMES-CNRS, in Odeillo France. **Record-high brightness figure of merit** of has been registered.

[1] C. W. Young, Appl. Opt. 5 (1966) 993-997. [2] H. Arashi et al., Jpn. J. Appl. Phys. 23 (1984) 1051-1053. [3] M. Weksler and J. Shwartz, IEEE J. Quantum Electron. 24 (1988) 1222-1228. [4] R. M. J. Benmair et al, Opt. Lett. 15 (1990) 36-38. [5] V. Krupkin at al., in: Proceedings of SPIE 2016 (1993) 50-60. [6] M. Lando et al., Opt. Commun. 222 (2003) 371-381. [7] T. Yabe et al., Appl. Phys. Lett. 90 (2007) 261120-261120-3. [8] D. Liang and J. Almeida, Opt. Express 19 (2011) 26399-26405. [9] J. Almeida, D. Liang and E. Guillot, Opt. Laser Technol. **44**, 2115-2119 (2012).

4. SOLAR-PUMPED Nd:YAG LASER SYSTEM

Fused silica light guide with tracking error compensation capacity



- 76% transmission efficiency

✓ beam homogenizer

✓ uniform pump light distribution

⇓

✓ stable absorbed pump power profile and laser power

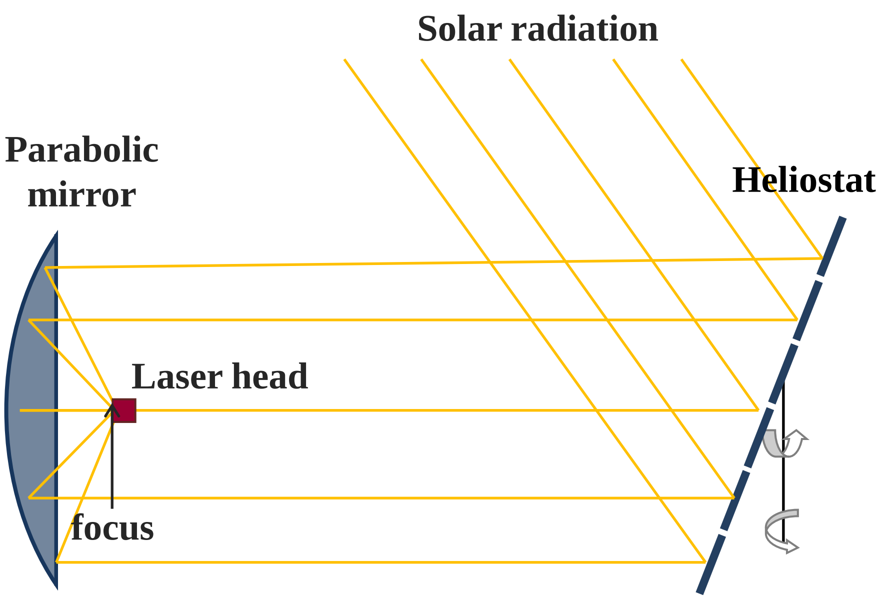
✓ reduction of the hot spots within the laser rod

Fused silica material

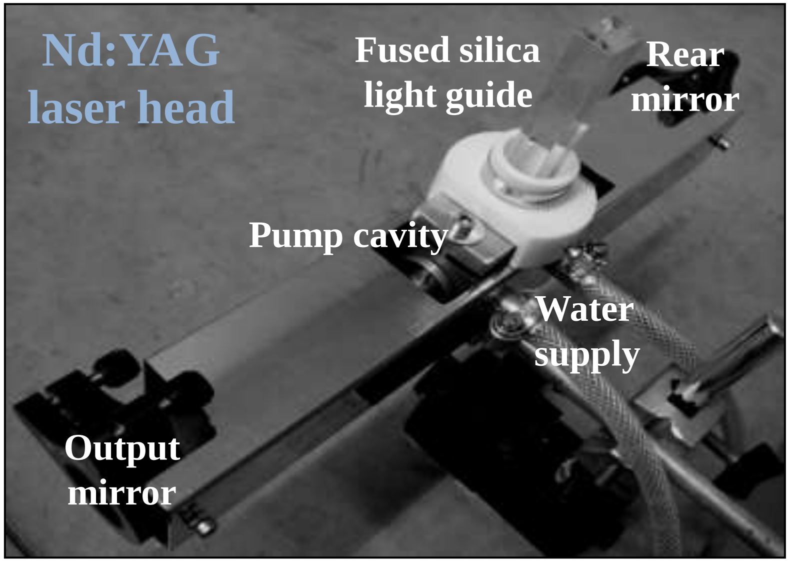
✓ transparent over the Nd:YAG absorption spectrum

✓ low coefficient of thermal expansion and resistant to scratching and thermal shock

4. SOLAR-PUMPED Nd:YAG LASER SYSTEM



PROMES-CNRS
2m diameter solar concentrator

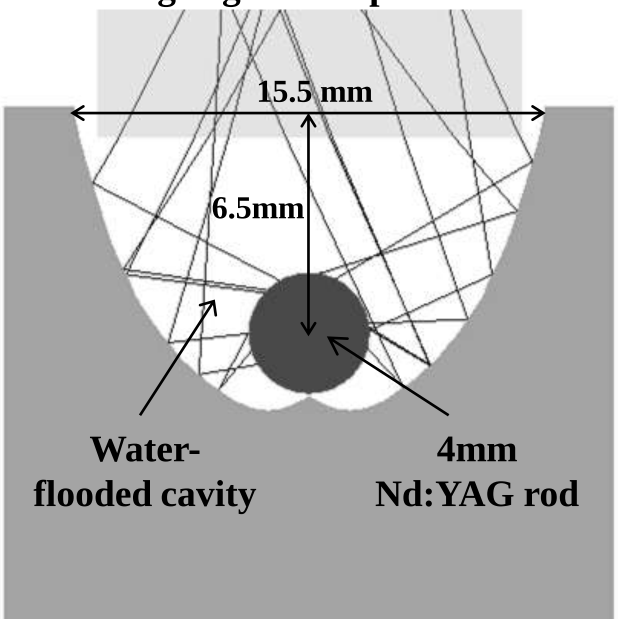


- The laser head is mounted on an automatic X-Y-Z axis mechanical support.

- The concentrated solar radiation is firstly collected by the light guide with rectangular cross-section

4. SOLAR-PUMPED Nd:YAG LASER SYSTEM

Modified 2D-CPC pump cavity



Non-imaging secondary concentrators concentrates **sunlight to intensities approaching the theoretical limit** → Compound parabolic concentrator **(CPC)**

Edge-ray design methods affect the laser beam quality
.

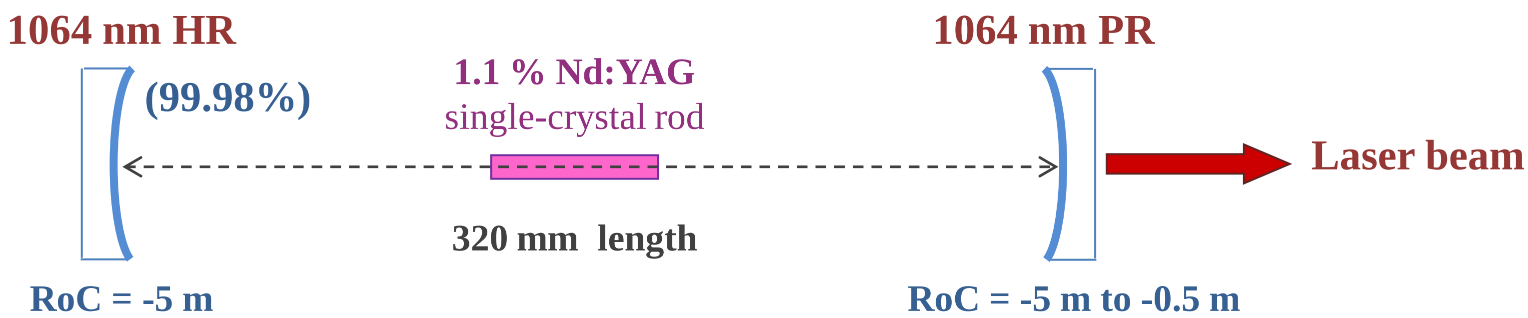
improve the absorbed pump distribution

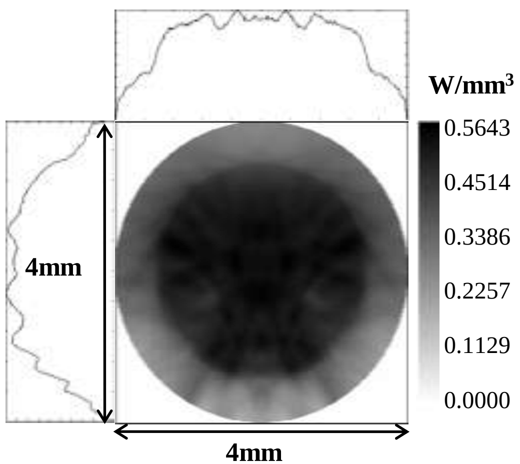
The **modified 2D-CPC cavity** is **more efficient for coupling of the rays with high incidence angles into the center of the laser rod**, leaving aside the rays with low incidence angles which contribute to only a small fraction of the total solar power at the focus.

ZEMAX ray-tracing analysis → Optimization of pumping parameters

LASCAD laser cavity analysis →Optimization of laser beam parameters

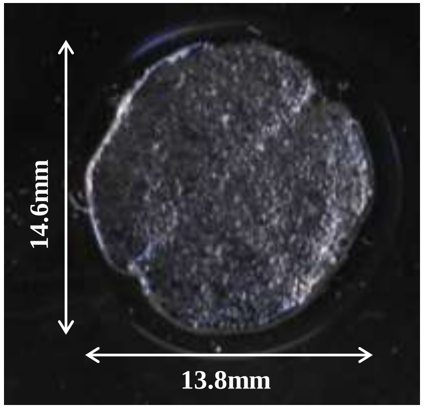
5. EXPERIMENTAL RESULTS





Near top-hat pump profile

in ZEMAX analysis

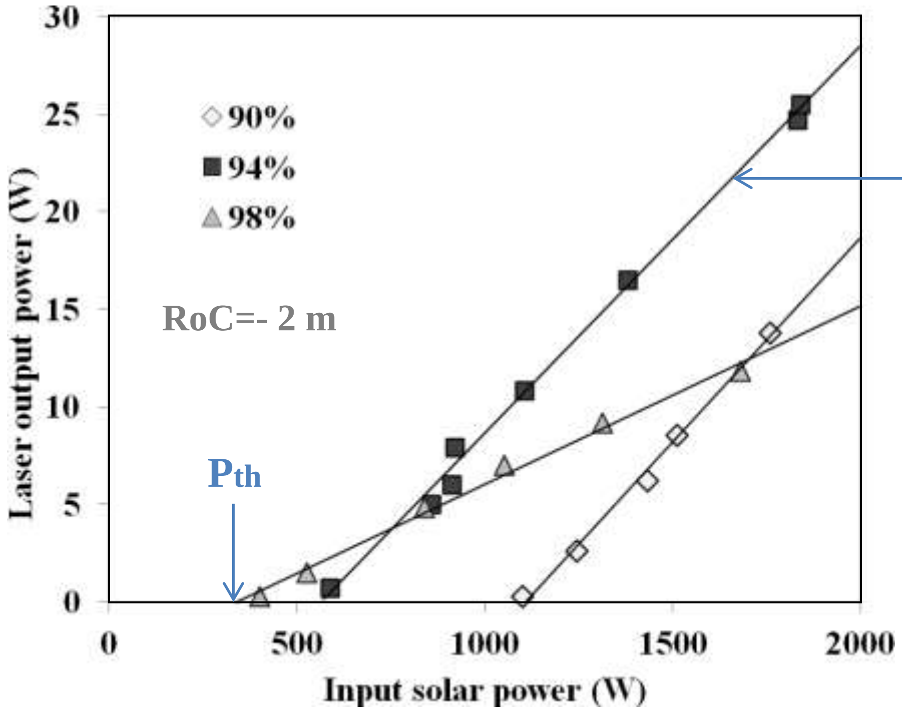


Laser beam profile

1.6 m away from the output mirror

RoC = - 2 m

5. EXPERIMENTAL RESULTS



(at the focus)

2.2 % slope efficiency

P_{th}~ 400 W

Maximum laser power = 27.7 W
(RoC=-0.8 m)

Record collection efficiency for heliostat – parabolic mirror system

$$\frac{\text{Laser power}}{\text{Collection area}} = 9.6\ W/m^2$$

- Two sliding doors and a shutter with motorized blades are used to regulate the incoming solar power from the heliostat.
- To achieve the maximum laser power, the shutter is totally removed.

5. EXPERIMENTAL RESULTS

Table 1. Measurements of the laser performance

RoC (m)	**-0.5**	**-0.8**	**-1**	**-2**	**-5**
Laser Power					
Laser output power (W)	23.6	**27.7**	27.3	25.5	24.7
Slope efficiency (%)	1.9	2.2	2.1	2.0	1.9
Laser Beam Quality					
M_x^2	24.5	12.3	12.3	9.2	8.9
M_y^2	29.7	14.1	13.2	10.0	9.6
Figure of merit B (W)	3.2×10^{-2}	1.6×10^{-1}	1.7×10^{-1}	2.8×10^{-1}	**2.9×10^{-1}**
Improvement over the previous record [8](%)	37	186	197	326	337

[8] D. Liang and J. Almeida, Highly efficient solar-pumped Nd:YAG laser, Opt. Express 19 (2011) 26399-26405.

6. CONCLUSIONS

- The **radiation coupling and homogenization capacity of the fused silica light guide** is combined with the **focusing properties of the modified 2D-CPC cavity** to provide the **efficient side-pumping** to the 4 mm diameter rod.

- **2.2 % slope efficiency** is reached.

- Record collection efficiency of **9.6 W/m^2** for solar laser pumped through heliostat - parabolic mirror system was attained.

- **Laser beam brightness figure of merit** B was three times higher than that of the most recent solar-pumped Nd:YAG laser by a Fresnel lens.

- The introduction of the rectangular cross-section light guide has also ensured a more **stable laser emission** than previous pumping schemes.

- The solar-pumped Nd:YAG laser system could provide an **effective solution for attaining high quality solar laser beam, essential for both tight focusing in high temperature material research and space applications**.

7. PUBLICATIONS

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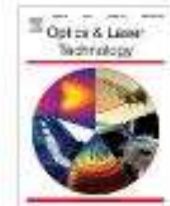

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