monocrom

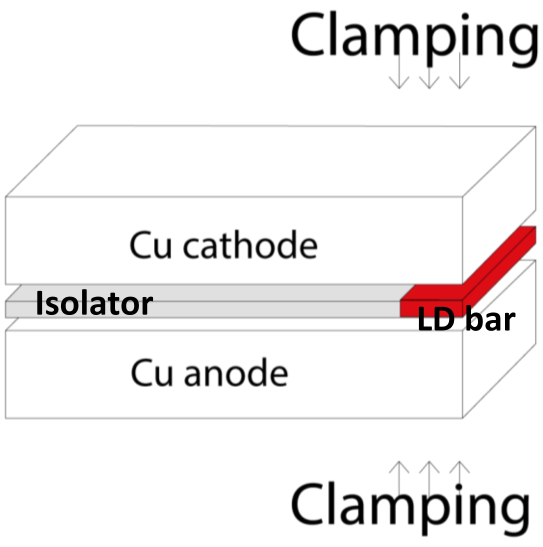
Laser-based Solution to Sort Composites and other Materials for Recycling

Dr. Igor Alexander

Outline

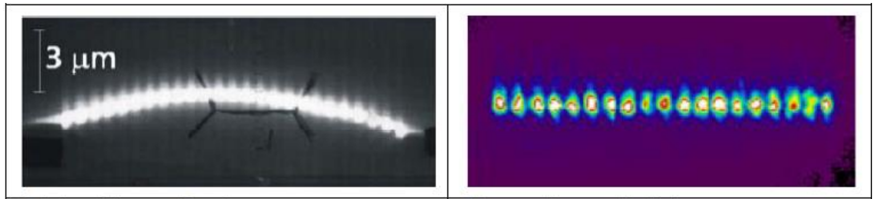
- Monocrom S.L. at a glance
- High energy pulsed lasers
- Examples of targeted applications:
  - Selective recovery of aluminum from end-of-life vehicles (shredder sorting)
  - Selective recovery of composites from end-of-live ships
- Conclusions

Clamping™ & Monocrom's Products



Clamping™ means:
- Mounting at Room Temperature
- Insensitive to CTE mismatch
- Having no Mechanical stress
- Using Macro- channels
- Cooling from both sides of the semiconductor
- Achieving longer Life Time
- Having (almost) no SMILE

No "SMILE" effect



Soldered bar smile >1µm | Clamped bar smile 0,1µm

1993

Low Power Diode Lasers & Laser Electronics

1999

Single & Stack Diode Laser Bars (passive or active cooling)

2000

Low & high power Laser Cavity (Pumping Heads)

2003

Low Energy Diode Pumped Solid State Lasers

High Energy Diode Pumped Solid State Lasers

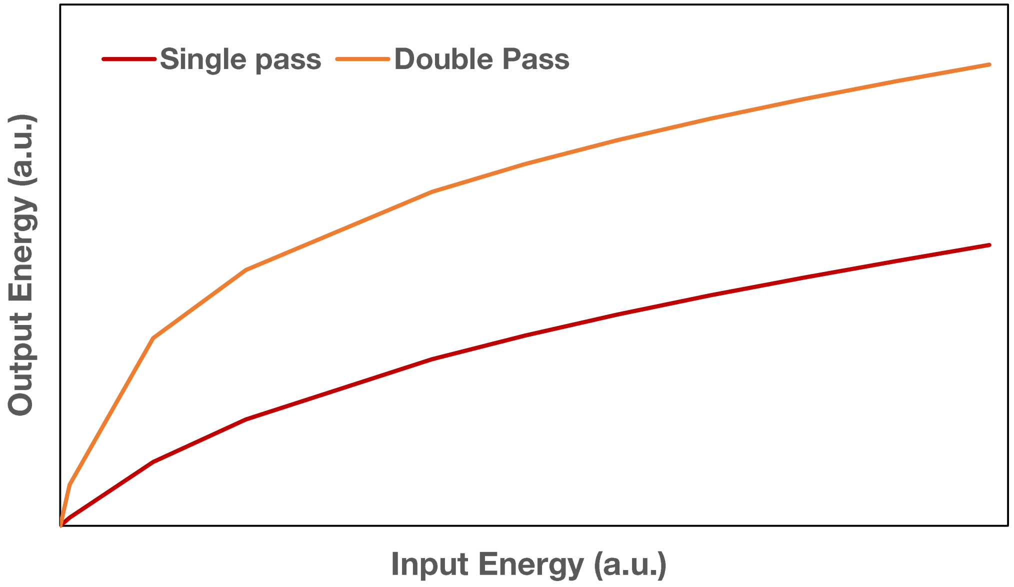
2018

From low to high energy pulsed lasers

The pulse-energy of a laser can be amplified in a master oscillator power amplifier (MOPA) system.

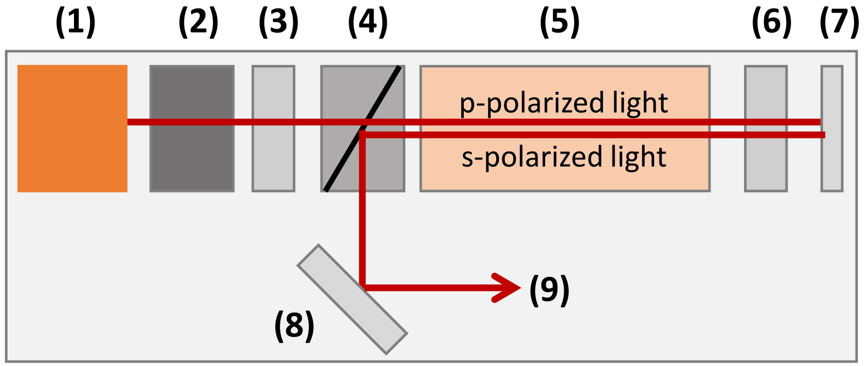
$$E_{out} = E_{sat} \ln\left\{1 + \left[exp^{\left(E_{in}/E_{sat}\right)} - 1\right] G\right\}.^{(*)}$$

E_{out}	**Output energy**	E_{sat}	**Saturation energy**
E_{in}	**Input energy**	G	**Gain factor**



(*) W. Koechner, "Solid-State Laser Engineering"

Our design is a double-pass (MOPA) system. Its basic building blocks are:

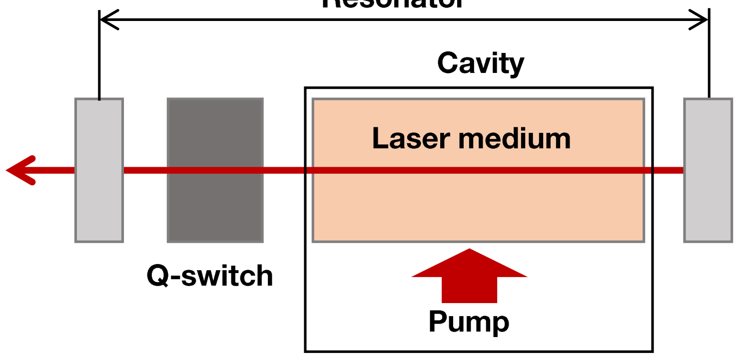


Item	Label	Description
1	Oscillator	Provide the seed signal
2	Isolator	Protect the oscillator from back reflections
3	l/2	Half waveplate: p-polarization
4	Pol.	Polarizer: transmits p- and reflects s-pol.
5	PH120	Amplifier
6	l/4	Quarter waveplate: double rotation (p to s)
7	M (100%, 0°)	Re-bounce mirror
8	M (100%, 45°)	Beam steering mirror
9	Output	Laser output or harmonics generation stages

ns-Pulsed Master Oscillators

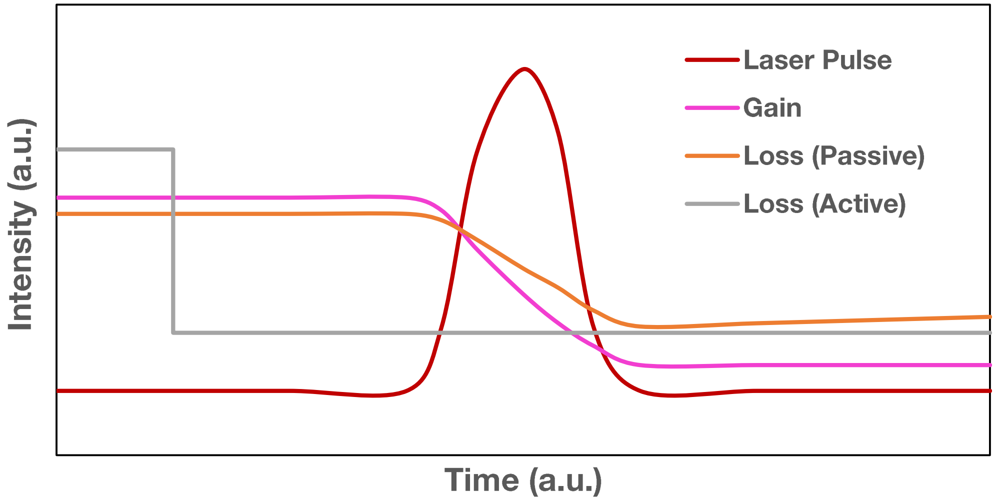
ns-pulsed laser configuration

- **Active medium: Nd^{3+}:YAG**
- **Pump: laser bars with a collimated beam in free space or coupled to a fiber at l=808 nm**
- **Pumping mode: CW or QCW**
- **Laser emission: l=1064 nm**
- **Q-switch: passive with a Cr^{4+}:YAG or active with an AOM**



Basic building blocks for a ns-pulsed laser

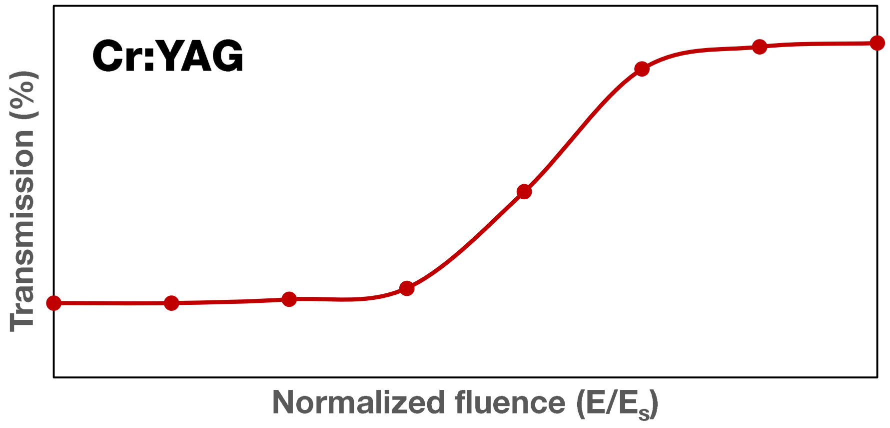
Q-switch mechanism

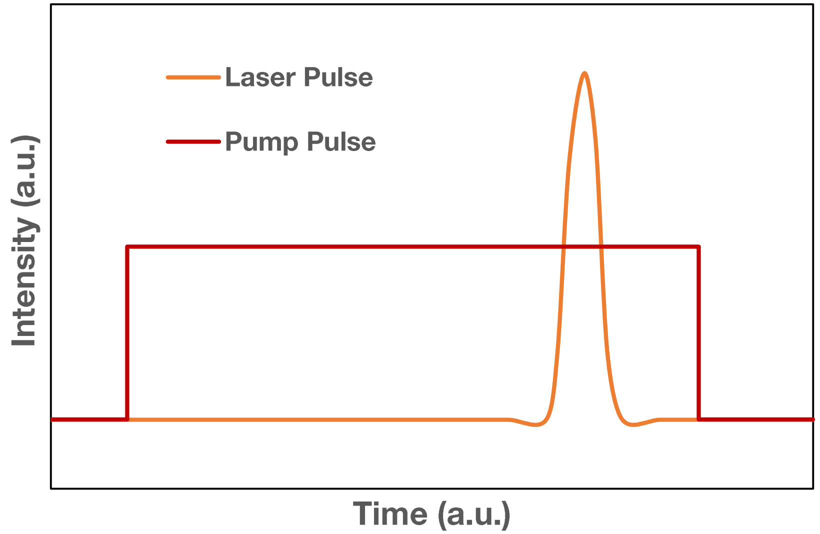


Q-switch technique	Passive	Active
Mechanism	Saturable absorber	RF modulation
Crystal	Cr^{4+}:YAG	Fused Silica
Pulse duration (ns)	0.7 – 1.5	0.6 – 3
Beam quality (M^2)	<1.5	<1.2
Max repetition rate (kHz)	40	100
Pulse energy	mJ up to ~1 mJ	mJ
Pulse timing jitter	ms	ns
Cost	Low	High

ns-Pulsed Nd^{3+}/Cr^{4+}:YAG Laser chip

Transmission vs. laser fluence in a saturable absorber



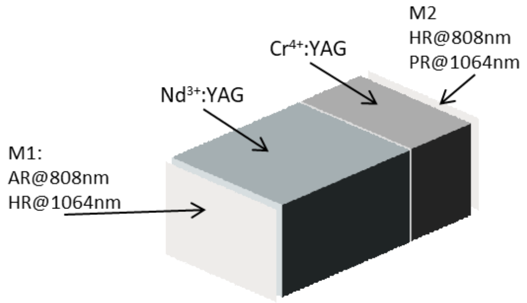


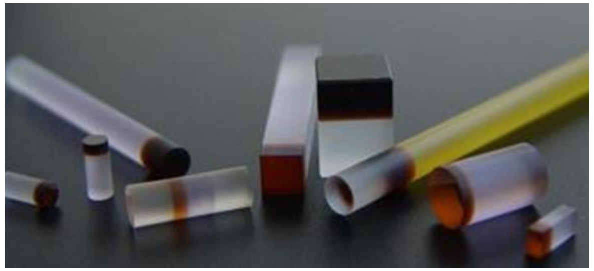
The Nd/Cr:YAG laser chip is formed by:

- Nd^{3+}:YAG crystal (gain medium)
- Cr^{4+}:YAG crystal (passive q-switch)

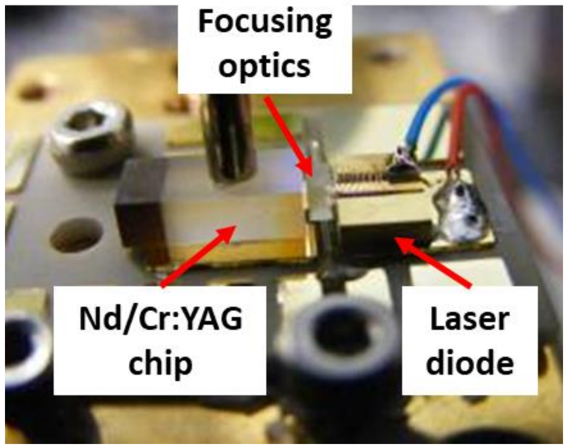
Under the right configuration of the pumping:

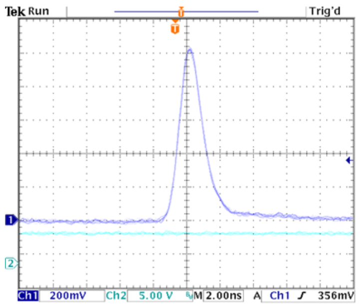
- Laser pulse duration **~1.5 ns**
- **TEM_{00} mode** laser beam
- Pulse energy ~0.8 mJ
- By increasing the incident pump density, **multiple pulses** are generated with a time-gap of ~ 50 ± 10 ms

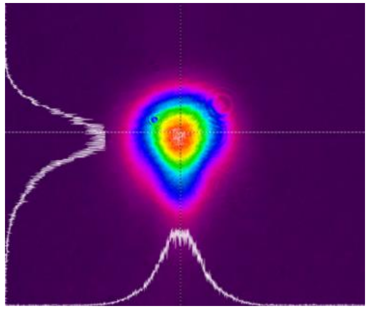




Monolithic Nd^{3+}/Cr^{4+}:YAG Laser chip







1.5ns

Low Power Laser Amplifier

Diode pumped solid state laser (DPSSL) Cavities where:

- **The active medium: Nd^{3+}:YAG rod**
- **Pump configuration: lateral with laser bars or *collimated and fiber-coupled* (*) laser bars with emission at l = 808 nm**
- **Pump mode: CW for high repetition rate (>40 kHz) or at 10% duty for 100 Hz repetition rates**
- **Laser emission and amplification at l = 1064 nm**

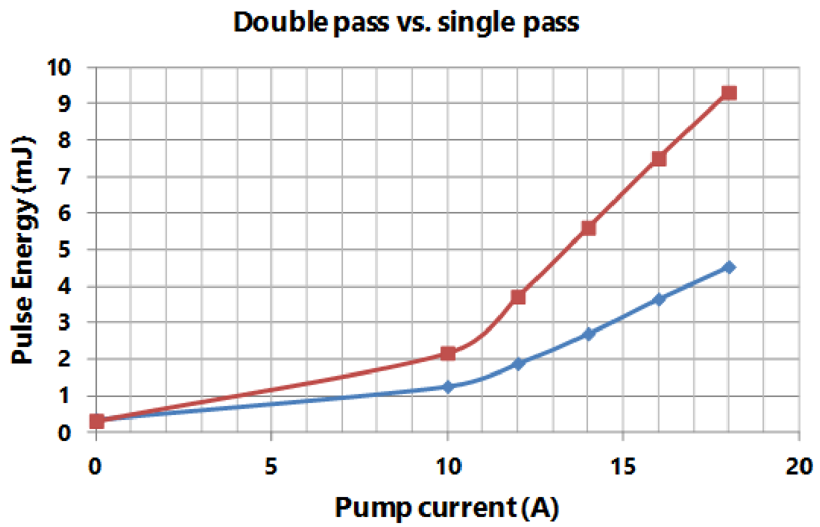
(*) where high brightness is needed, for instance, low energy oscillator signal.

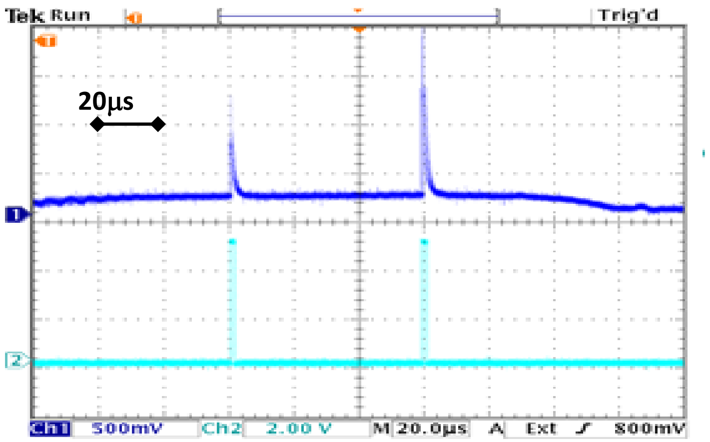
Parameter	Low power cavity	Fiber pumped
Nd^{3+}:YAG bar diameter (mm)	3	3
Pump configuration	Lateral	Colinear
Pump power / duty cycle	120 / CW	150 / 10%
Repetition rate	100 kHz	100 Hz
Cooling	Distilled water	Passive

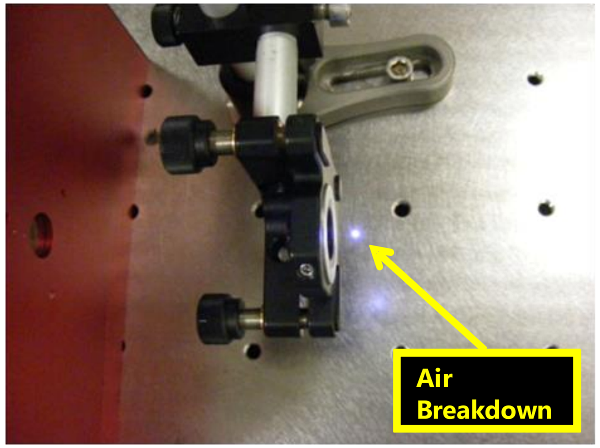
Double-pass MOPA Laser Device

The device based on the Nd^{3+}/Cr^{4+}:YAG laser chip is characterized by:

- Laser wavelength: 1064 nm
- Two operating modes (single or dual-pulse)
- Laser pulse energy:
  - in single pulse mode >10 mJ
  - in dual-pulse mode up to 20 mJ (10 + 10 mJ)
- The inter-pulse delay in dual-pulse mode is ~ 50 ± 10 ms
- Laser pulse duration is ~1.5 ns
- Beam quality: TEM_{00} mode





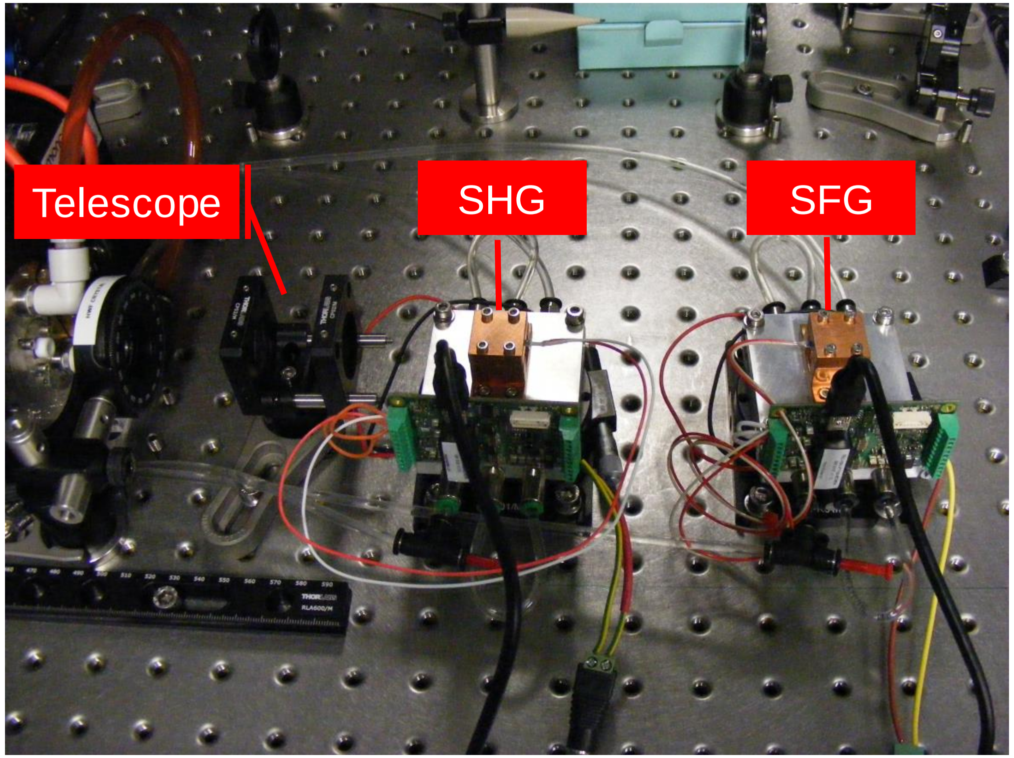


Harmonics Generation (Green & UV laser)

For ns-pulsed lasers, harmonic generation is performed with LBO crystals (best efficiency)

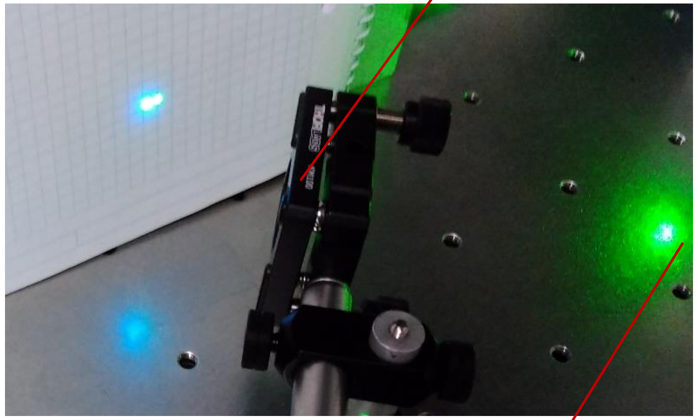
Second harmonic generation (SHG) of laser emission at 532 nm (green)

Third harmonic generation (THG) of laser emission at 355 nm (UV)



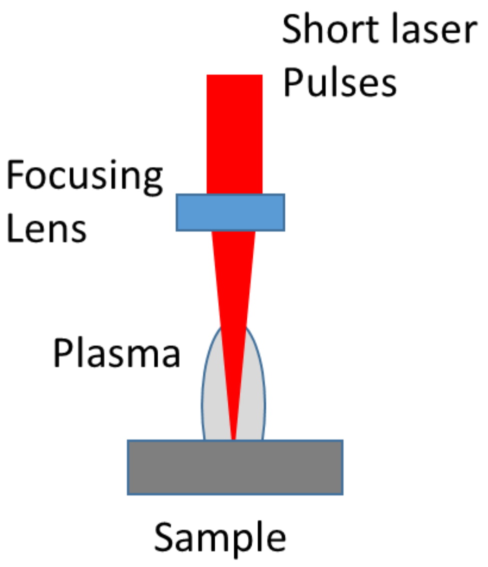
THG @ 355 nm

Dicroico HR
355 nm @ 45º

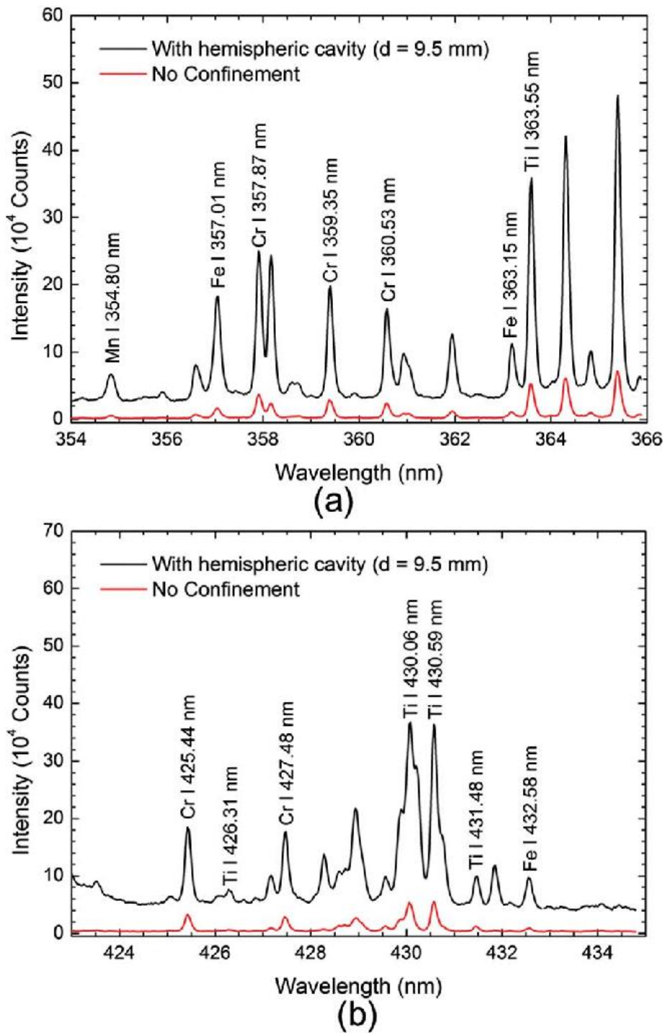


SHG @ 532 nm and 1064 nm

Laser Induced Break down Spectroscopy (LIBS)



Plasma spectra analysis



Applications: selective recovery of aluminum

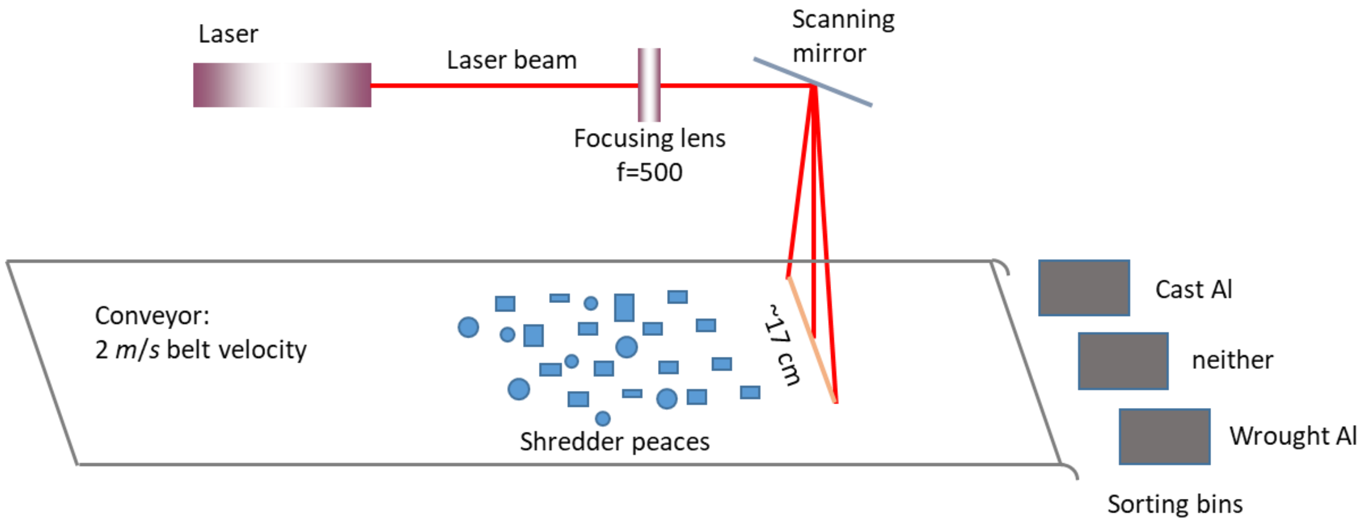
State of the art of the recovery of nonferrous metals:

- **Heavy, expensive and chemical, Non-environment friendly**
- **Does not selectively recover elements with similar composition**
- **Shipped overseas for hand picking (loss of raw-materials in the EU)**
- **Only 75% of ELV waste is recovered, well under the 95% targeted by the EU directive 200/53/EC**

The ShredderSort project approach is to:

- **Use LIBS analysis to selectively recovery aluminum and magnesium alloys,**
- **Build a high-throughput sorting line to enable processing industrial waste volumes.**

Applications: selective recovery of aluminum



Block diagram of a LIBS-based selective sorting line

- **Shredder pieces of different heights and shapes,**
- **Arrive at 2 m/s and at different angles,**
- **Focusing with a 500 mm focal lens.**

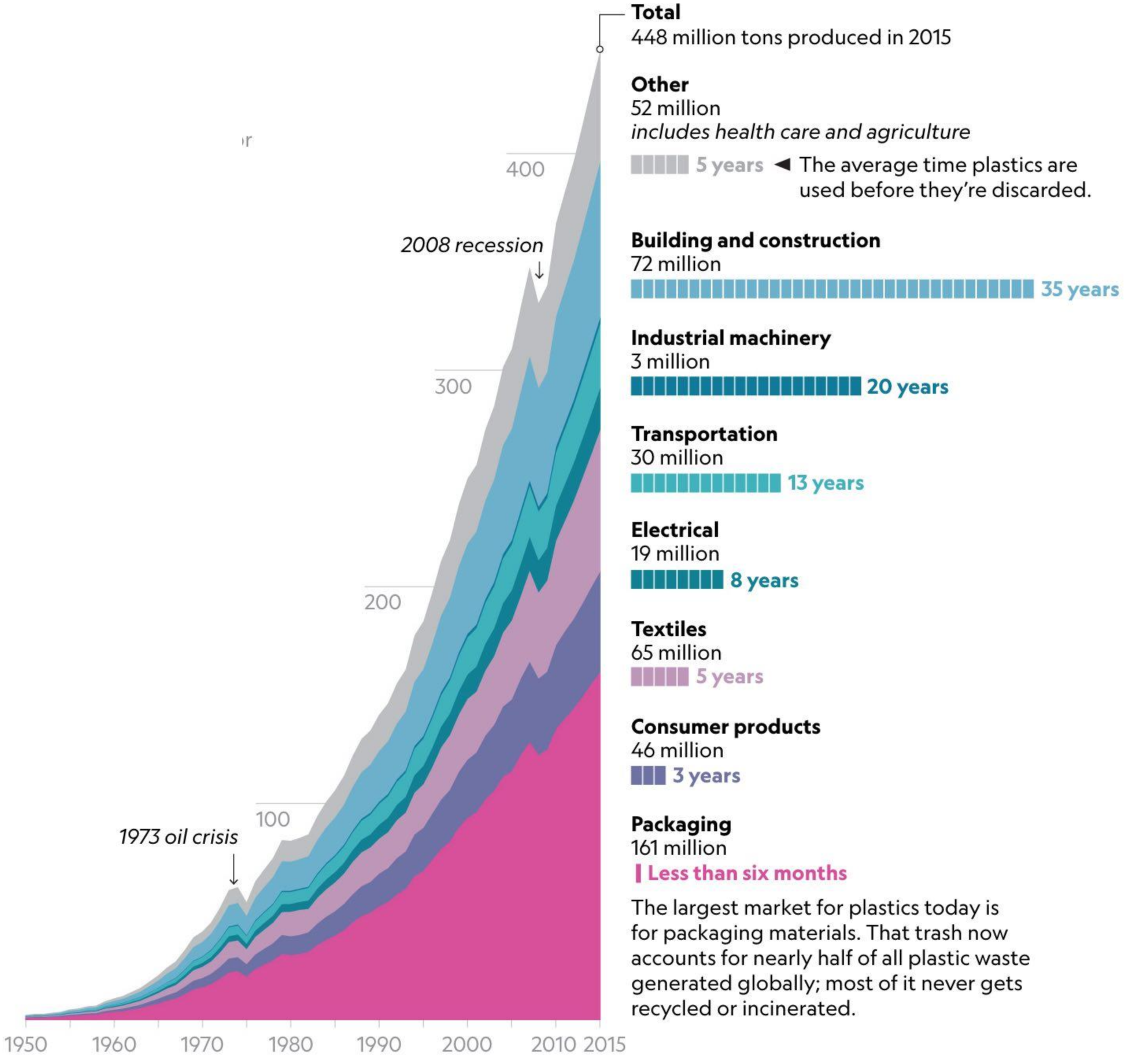
To achieve high-throughput, we combined several high energy lasers and a fast polychromator.

The laser controlling unit requirements:

- **Remote control**
- **Internal and external trigger**
- **Deliver a TTL signal after each laser shot**

High-throughput LIBS-based selective sorting line

Applications: selective recovery of composites

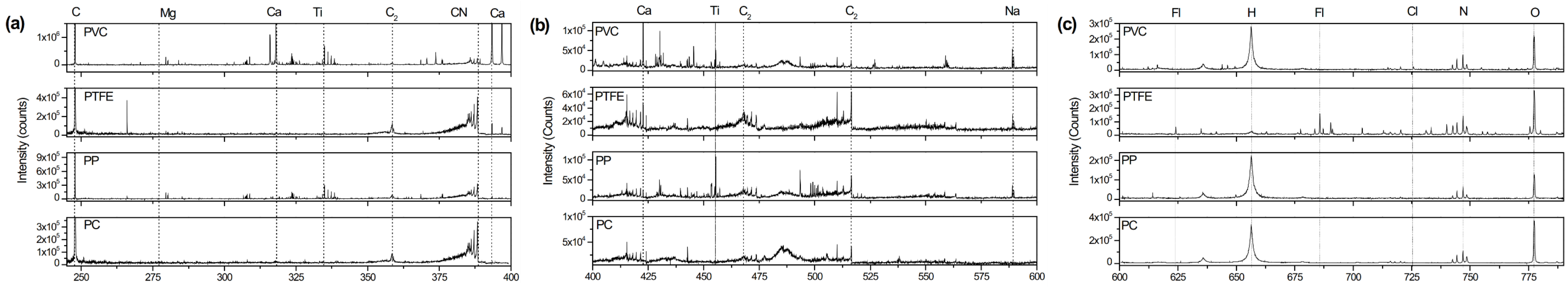


Roland Geyer, University of California, Santa Barbara

Applications: selective recovery of composites

C/H	Name	Polymer	Use
1.25	PET	polyethylene terephthalate	Water and soft drink bottles
0.5	HDPE	high density polyethylene	Household bottles (cosmetics, food, detergent), industrial wrapping
0.66	PVC	polyvinyl chloride	Medical bottles, water pipes, window panes, credit cards, flooring
0.5	LDPE	low density polyethylene	Garbage bags, food wrap
0.5	PP	polypropylene	Joghurt containers, margarine containers, milk and beer crates
1	PS	polystyrene	Disposable cups and plates, egg cartons
	other	the rest of all plastics	Plastic mixtures

Applications: selective recovery of composites

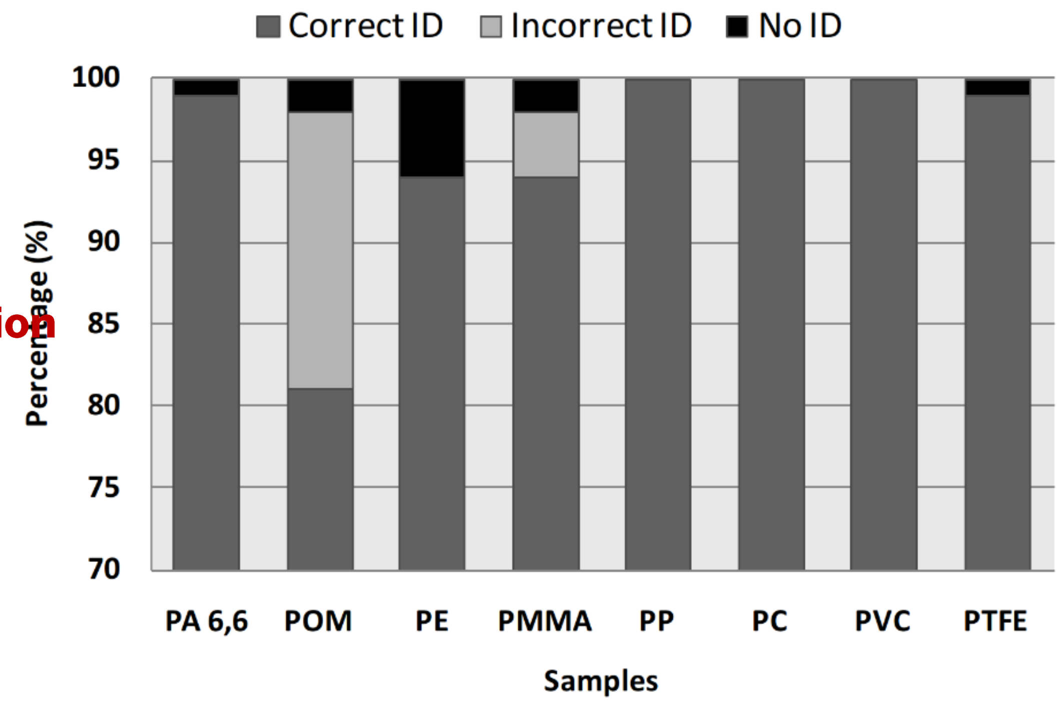


Graphes: Myriam Boueri: Laser-induced plasma on polymeric materials and applications for the discrimination and identification of plastics; Université Claude Bernard - Lyon I; 2010

Applications: selective recovery of composites

- **Pulse length optimization can increase the differenciation between the composites**
- **Double pulse LIBS can decrease the Limit of Detection (LoD) (**)**
- **2nd pulse under 60deg. increase the signal intensity dramatically (*)**
- **Train a Artificial Neural Network (ANN) to interpret the spectra**

A well trained ANN can lead to a high level of identification



monocrom

Conclusions

- High energy MOPA laser systems are been developed by Monocrom SL, with the follow characteristics:
  - Good beam quality ($M^2 < 1.5$),
  - ~0,6 – 3 ns-laser pulses,
  - From single-shot up to 100 kHz repetition rate,
  - Laser emissions at l=1064 nm, 532 nm, 355 nm,
  - Up to 20 mJ of pulse energy have been achieved at 1064 nm.
- Our targeted applications, but not limited to, are:
  - Selective recovery of aluminum from end-of-life vehicles (shredder sorting),
  - Selective recovery of composites from end-of-life ships

Thank you for your attention!

Visit us at www.monocrom.com

i.alexander@monocrom.com

References

Graphes: Myriam Boueri: Laser-induced plasma on polymeric materials and applications for the discrimination and identification of plastics; Université Claude Bernard - Lyon I; 2010

(*) Guang Yang, Qingyu Lin, Yu Ding, Di Tian & Yixiang Duan
Laser Induced Breakdown Spectroscopy Based on Single Beam Splitting and Geometric Configuration for Effective Signal Enhancement; Scientific Reports volume 5, Article number: 7625 (2015)

(**) R.Viskup, B.Praher, T.Linsmeyer, H.Scherndl, J.D.Pedarnig, J.Heitz
Influence of pulse-to-pulse delay for 532 nm double-pulse laser-induced breakdown spectroscopy of technical polymers; Spectrochimica Acta Part B: Atomic Spectroscopy Volume 65, Issue 11, November 2010, Pages 935-942