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Improved conduction cooled compact laser for LIBS – Raman instruments

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ABSTRACT

Based on ChemCam/SuperCam heritage, a laser with improved performances is built on a table top set-up. The optical configuration is implemented into new lasers proposed for next generation of LIBS – Raman instruments.

Keywords: diode pumped, space qualified solid state laser, ChemCam, SuperCam

1. INTRODUCTION

This communication describes an improved conduction cooled solid state laser for LIBS – Raman instruments. This laser is based on ChemCam laser aboard Curiosity rover and on SuperCam laser whose Flight Model is currently being integrated on SuperCam Instrument for Mars 2020 rover.

2. CHEMCAM LASER

Thales has developed for ChemCam instrument a diode pumped laser, emitting high energy laser pulses (30 mJ/5 ns) at 1067 nm with good beam quality (M2 < 2). These performances are particularly suited for planetology applications, as they are maintained over large temperature ranges without thermal regulation. This laser was qualified in stringent mechanical and thermal environments. It has been used for LIBS analysis on Mars for more than 6 years and is still in operation.

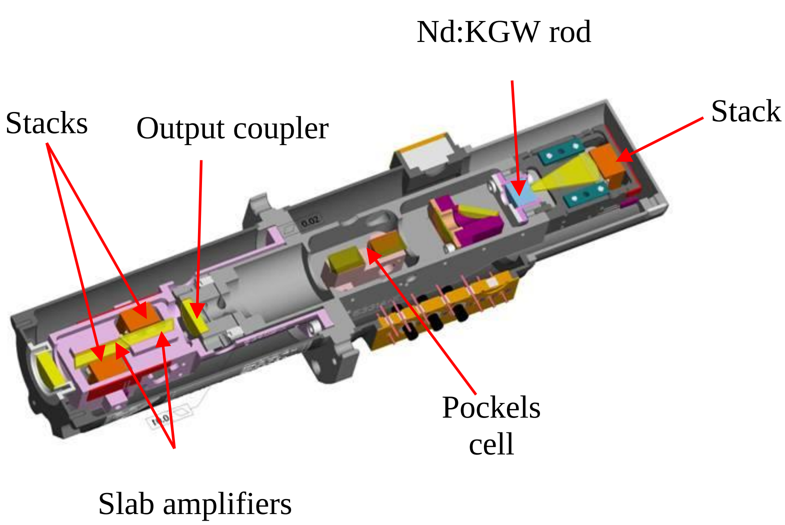

Figure 1. Optical configuration of ChemCam laser.

Figure 1 shows the optical configuration of ChemCam laser. Laser dimensions are about ϕ55 x 220 mm and weight is about 560 g. The laser is operated in the nanosecond regime, at a repetition rate of 10Hz maximum. Its architecture is based on an oscillator followed by two slab amplifiers. The oscillator is designed to provide a high beam quality. The output energy is enhanced in the amplifiers while keeping good spatial beam characteristics.

2.1 The oscillator

Oscillator is based on a Nd : KGW rod longitudinally pumped by a diode stack. The very wide spectral acceptance of the Nd : KGW rod provides very small absorption variations over wide temperature ranges. This allows both the diode and the rod to be conductively cooled and run on large temperature ranges of the Mars rover. Oscillator is Q-switched with a RTP Pockels cell to produce the nanosecond pulses needed for LIBS.

Oscillator resonator is linear, closed on one side by the rod and by the output coupler on the other side. Reflectivity of the output coupler is 60%. A polarizer, wave-plate and Pockels cell Q-switch the cavity. The oscillator provides an output energy of about 10mJ with a pulse duration < 8ns and a beam quality factor < 2.

2.2 Amplifiers

Amplifiers are based on transversally diode pumped Nd : KGW slabs. Two identical amplifiers increase the energy at the oscillator output. Each amplifier is pumped by a 700W stack. An energy in excess of 30 mJ is obtained at the laser output, with a M2 factor < 3.

3. SUPERCAM LASER

SuperCam instrument has been selected to be aboard Mars 2020 rover. This instrument integrates a new laser based on ChemCam heritage. Besides the LIBS capability at 1064 nm, it provides the following improvements:

- number of shots per burst has been increased by a factor of 10,
- a new wavelength (532 nm) is emitted, using Second Harmonic Generation (SHG), enabling Raman analysis.

These new functions have been implemented in a volume similar to ChemCam laser. The laser has been qualified and Flight model was delivered to CNES/IRAP end of 2017. Integration of FM laser into SuperCam instrument is under progress.

Figure 2 shows a picture of SuperCam laser. Laser dimensions are about ϕ55 x 230 mm and weight is about 550 g. SuperCam laser is operated in the nanosecond regime, at a repetition rate of 10Hz maximum. Its architecture is based on a single oscillator followed by a Second Harmonic Generator.

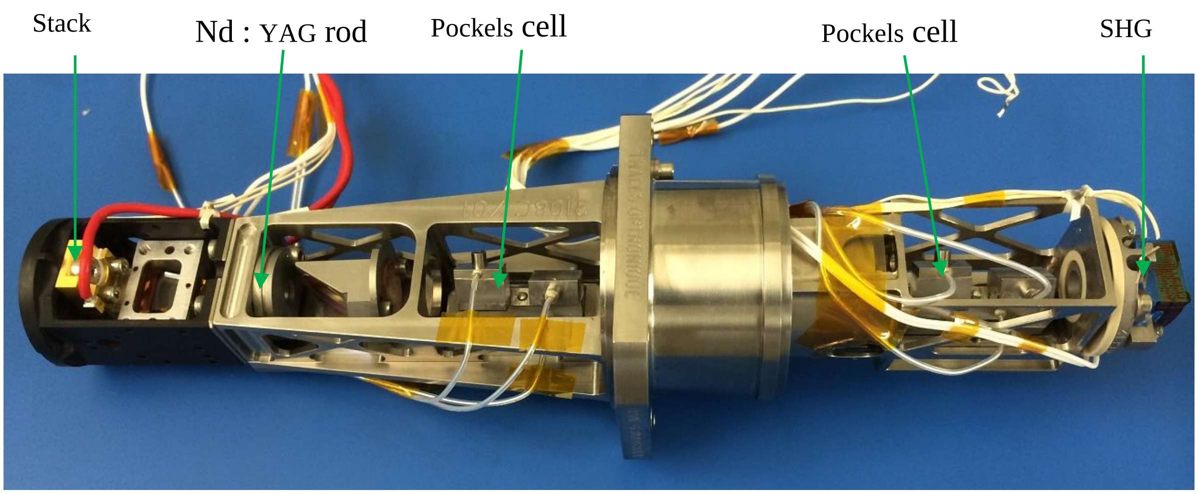

Figure 2. Picture of SuperCam laser.

3.1 The oscillator

The oscillator provides the high beam quality and short pulse length needed for LIBS analysis. It is based on a Nd : YAG rod longitudinally pumped by a multicolor stack, insuring pump absorption over large temperature range. This allows both the diode and the rod to be conductively cooled and operated on large temperature range. The oscillator is Q-switched with a RTP Pockels cell to produce nanosecond pulses.

Oscillator resonator is linear, closed on one side by the HR coated rod side and by the output coupler on the other side. Reflectivity of the output coupler is 40%. A polarizer, wave-plate and Pockels cell are associated to Q-switch the cavity. The oscillator provides output energy of about 30mJ at 1064 nm with a pulse duration < 5ns and a beam quality factor < 2.

3.2 Commutator and Second Harmonic Generator

A KTP Second Harmonic Generator (SHG), placed at the output of the oscillator, produces the 532 nm beam used in Raman mode. A RTP electro-optical switch, between the oscillator and SHG, allows the operation mode selection (LIBS or RAMAN). In the absence of high voltage, infrared beam at 1064 nm is emitted. When the high voltage is applied to the RTP switch, beam is converted to 532 nm for Raman analysis. An SHG conversion efficiency of about 50% is obtained corresponding to about 15 mJ delivered for Raman spectroscopy.

4. NEXT GENERATION OF LIBS – RAMAN LASERS

Next generation of LIBS-Raman lasers may mix ChemCam and SuperCam to provide:

- Higher energy using oscillator + amplifier design (implemented on ChemCam laser),
- Increase number of shots per burst using Nd : YAG material (implemented on SuperCam laser),
- Raman capability using Second Harmonic Generation (implemented on SuperCam laser).

A table top laser, representative in terms of optical configuration, has been built and tested to demonstrate laser performances.

4.1 Table-top laser

Figure 3 shows the experimental setup of the table top laser. The laser is operated in the nanosecond regime, at 3 Hz repetition rate. Its architecture is based on a single oscillator amplified into two power amplifiers and followed by a Second Harmonic Generator.

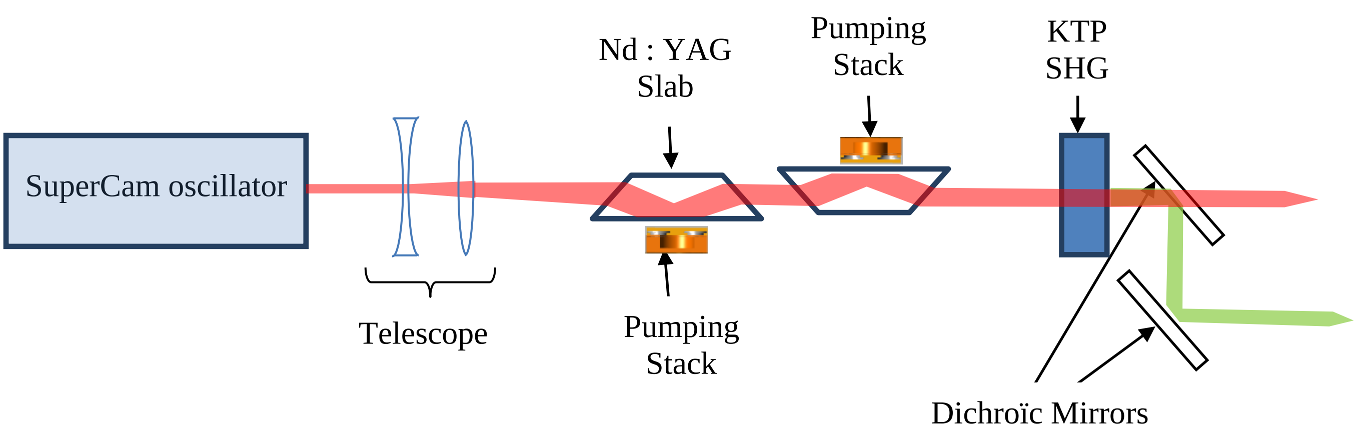

Figure 3. Optical configuration of the table top laser

The oscillator, in the same configuration as SuperCam oscillator, provides a high beam quality beam ($M^2 < 2$) with an energy of about 30 mJ and a pulse length of about 5 ns.

Amplifiers are based on transversally diode pumped Nd : YAG slabs. Two identical amplifiers (dimensions 6 x 6 x 22 mm) increase the energy at the oscillator output. Each amplifier is pumped by one 1800W stack. These slab amplifiers are derived from ChemCam amplifiers:

- Nd : KGW has been replaced by Nd : YAG,
- Two identical multicolor stacks pump the Nd : YAG slab amplifiers to keep running on large temperature range without thermal regulation of the stacks,
- Number of shots per burst has been increased due to improved thermal properties of Nd : YAG compared to Nd : KGW (a few hundred shots can be done instead of 100 shots).

A KTP Second Harmonic Generator (SHG), placed at the output of the amplifiers, produces the 532 nm beam used in Raman mode. Crystal dimensions are 6 x 6 x 4.5 mm. Two dichroic mirrors after SHG crystal separate the green beam at 532 nm from the infrared beam at 1064 nm.

4.2 Results

Fig. 4 shows the amplified energy at 1064 nm versus pump energy for different oscillator energy at 3 Hz repetition rate. As shown on this figure, an amplified energy higher than 100 mJ is obtained for oscillator energy higher than 25 mJ. Beam profile in the near field is shown on Fig. 5. Beam quality factor was measured after amplification and remains < 2.

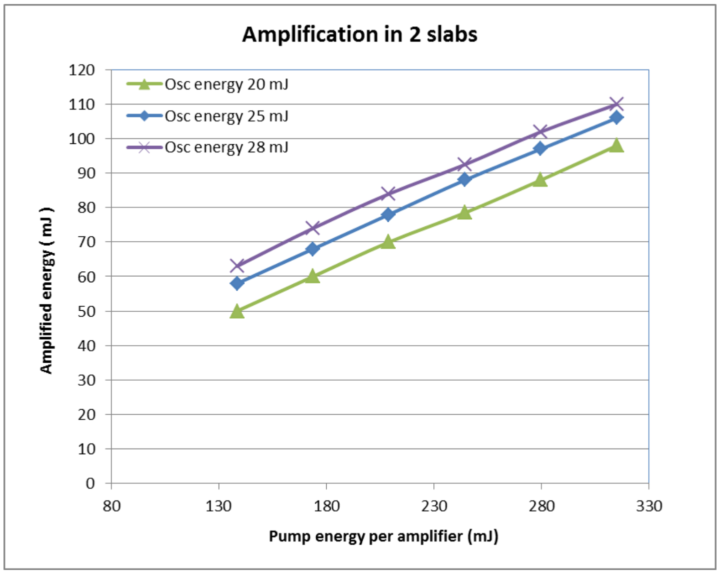

Figure 4. amplified energy versus pump energy per amplifier for different oscillator energy

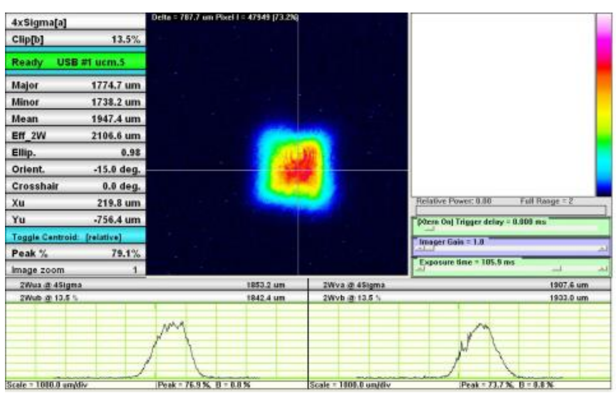

Figure 5. near field beam profile of the amplified beam

At 532 nm, 55 mJ output is obtained with 100 mJ infrared input energy using a 4.5 mm long KTP crystal (Figure 6).

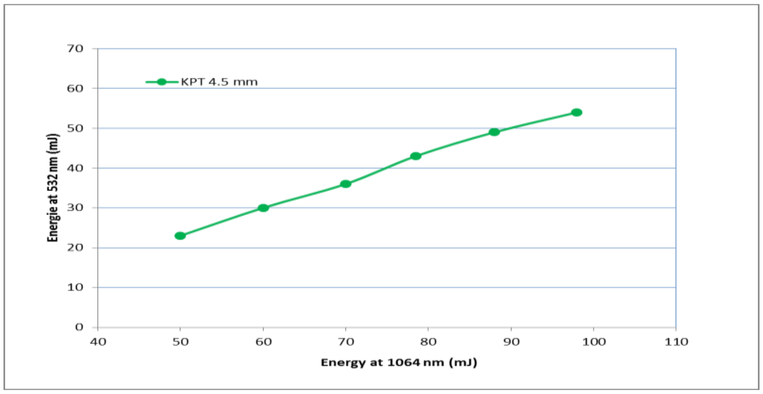

Figure 6. Green energy at 532 nm versus infrared energy with a 4.5 mm KTP

4.3 Next generation of infrared lasers for LIBS instrument

Based on the results obtained with the table top laser described above, new lasers could be developed and manufactured for the next generation of LIBS or Raman instruments.

For LIBS, configuration with SuperCam oscillator followed by two Nd : YAG slab amplifiers, could provide an increased energy at 1064 nm compared to ChemCam/SuperCam lasers, in a similar volume. With an overall length increased by a few cm, to integrate a telescope between oscillator and amplifiers, energies higher than 100 mJ may be obtained with beam quality factor $M^2 < 2$. The new LIBS laser is shown on Figure 7 left.

For the Raman laser, the new laser followed by a SHG crystal could deliver up to 50 mJ at 532 nm. Overall length of the Raman laser will be a couple of cm longer than the LIBS laser. The new Raman laser is shown on Figure 7 right.

These lasers will be based on ChemCam/SuperCam heritage: integration processes will be re-used, lasers will be sealed by laser welding of the titanium covers. This will insure the long term reliability needed for spatial lasers.

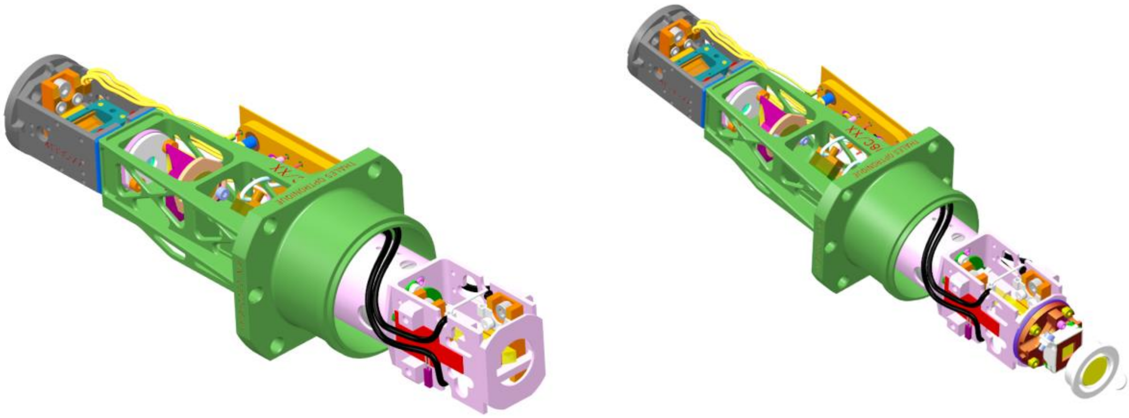

Figure 7. Next generation of LIBS (left) and Raman (right) lasers

5. CONCLUSION

Using SuperCam oscillator and two slab amplifiers pumped by multicolor stacks derived from ChemCam, a new laser has been built on a table top setup. 100 mJ output energy has been obtained at 1064 nm with good beam quality. Using a 4.5 mm KTP crystal, 50% conversion efficiency was demonstrated at 532 nm.

Based on these results, new LIBS and Raman space lasers have been designed, taking SuperCam and ChemCam heritage into account. These lasers will procure improved performances while keeping compactness, resistance to harsh environments and reliability.

Acknowledgement

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