Materials Science and Technology

Materials processing with intelligent systems (MICRO-457)

Introduction

Shevchik Sergey & Patrik Hoffmann

Content of the lecture

- Who are we?
- What is advanced materials processing?
- What is intelligent systems?
- Why this lecture?
- Main objectives of this lecture?
  - Acoustics (use, type, else)
  - Optics
  - Opto-acoustic (in particular Fiber Bragg Grating)
  - Visual

Who are we?

Prof. Dr. Patrik Hoffmann

Head of laboratory
Laboratory for Advanced Materials Processing (LAMP)

Dr. Sergey Shevchik

Scientist
Intelligent Manufacturing Group (IMG)

Laboratory for Advanced Materials Processing (LAMP)

Ms. Abdollahinejad, Golnoosh

PhD
Intelligent Manufacturing Group (IMG)

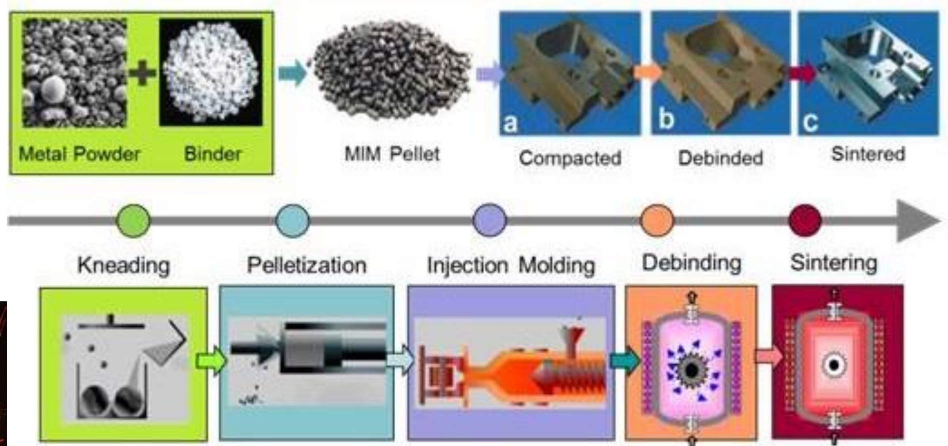
Laboratory for Advanced Materials Processing (LAMP)

Empa – Swiss Federal Laboratories for Materials Science & Technology

What is advanced materials processing?

Advanced materials processing (and manufacturing) is the use of innovative technology to improve products or processes, with the relevant technology being described as "advanced," "innovative," or “cutting edge“.

Source Wikipedia



What are intelligent systems?

- Definition
  - An intelligent system is a machine with an embedded, Internet-connected computer that has the capacity to gather and analyze data and communicate with other systems. Other criteria for intelligent systems include the capacity to learn from experience, security, connectivity, the ability to adapt according to current data and the capacity for remote monitoring and management.

Margaret Rouse WhatIs.com

What are intelligent systems?

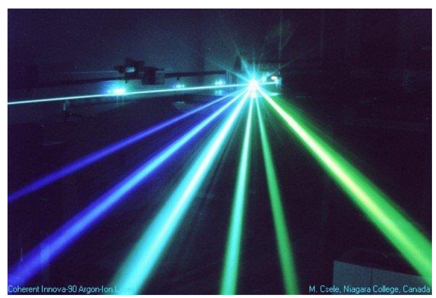
- Definition
  - Intelligent systems are embedded with elements of artificial intelligence and are emerging in response to the convergence of the virtual and physical worlds through the development of autonomous systems, wearable technologies, robotic co-workers, smart devices, drone technology, augmented reality, intelligent houses, digital twins, intelligent manufacturing, and many other applications.

Center for Intelligent Systems (CIS) EPFL

LASER

- **L**ight
- **A**mplification by
- **S**timulated
- **E**mission
- **R**adiation

- **L**egal
- **A**musement of
- **S**tudents
- **E**ngineers and
- **R**esearchers

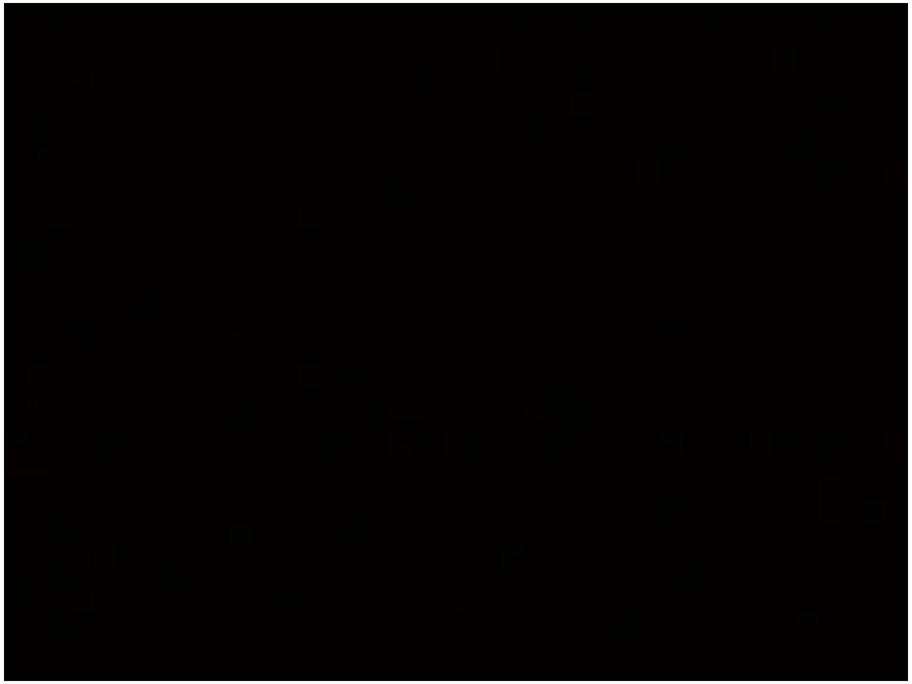


Basics of lasers in case of interest:

Principles of Lasers. by **Orazio Svelto (Springer, 5ed. 2010)**.

Lasers. by **Anthony E. Siegman**. **(Univ Science Books, 1986)**

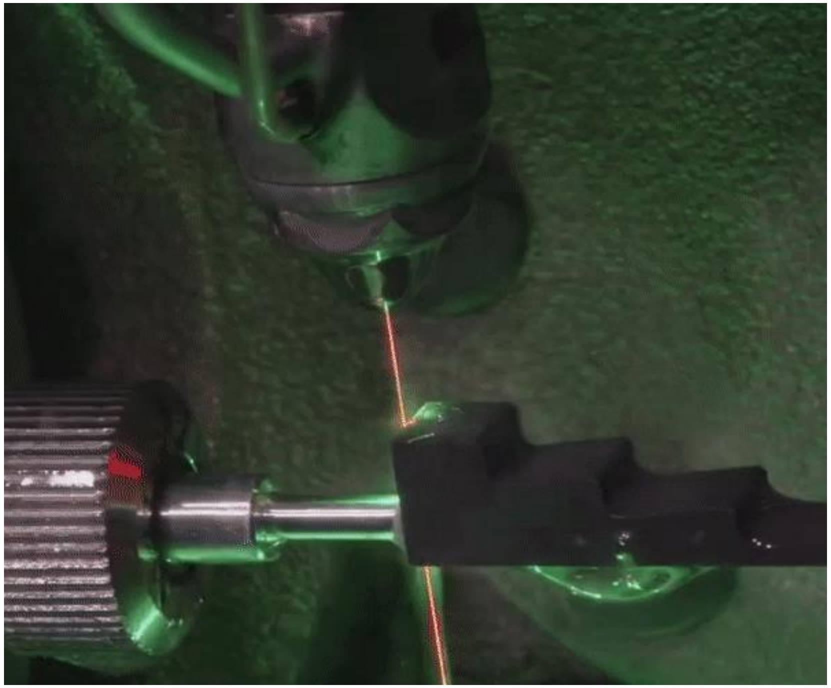
Laser processing: some nice examples



Laser cutting

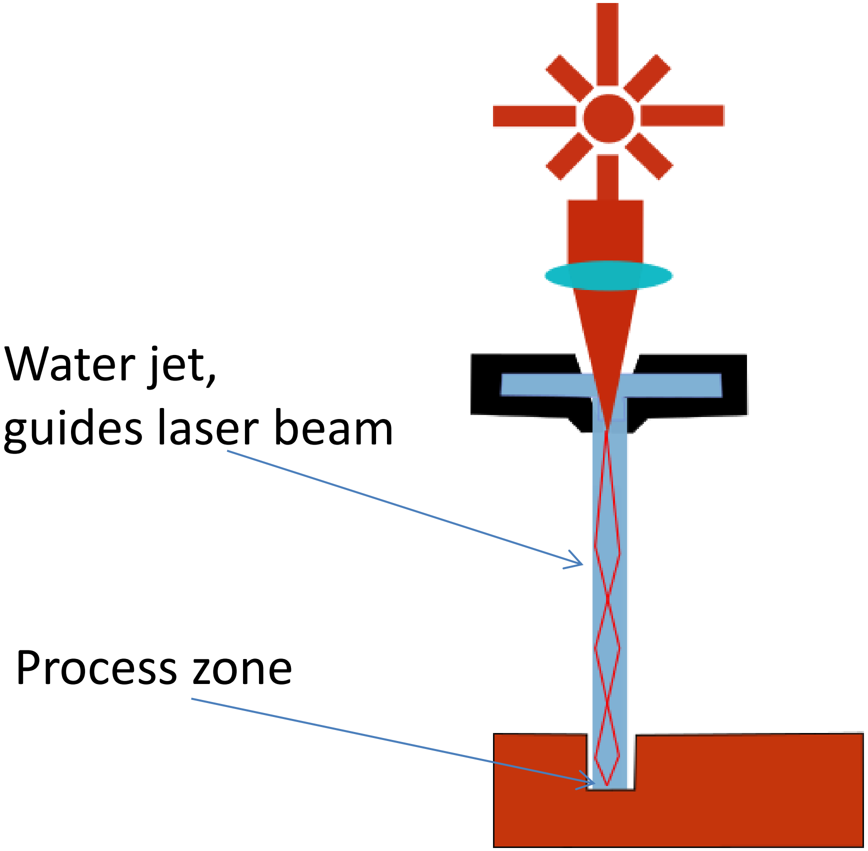
Laser
«shooting« in air
(filamintation)

Laser processing: some nice examples



Water jet laser cutting

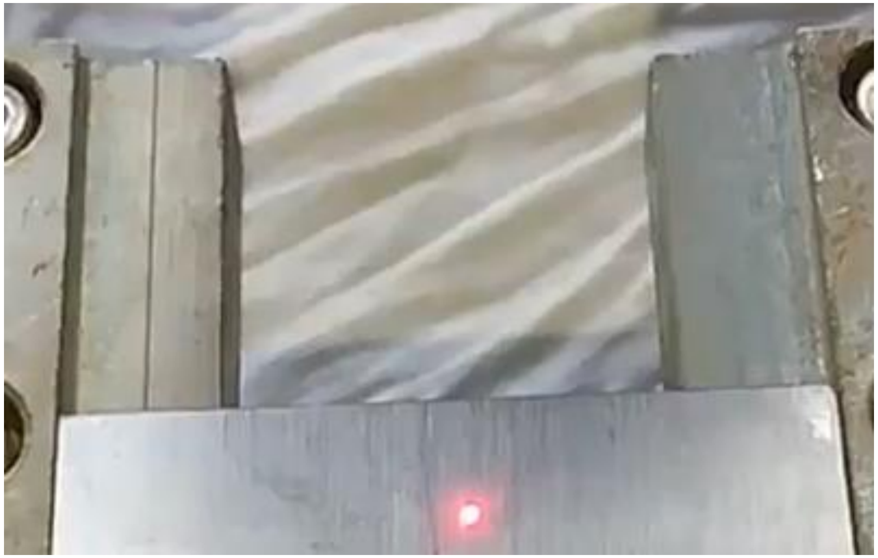
SYNOVA
Water Jet Guided Laser Systems



Laser processing: some nice examples

Laser welding

https://www.youtube.com/watch?time_continue=323&v=xXaabt9urss&feature=emb_logo



Laser marking /
laser engraving

https://www.youtube.com/watch?v=TwSeFoD72EA&feature=emb_logo

Laser processing: some nice examples

https://www.youtube.com/watch?v=B2j-51LfL60&feature=emb_logo

Why monitoring a laser process is important?

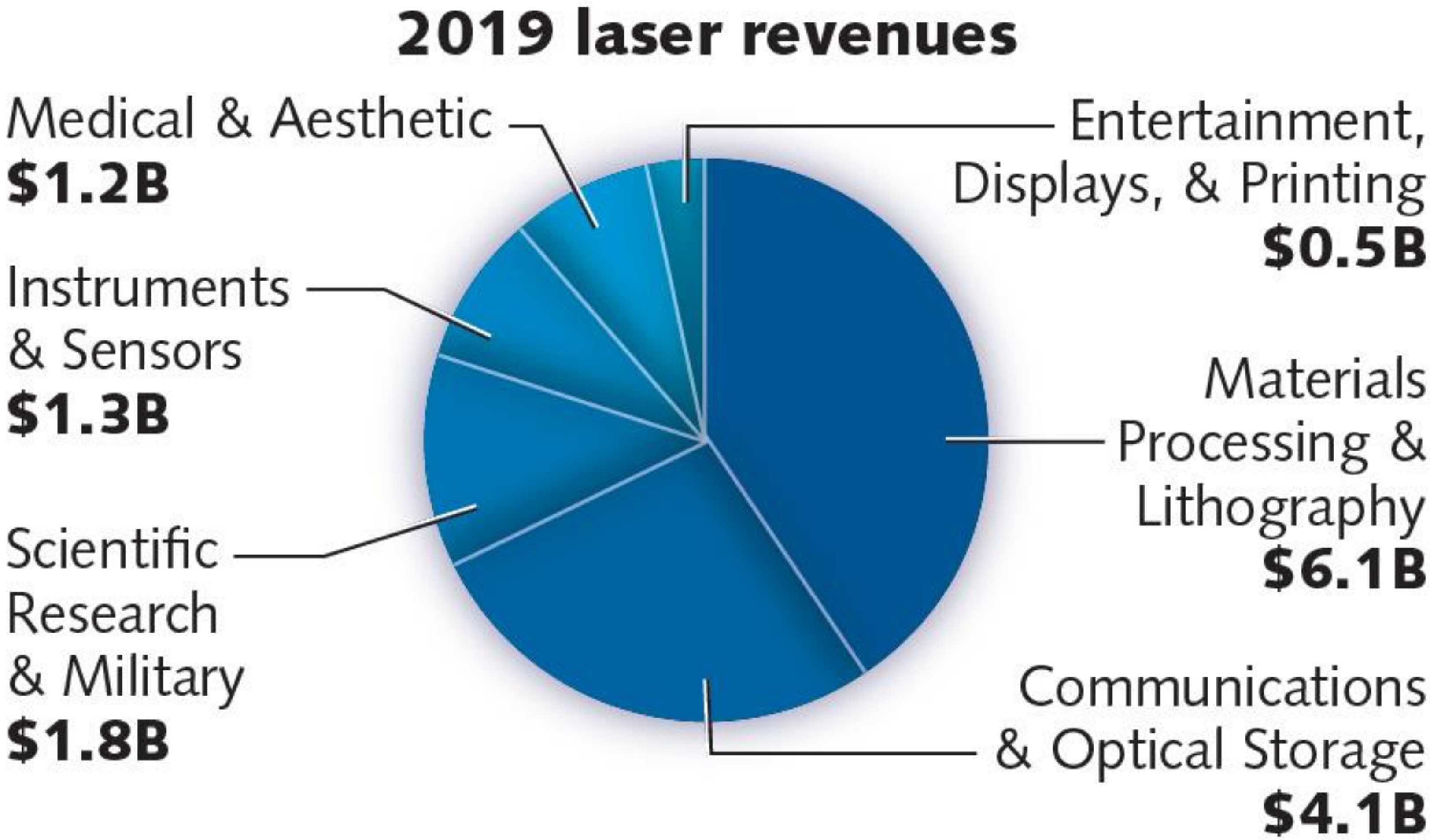
https://www.youtube.com/watch?v=Pjqysyy1ySs

Laser processing: some nice examples

3D printing

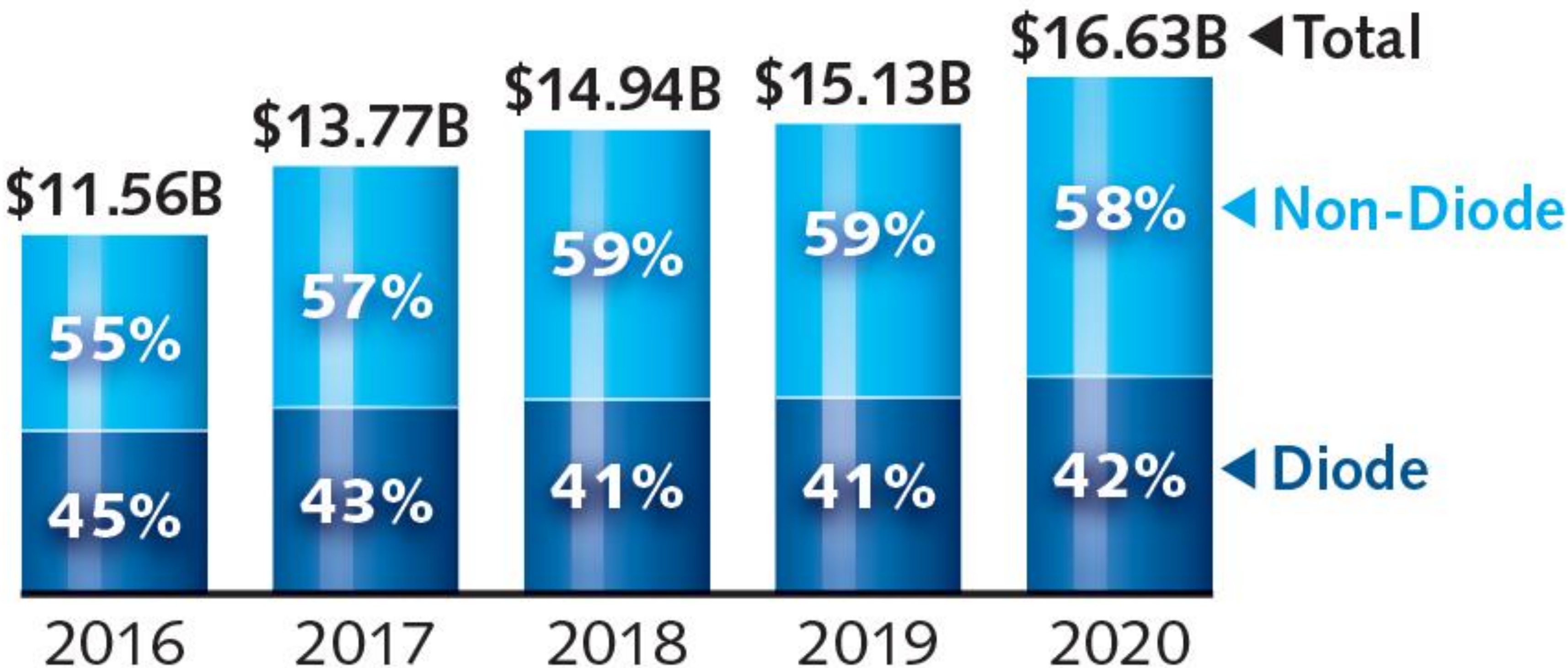
https://www.youtube.com/watch?v=Pjqysyy1ySs

Laser market segments



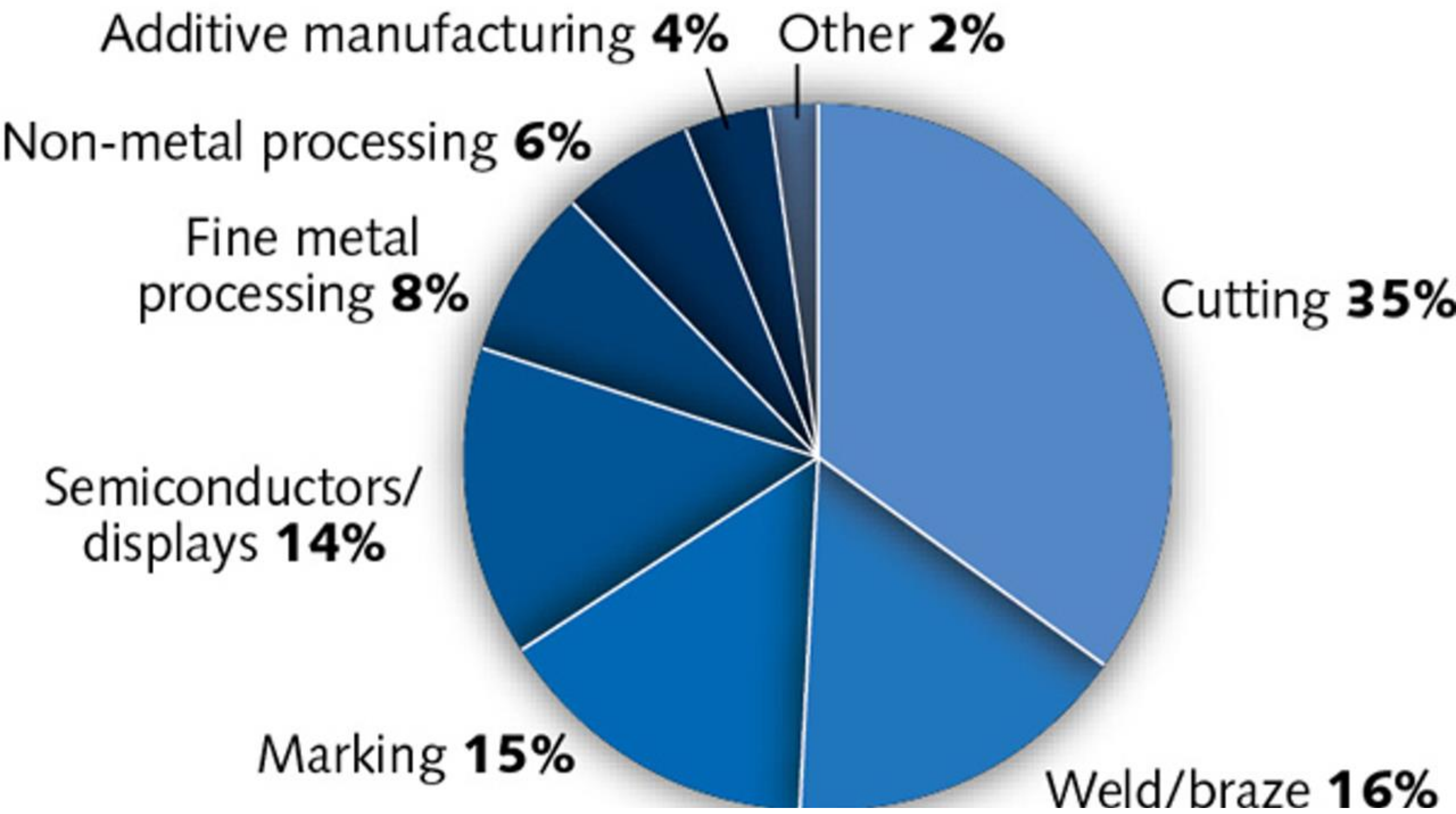
2019 total laser revenues: $ 15.0B

Past laser revenues and 2020 forecast



Source: Strategies Unlimited

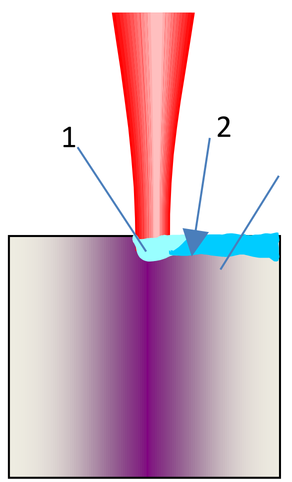
Industrial laser applications 2017



Different laser processes

Conduction welding

Heat the material above melting temperature but without evaporation

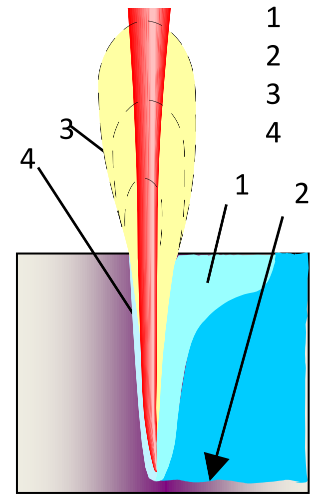


1 Melted materials
2 Weld depth
3 Heat affected zone (HAZ)

- Aspect ratio (depth/diameter): ~1
- Weld depth < 1 mm

Keyhole welding

Heat the material above the evaporation temperature and create a keyhole

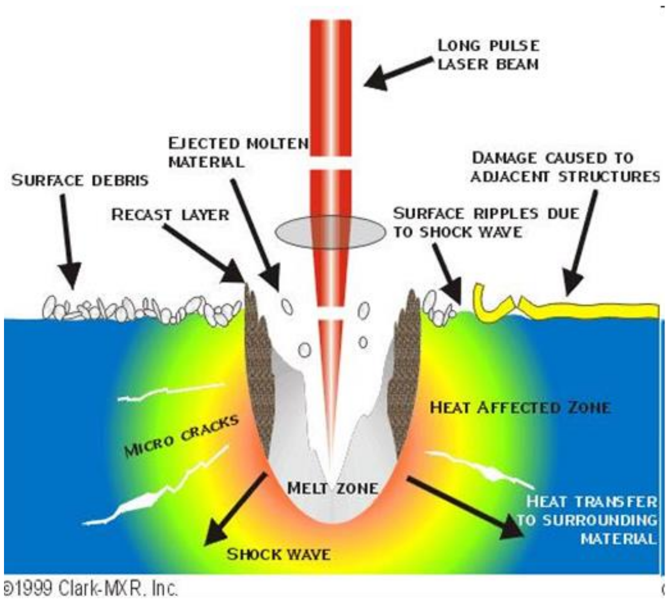


1 Melted materials
2 Weld depth
3 Plume
4 Keyhole

- Aspect ratio (depth/diameter) < 10
- Keyhole-diameter ≈ Spot ∅
- CW max. depth f(laser power)
- Pulse depth: max. depth ≈ 3 mm

Quelle: Rofin-Baasel, Fine Welding with Lasers

Comparison of laser pulse duration



ns

Stefan Nolte, Uni Jena

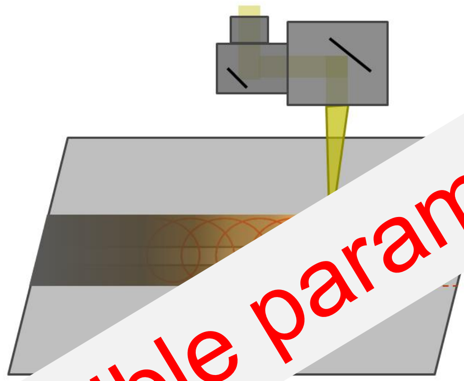
There are many laser processing parameters

Laser beam characteristics

- Peak power
- Pulse width
- Spot size
- Beam quality
- Wavelength
- Mode
- Polarization
- Spatial profile
- Temporal profile

Process parameters

- Wobbling speed
- Welding speed
- Focal position
- Beam inclination
- Operation environment
- Joint design
- Alignment, gap size, etc.



23 possible parameters!

Material properties

- Thickness
- Reflectivity
- Chemical components
- Mechanical properties
- Thermal properties
- Surface finish
- Oxidation

ality parameters

eld geometry
Penetration
- Weld width/reinforcement
- Fusion area
- HAZ area
- Surface roughness
- Bumping/undercut
- Spattering
- Oxidation/coloration
- Porosity
- Hardness
- Tensile/shear strength
- Stiffness
- Distortion
- Thermal efficiency
- Cost

The laser processing of materials

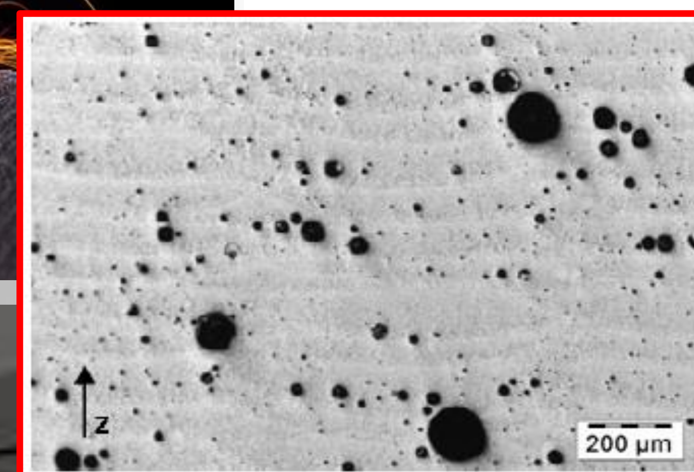
Laser p

Thermo

WHY!

Starting the AM process

What happened to my sample?



the sample is

ct occuring

the process

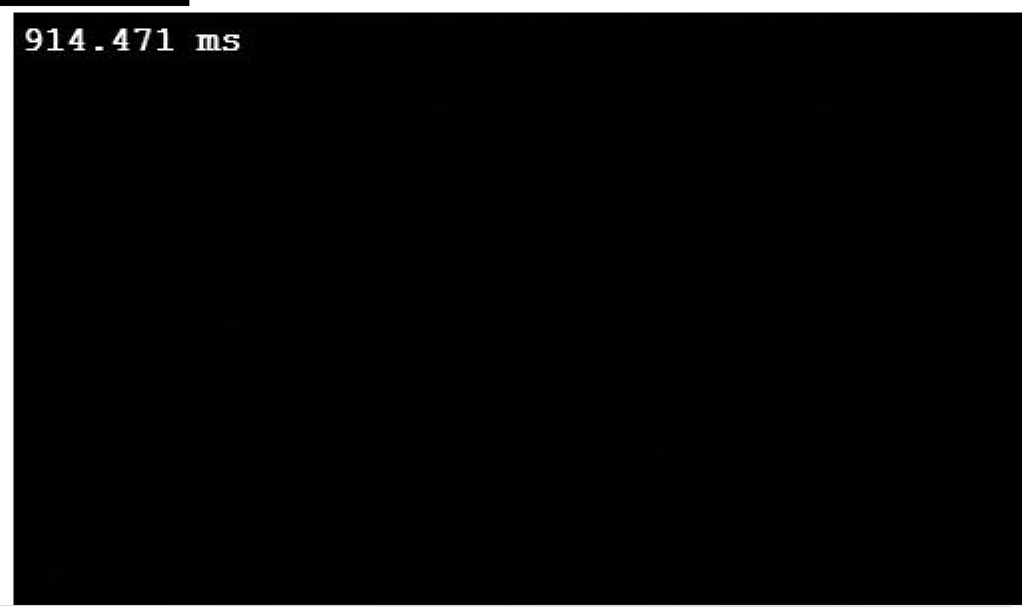
An explanation: Dynamic of surface melting

Evolution of the melt pool for a moving sample during the first line

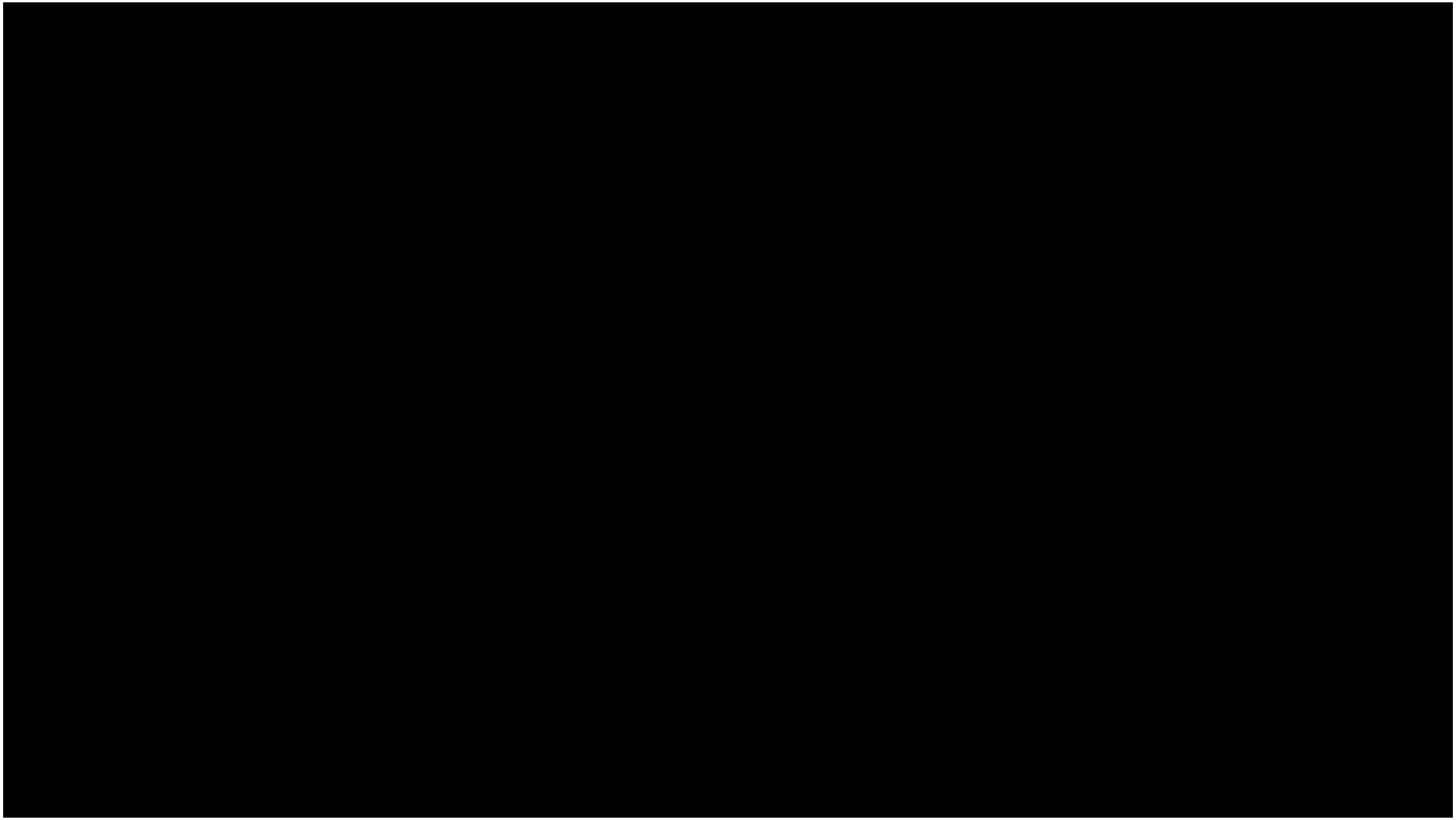
Empa- LAMP

Empa- LAMP

Evolution of the melt pool for a moving sample – return with 90% overlap



Another explanation: Dynamic of laser welding



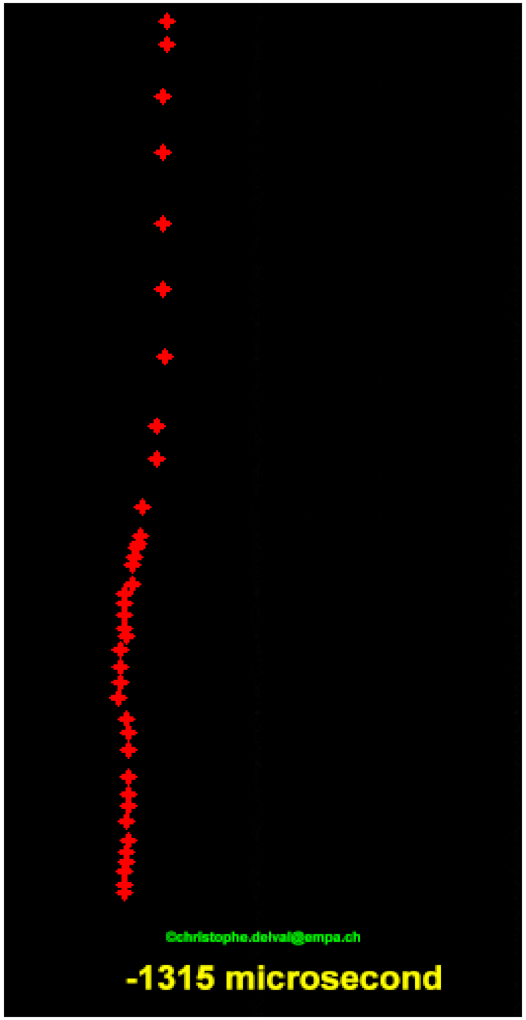
Slow motion - laser welding of different materials with high power LED illumination

https://www.youtube.com/watch?v=mHjn5xIuFko&feature=emb_logo

Another explanation: Dynamic of plasma plume

Another high speed camera video

https://www.youtube.com/watch?time_continue=38&v=BKdaBRkz8Vo&feature=emb_logo

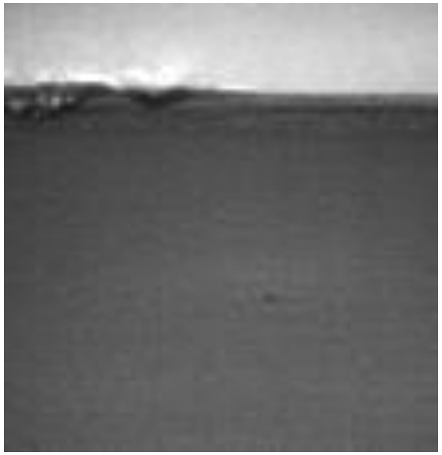


Plasma expansion and spatter during Al composite laser welding

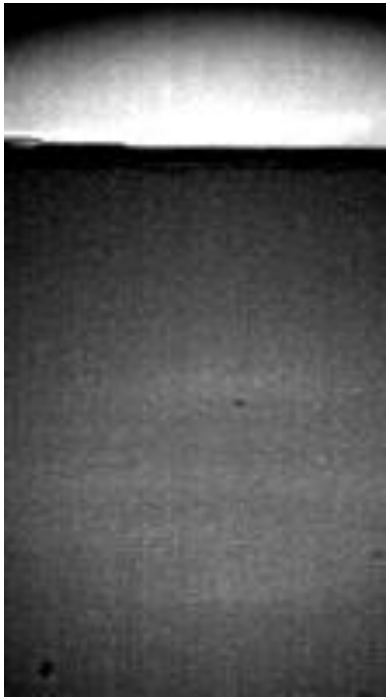
Empa- LAMP

Yet another explanation: Dynamic transients taking place inside the material at high velocities

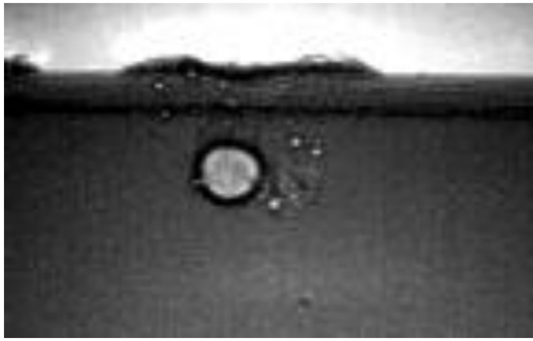
Conduction ⇨ keyhole



Conduction ⇨ unstable keyhole



Deep keyhole



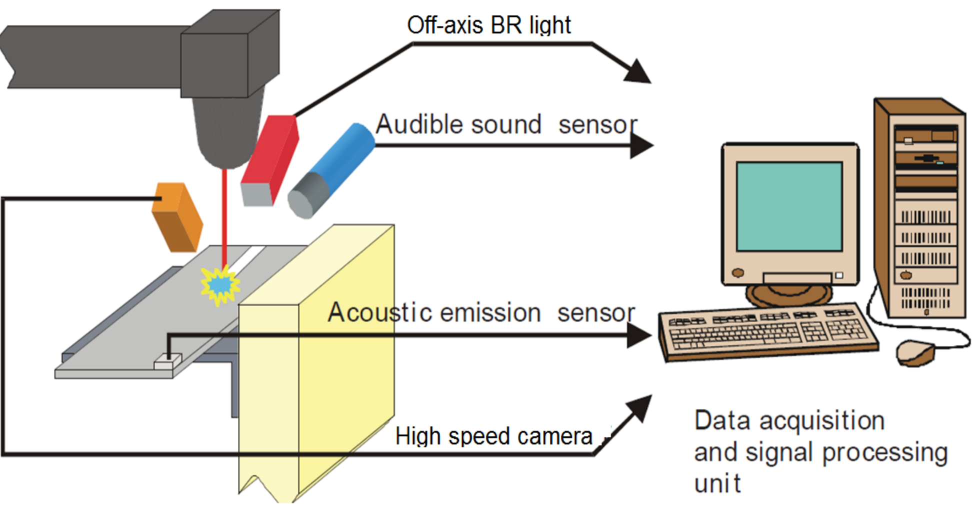
Pores removal

All videos from Empa- LAMP

One way to tackle these difficulties: Add sensors

Sensors

General Setup



Acoustic

Piezo

ptical fibre

You name it!

High

g

Optical sensors

OES

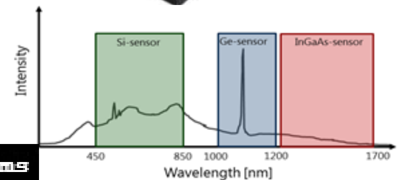
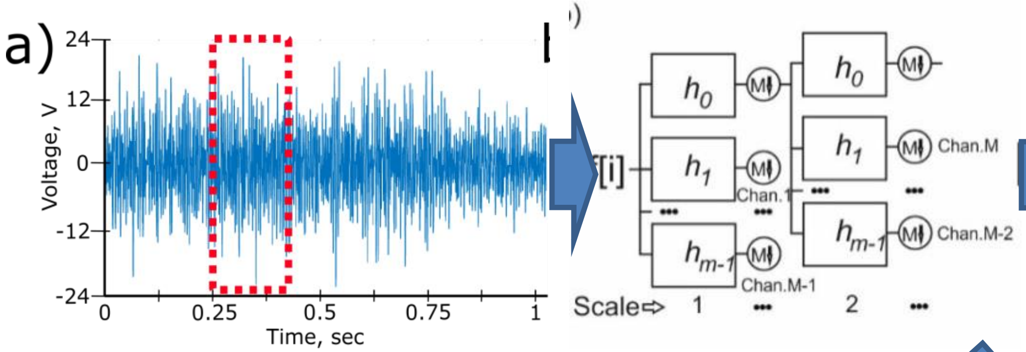
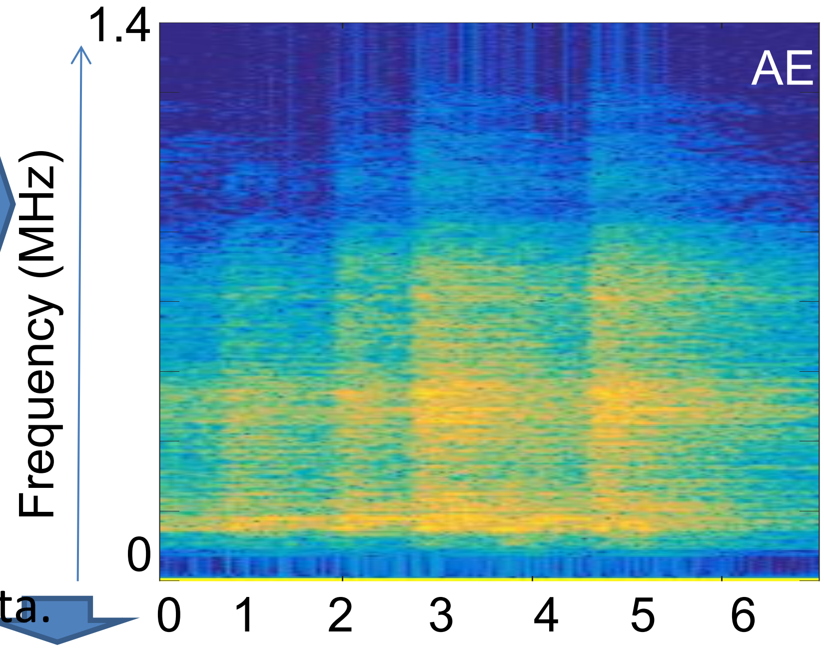


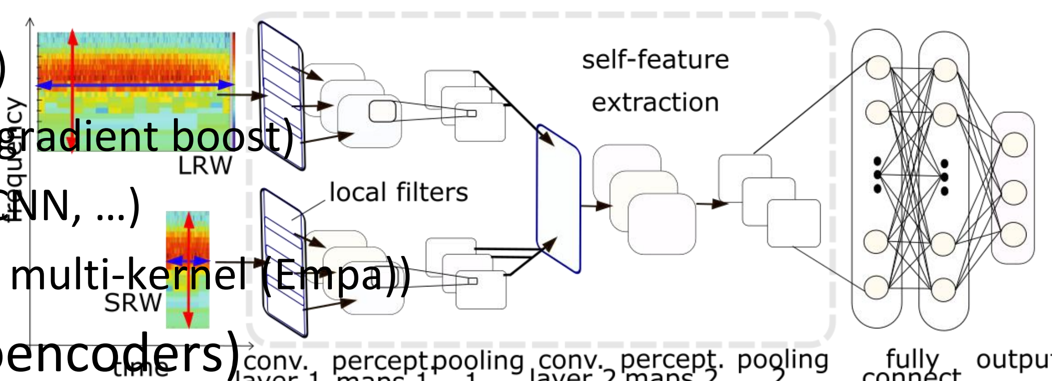
Photo-diode

One way to tackle these difficulties: Signal processing

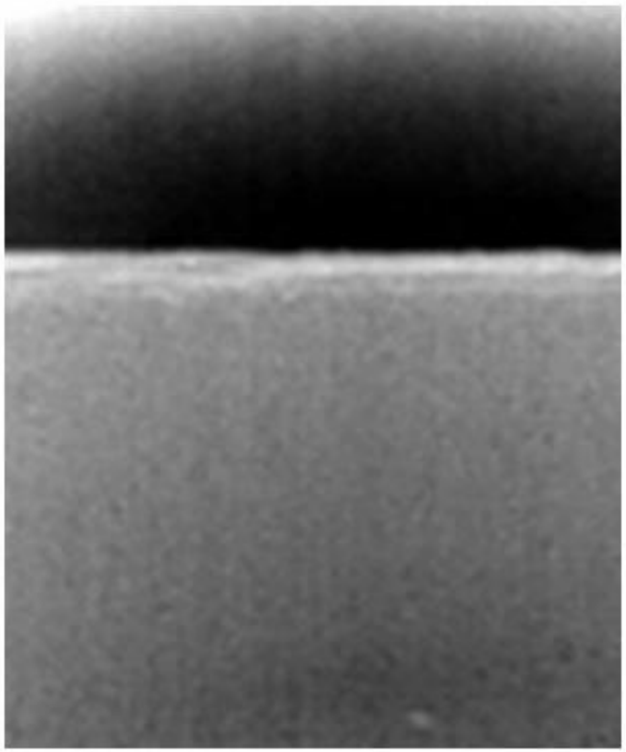


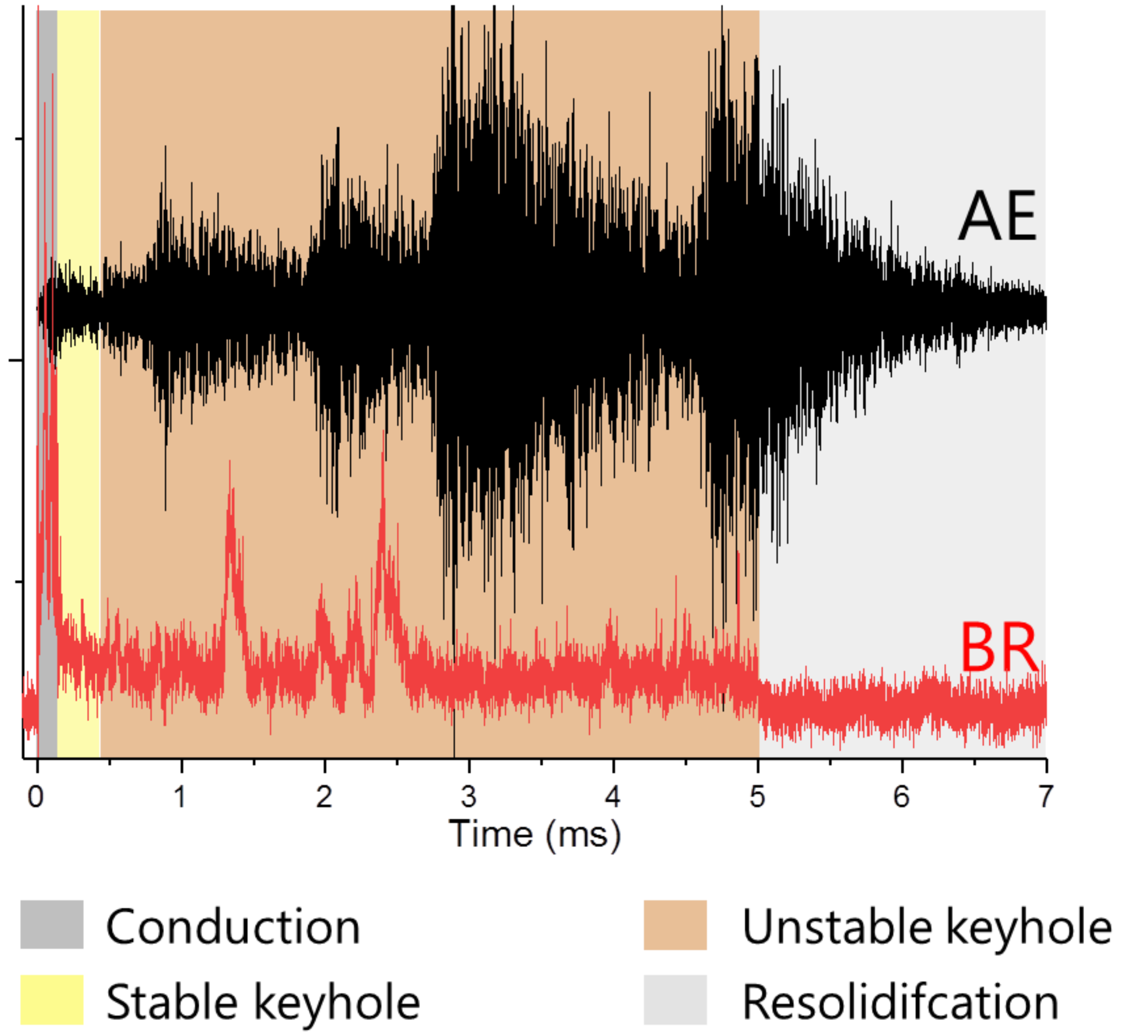


- Supervised learning
  - Infers a function from labelled training data.
  - Typical supervised learning
    - Support Vector Machine (SVM)
    - Decision tree (Random forest, gradient boost)
    - Deep Neural Network (CNN, SCNN, …)
    - Laplacian Graph (single kernel, multi-kernel (Empa))
- Unsupervised (e.g. k-mean, autoencoders)
- Reinforcement learning (game Go)



But linking signal to event is a real challenge





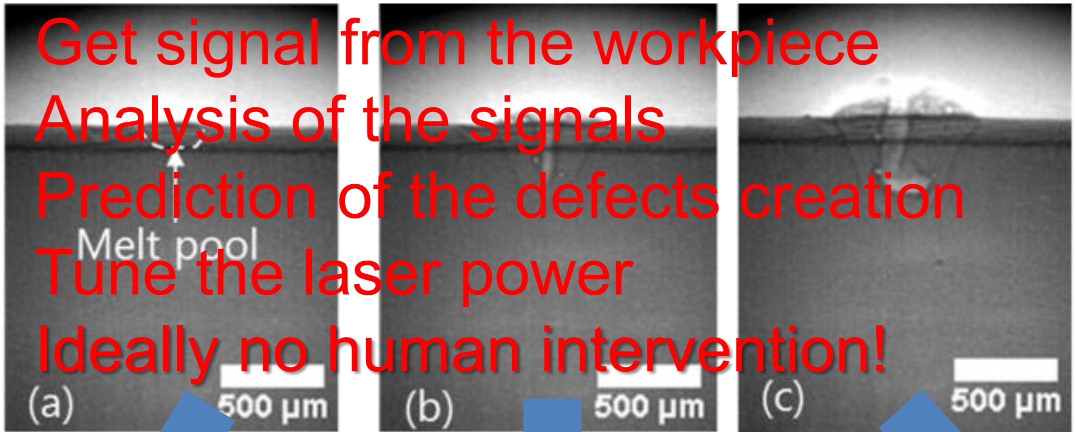
Aluminum plate 2mm thick,
no gas shielding, room temperature
Keyhole experiment with defects
Laser 1070 nm, pulse length 10 ms,
laser spot ∅ 30 μm
ESRF ID19 X-ray beam

The final objective: Realise the dreams of companies

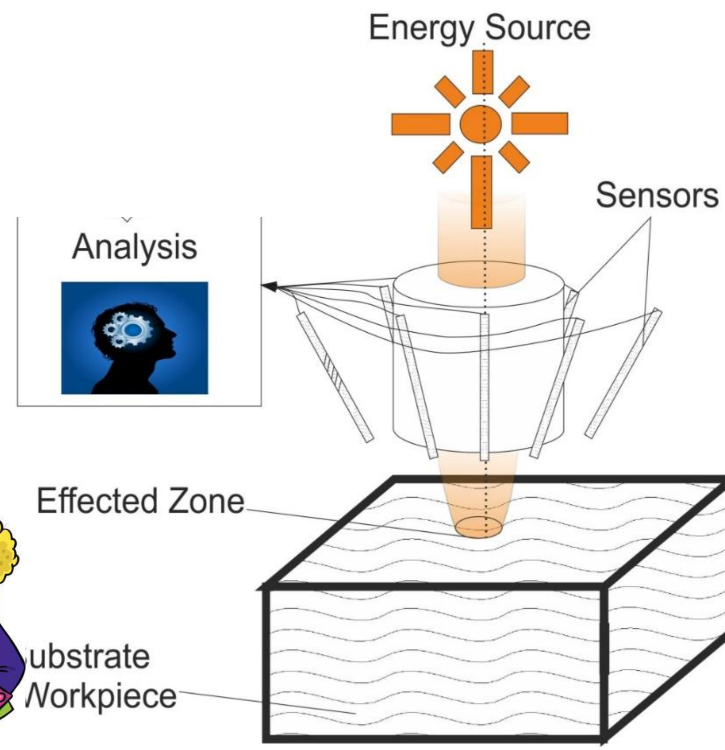
Classification tasks

Process runs

- Get signal from the workpiece
- Analysis of the signals
- Prediction of the defects creation
- Tune the laser power
- Ideally no human intervention!



Conduction weld · Stable keyhole · Unstable keyhole



You name it!

Sensors **Spatter** **Machine learning / Artificial intelligence** **Pore formation** **Human intelligence**

What is the team to achieve this goal?

An excellent technician/ engineer

ineer

A laser physicist

A conductor / A translator

An optics specialist

An acoustic specialist

A material scientist

Contents of the lecture

- Laser processing
  - Laser Principles
  - Laser types (e.g. fs, ps, ns, ms, continuous)
- Sensors
  - Acoustics (use, type, else)
  - Optics
  - Opto-acoustic (in particular Fiber Bragg Grating)
  - Visual

Contents of the lecture

- Data acquisition
  - Principles
  - Possibilities, limits
- Introduction to machine learning
  - Linear regression
  - Supervised methods
  - Semi-supervised methods
  - Unupservised methods
  - Reinforcement learning

Contents of the lecture

- A complete example of the approach for
  - Laser welding
  - Additive manufacturing

So le'ts start?