CENTRO SPERIMENTALE DEL MOBILE E DELL'ARREDAMENTO

dID distretto INTERNI DESIGN

NANJING FORESTRY UNIVERSITY

UNIVERSITÀ DEGLI STUDI FIRENZE

DIDA Dipartimento di Architettura

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University of Pisa

Department of Civil and Industrial Engineering

Additive manufacturing, 3D printing, prototyping

Tuesday July 30th 2019

h 14-17

Intensive Training Activity

Final Program

DIDA Department Santa Teresa

Florence

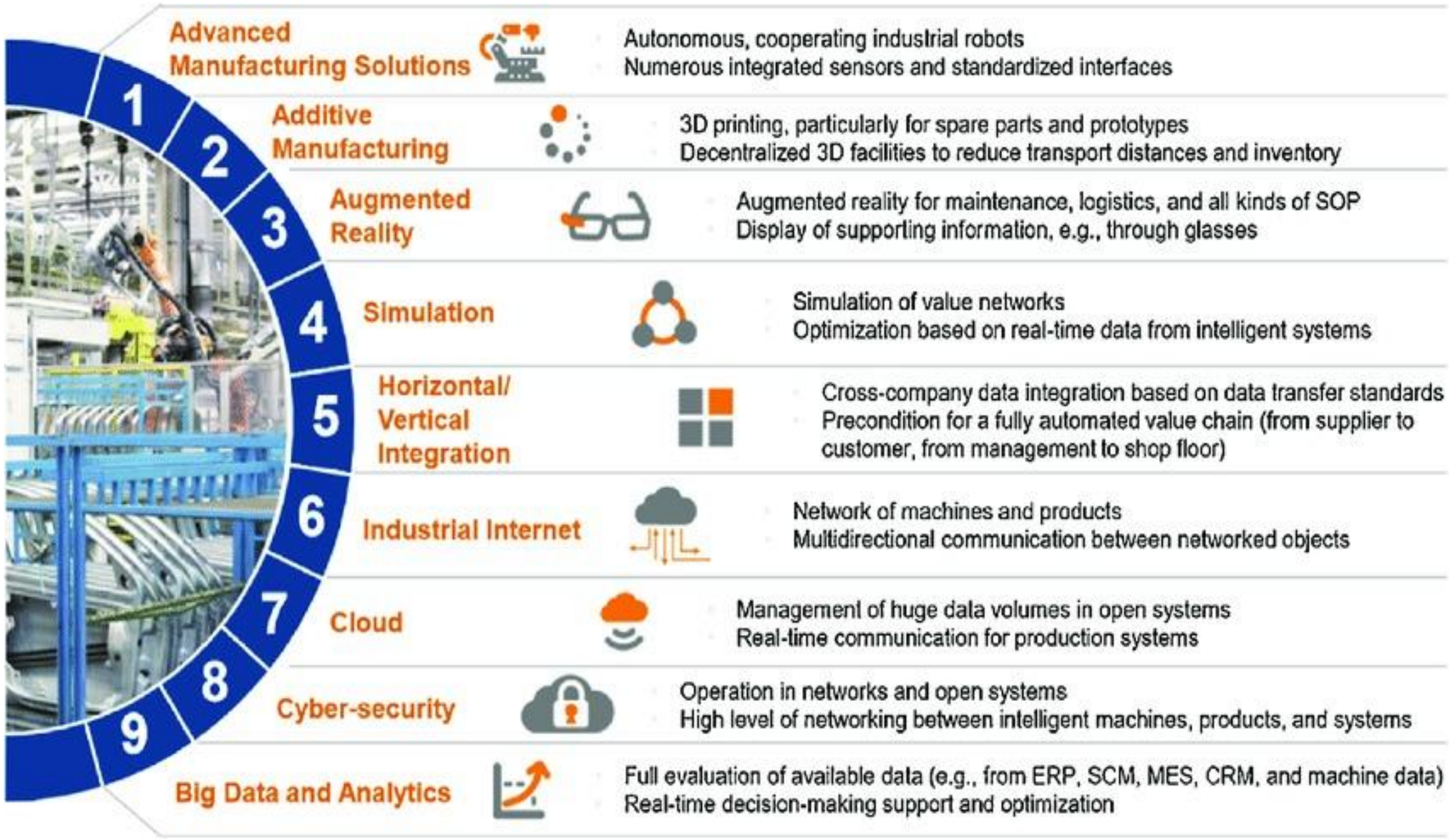
This presentation: www.lanzetta.unipi.it/research/am

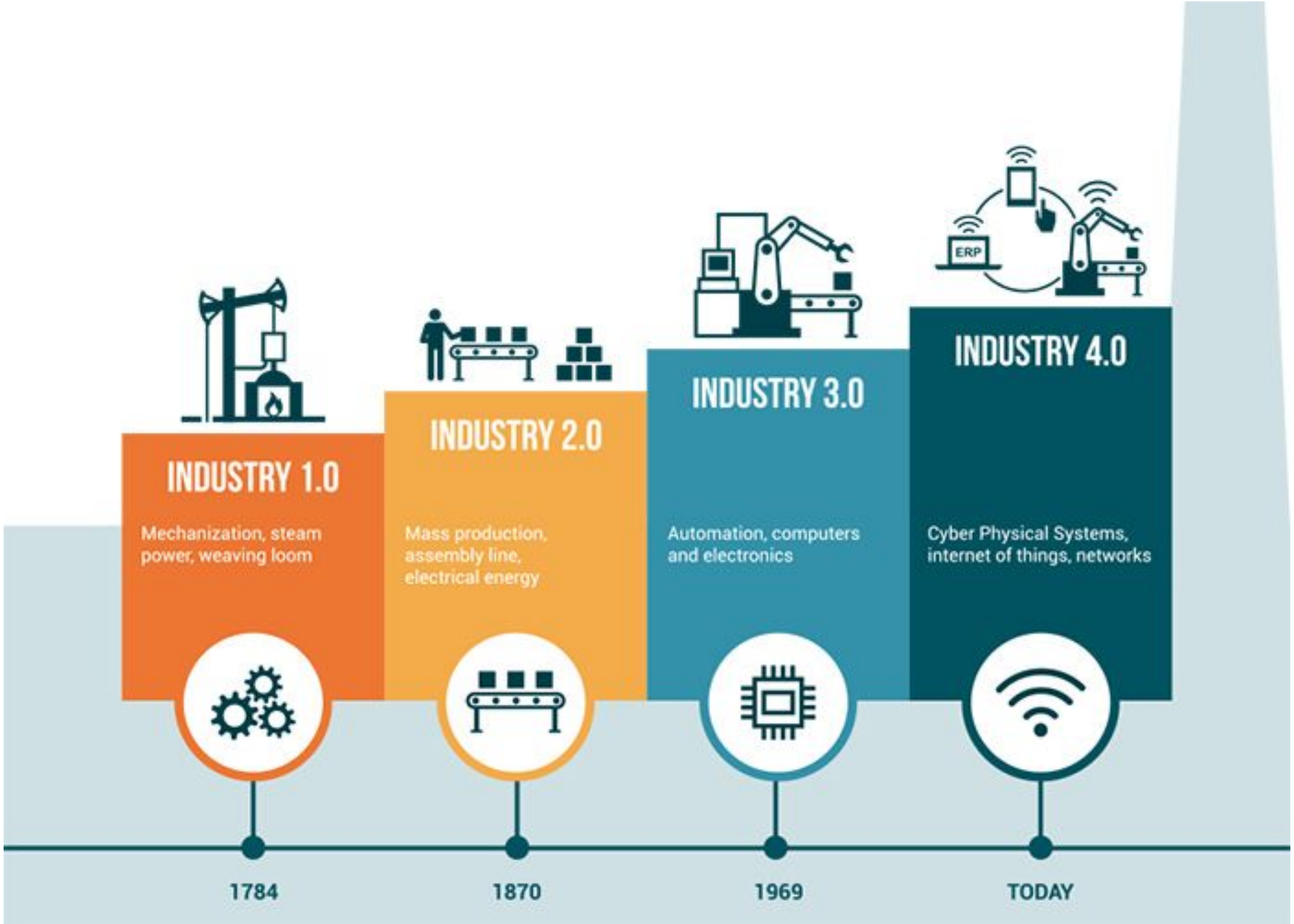
Photos

Shared Google Photos album (you can add your photos)

https://photos.app.goo.gl/dzDSNcG4vVYyeE5m7

Industry 4.0


1
Advanced Manufacturing Solutions
Autonomous, cooperating industrial robots
Numerous integrated sensors and standardized interfaces
2
Additive Manufacturing
3D printing, particularly for spare parts and prototypes
Decentralized 3D facilities to reduce transport distances and inventory
3
Augmented Reality
Augmented reality for maintenance, logistics, and all kinds of SOP
Display of supporting information, e.g., through glasses
4
Simulation
Simulation of value networks
Optimization based on real-time data from intelligent systems
5
Horizontal/ Vertical Integration
Cross-company data integration based on data transfer standards
Precondition for a fully automated value chain (from supplier to customer, from management to shop floor)
6
Industrial Internet
Network of machines and products
Multidirectional communication between networked objects
7
Cloud
Management of huge data volumes in open systems
Real-time communication for production systems
8
Cyber-security
Operation in networks and open systems
High level of networking between intelligent machines, products, and systems
9
Big Data and Analytics
Full evaluation of available data (e.g., from ERP, SCM, MES, CRM, and machine data)
Real-time decision-making support and optimization


ERP
INDUSTRY 1.0
Mechanization, steam power, weaving loom
INDUSTRY 2.0
Mass production, assembly line, electrical energy
INDUSTRY 3.0
Automation, computers and electronics
INDUSTRY 4.0
Cyber Physical Systems, internet of things, networks
1784
1870
1969
TODAY

Additive manufacturing: rapid prototyping comes of age

Ian Campbell, David Bourell, Ian Gibson

Rapid Prototyping Journal

ISSN: 1355-2546

Publication date: 8 June 2012

Purpose

The purpose of this paper is to provide a personalised view by the Editors of the *Rapid Prototyping Journal*.

Design/methodology/approach

It collects their years of experience in a series of observations and experiences that can be considered as a snapshot of where this technology is today.

Findings

Development of these technologies has progressed according to application, materials and how the designers have applied their creativity to such a unique manufacturing tool.

Originality/value

The paper predicts how the future of additive manufacturing will look from the perspective of three key elements: applications, materials and design.

Patent growth 2008-2017

Patent Classification B33Y Additive Manufacturing grew at a compound annual rate of 35% from 2013 to 2017

The only technology with a higher 5 year growth rate was e-Cigarettes at 45%. Machine Learning took third place at 34%, Autonomous Vehicles had a 27% CAGR, Moulding Materials 27%, Hybrid Vehicles 26%, Aerial Drones also 26% and Food at 24% was the 8th fastest growing technology by patent.

Filed patents in 2017

General Electric 89 - Xerox 78 - Boeing 50 - Desktop Metal 48 - Hewlett-Packard Development 48 - Ricoh Co 45 - Stratasys 40

https://3dprintingindustry.com/news/interview-new-study-shows-3d-printing-second-fastest-growing-technology-2017-127179/

Windows

Paint 3D

Additive Manufacturing Taxonomy

a quiz

Main areas of interest of Additive Manufacturing

… and material classes and costs

- Manufacturing - metal - 100k€
- Architectural/prototyping - plastics - 1k€
- Biomedical - living material

Designation: F2792 – 12a

Standard Terminology for Additive Manufacturing Technologies[1,2]

This standard is issued under the fixed designation F2792; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This terminology includes terms, definitions of terms, descriptions of terms, nomenclature, and acronyms associated with additive-manufacturing (AM) technologies in an effort to standardize terminology used by AM users, producers, researchers, educators, press/media and others.

NOTE 1—The subcommittee responsible for this standard will review definitions on a three-year basis to determine if the definition is still accurate as stated. Revisions will be made when determined to be necessary.

2. Referenced Documents

2.1 *ISO Standard:*[3]

ISO 10303 -1:1994 Industrial automation systems and integration -- Product data representation and exchange -- Part 1: Overview and fundamental principles

3. Significance and Use

3.1 The definitions of the terms presented in this standard were created by this subcommittee. This standard does not purport to address safety concerns associated with the use of AM technologies. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use of additive manufacturing.

4. Additive Manufacturing Process Categories

4.1 The following terms provide a structure for grouping current and future AM machine technologies. These terms are useful for educational and standards-development purposes and are intended to clarify which machine types share processing similarities. For many years, the additive manufacturing industry lacked categories for grouping AM technologies, which made it challenging educationally and when communicating information in both technical and non-technical settings. These process categories enable one to discuss a category of machines, rather than needing to explain an extensive list of commercial variations of a process methodology.

binder jetting, *n*—an additive manufacturing process in which a liquid bonding agent is selectively deposited to join powder materials.

directed energy deposition, *n*—an additive manufacturing process in which focused thermal energy is used to fuse materials by melting as they are being deposited.

DISCUSSION—"Focused thermal energy" means that an energy source (e.g., laser, electron beam, or plasma arc) is focused to melt the materials being deposited.

material extrusion, *n*—an additive manufacturing process in which material is selectively dispensed through a nozzle or orifice.

material jetting, *n*—an additive manufacturing process in which droplets of build material are selectively deposited.

DISCUSSION—Example materials include photopolymer and wax.

powder bed fusion, *n*—an additive manufacturing process in which thermal energy selectively fuses regions of a powder bed.

sheet lamination, *n*—an additive manufacturing process in which sheets of material are bonded to form an object.

vat photopolymerization, *n*—an additive manufacturing process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization.

5. Terminology

5.1 *Definitions:*

3D printer, *n*—a machine used for 3D printing.

3D printing, *n*—the fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology.

DISCUSSION—Term often used synonymously with additive manufacturing; in particular associated with machines that are low end in price and/or overall capability.

[1] This terminology is under the jurisdiction of Committee F42 on Additive Manufacturing Technologies and is the direct responsibility of Subcommittee F42.91 on Terminology.

Current edition approved March 1, 2012. Published March 2012. Originally approved in 2009. Last previous edition approved in 2012 as F2792–12. DOI: 10.1520/F2792-12A.

[2] Through a mutual agreement with ASTM International (ASTM), the Society of Manufacturing Engineers (SME) contributed the technical expertise of its RTAM Community members to ASTM to be used as the technical foundation for this ASTM standard. SME and its membership continue to play an active role in providing technical guidance to the ASTM standards development process.

[3] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=20579

3D scanning, *n*—a method of acquiring the shape and size of an object as a 3-dimensional representation by recording x,y,z coordinates on the object's surface and through software the collection of points is converted into digital data.

DISCUSSION—Typical methods use some amount of automation, coupled with a touch probe, optical sensor, or other device. Synonym: 3D digitizing.

additive manufacturing (AM), *n*—a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. Synonyms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, and freeform fabrication.

additive systems, *n*—machines used for additive manufacturing.

binder jetting, *n*—an additive manufacturing process in which a liquid bonding agent is selectively deposited to join powder materials.

direct metal laser sintering (DMLS®), *n*—a powder bed fusion process used to make metal parts directly from metal powders without intermediate "green" or "brown" parts; term denotes metal-based laser sintering systems from EOS GmbH - Electro Optical Systems. Synonym: direct metal laser melting.

directed energy deposition, *n*—an additive manufacturing process in which focused thermal energy is used to fuse materials by melting as they are being deposited.

DISCUSSION—"Focused thermal energy" means that an energy source (e.g., laser, electron beam, or plasma arc) is focused to melt the materials being deposited.

facet, *n*—typically a three- or four-sided polygon that represents an element of a 3D polygonal mesh surface or model; triangular facets are used in STL files.

fused deposition modeling (FDM®), *n*—a material extrusion process used to make thermoplastic parts through heated extrusion and deposition of materials layer by layer; term denotes machines built by Stratasys, Inc.

laser sintering (LS), *n*—a powder bed fusion process used to produce objects from powdered materials using one or more lasers to selectively fuse or melt the particles at the surface, layer by layer, in an enclosed chamber.

DISCUSSION—Most LS machines partially or fully melt the materials they process. The word "sintering" is a historical term and a misnomer, as the process typically involves full or partial melting, as opposed to traditional powdered metal sintering using a mold and heat and/or pressure.

material extrusion, *n*—an additive manufacturing process in which material is selectively dispensed through a nozzle or orifice.

material jetting, *n*—an additive manufacturing process in which droplets of build material are selectively deposited.

DISCUSSION—Example materials include photopolymer and wax.

powder bed fusion, *n*—an additive manufacturing process in which thermal energy selectively fuses regions of a powder bed.

prototype tooling, *n*—molds, dies, and other devices used to produce prototypes; sometimes referred to as bridge tooling or soft tooling.

rapid prototyping, *n*—additive manufacturing of a design, often iterative, for form, fit, or functional testing, or combination thereof.

rapid tooling, *n*—the use of additive manufacturing to make tools or tooling quickly, either directly, by making parts that serve as the actual tools or tooling components, such as mold inserts, or indirectly, by producing patterns that are, in turn, used in a secondary process to produce the actual tools.

rapid tooling, *n*—*in machining processes*, the production of tools or tooling quickly by subtractive manufacturing methods, such as CNC milling, etc.

reverse engineering, *n*—*in additive manufacturing*, method of creating a digital representation from a physical object to define its shape, dimensions, and internal and external features.

selective laser sintering (SLS®), *n*—denotes the LS process and machines from 3D Systems Corporation.

sheet lamination, *n*—an additive manufacturing process in which sheets of material are bonded to form an object.

stereolithography (SL), *n*—a vat photopolymerization process used to produce parts from photopolymer materials in a liquid state using one or more lasers to selectively cure to a predetermined thickness and harden the material into shape layer upon layer.

stereolithography apparatus (SLA®), *n*—denotes the SL machines from 3D Systems Corporation.

subtractive manufacturing, *n*—making objects by removing of material (for example, milling, drilling, grinding, carving, etc.) from a bulk solid to leave a desired shape, as opposed to additive manufacturing.

surface model, *n*—a mathematical or digital representation of an object as a set of planar or curved surfaces, or both, that may or may not represent a closed volume.

DISCUSSION—May consist of Bezier B-spline surfaces or NURBS surfaces. A surface model may also consist of a mesh of polygons, such as triangles, although this approach approximates the exact shape of the model.

tool, tooling, *n*—a mold, die, or other device used in various manufacturing and fabricating processes such as plastic injection molding, thermoforming, blow molding, vacuum casting, die casting, sheet metal stamping, hydroforming, forging, composite lay-up tools, machining and assembly fixtures, etc.

vat photopolymerization, *n*—an additive manufacturing process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization.

5.2 *Acronyms:*

CAD, *n*—Computer-Aided Design. The use of computers for the design of real or virtual objects.

CAM, *n*—Computer-Aided Manufacturing. Typically refers to systems that use surface data to drive CNC machines, such as digitally-driven mills and lathes, to produce parts, molds, and dies.

CNC, *n*—Computer Numerical Control. Computerized control of machines for manufacturing.

DISCUSSION—Common CNC machines include mills, lathes, grinders, and flame, laser, and water-jet cutters.

IGES, *n*—Initial Graphics Exchange Specification, a platform neutral CAD data exchange format intended for exchange of product geometry and geometry annotation information; IGES version 5.3 was superseded by ISO 10303, STEP in 2006.

DISCUSSION—IGES is the common name for a United States National Bureau of Standards standard NBSIR 80-1978, Digital Representation for Communication of Product Definition Data, which was approved by ANSI first as ANS Y14.26M-1981 and later as ANS USPRO/IPO-100-1996.

PDES, *n*—Product Data Exchange Specification or Product Data Exchange using STEP.

DISCUSSION—originally a product data exchange specification developed in the 1980s by the IGES/PDES Organization, a program of US Product Data Association (USPRO), it was adopted as the basis for and subsequently superseded by ISO 10303 STEP.

STEP, *n*—Standard for the Exchange of Product Model Data.

DISCUSSION—The common name for ISO 10303 that "provides a representation of product information, along with the necessary mechanisms and definitions to enable product data to be exchanged. [The standard] applies to the representation of product information, including components and assemblies; the exchange of product data, including storing, transferring, accessing, and archiving."

STL, *n*—*in additive manufacturing*, file format for 3D model data used by machines to build physical parts; STL is the de facto standard interface for additive manufacturing systems. STL originated from the term stereolithography.

DISCUSSION—The STL format, in binary and ASCII forms, uses triangular facets to approximate the shape of an object. The format lists the vertices, ordered by the right-hand rule, and unit normals of the triangles, and excludes CAD model attributes.

6. Keywords

6.1 additive manufacturing; rapid prototyping; 3D printing

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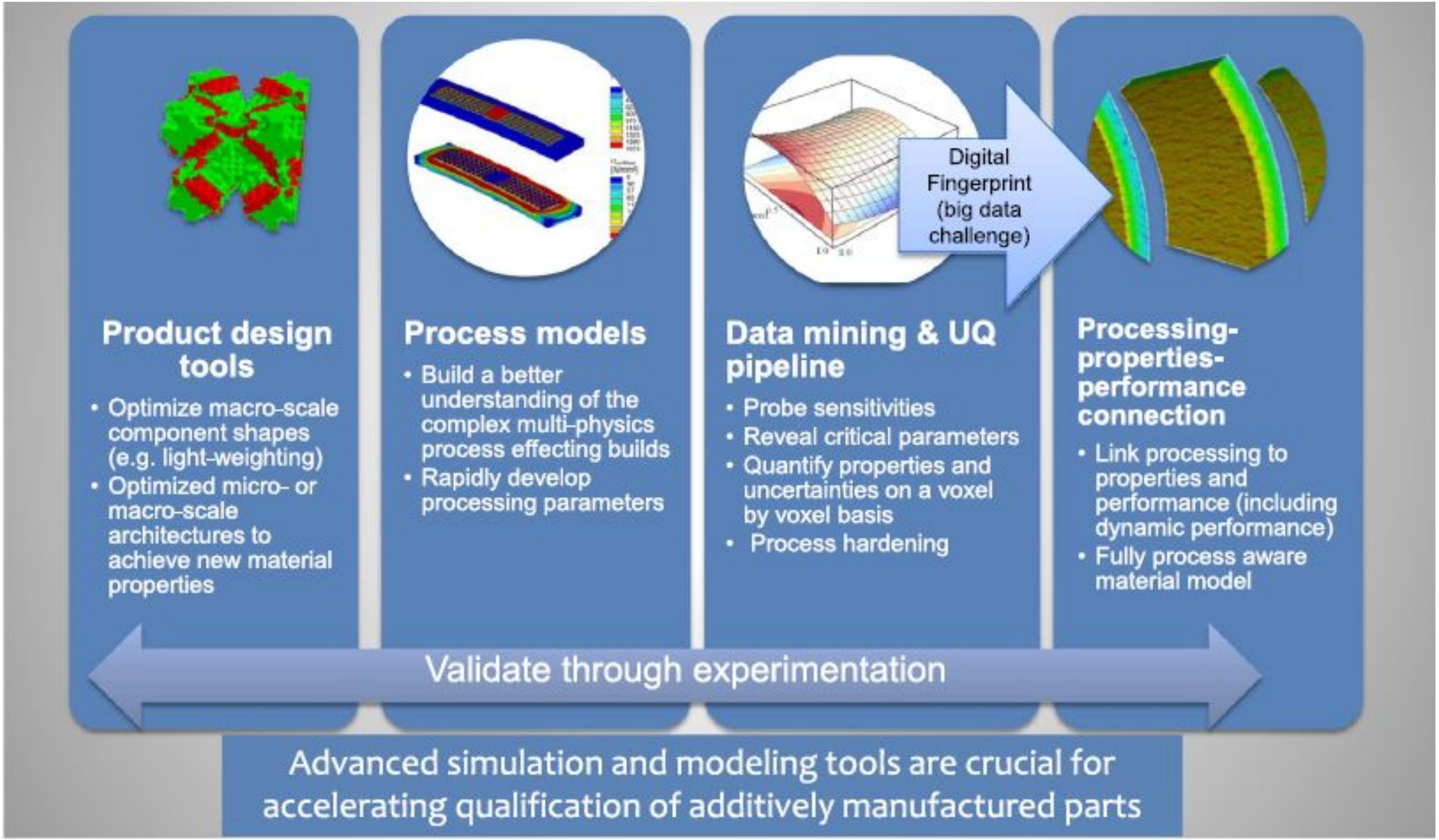
(1) Wohlers Report 2011; http://wohlersassociates.com

(2) Castle Island; http://www.additive3d.com

http://web.mit.edu/2.810/www/files/readings/AdditiveManufacturingTerminology.pdf

LLNL'S HPC Lawrence Livermore National Laboratory High Performance Computing Modelling and Simulation Capabilities



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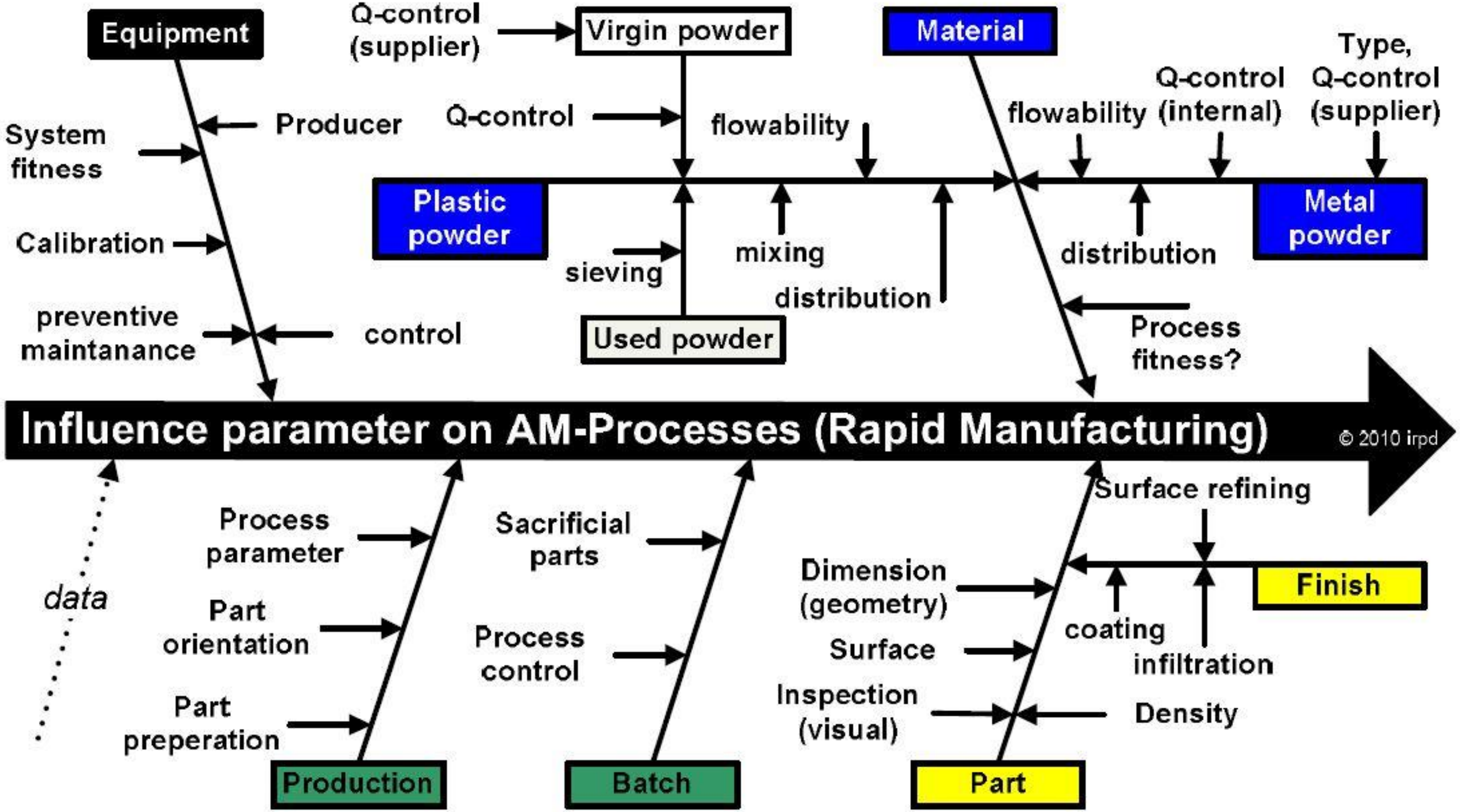
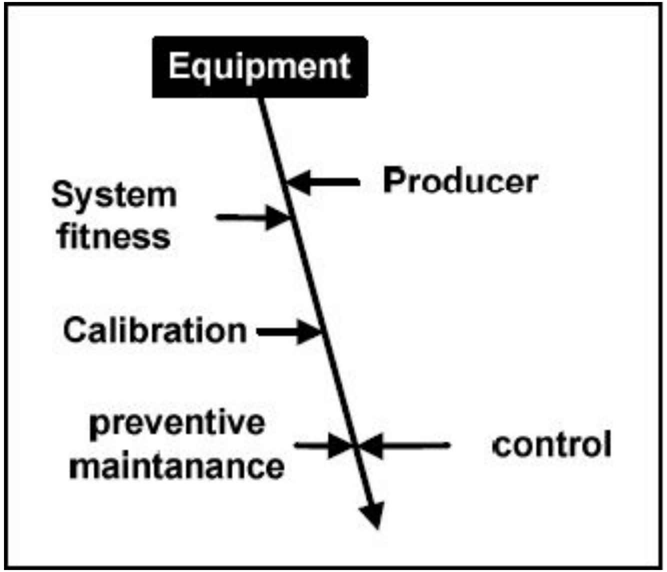
Q-Management Ishikawa AM



Schmid, M., & Levy, G. (2012). Quality management and estimation of quality costs for additive manufacturing with SLS. In *Fraunhofer Direct Digital Manufacturing Conference 2012*. ETH-Zürich.

Equipment/System



a)

Action	Documentation	Comments	F*	R*
conduct equipment logbook and machine checklist (eventually integrated in e-RP)	any relevant Q-activity (see below) and any machine problem and maintenance	conduct a logbook/checklist for every production equipment;	---	The system fitness and performance and all connected aspects regarding equipment are under the responsibility of the part producer
Cleanliness: maintain constant cleaning; sustain overall cleanness; check clarity of laser window (after every build);	any activity must be confirmed at a machine checklist	for cleaning activities see also specification of equipment supplier	daily	
System fitness: Periodical complete machine service (preferably every three month - service contract)	check of laser and optical system, temperature control, inert gas supply, replacement of wear parts (filter, scraper,…);	Service should be performed by special skilled people (e.g. machine supplier service or service companies;	quaterly	
System performance: A specially designed reference part (benchmark) must be built and analysed	benchmark part to be analysed regarding: - Weight (density) - Scaling - Tolerances - Beam offset - Surface roughness (R_a, R_z and different orientation) ??	producer without analytical equipment should have a contract with a service laboratory; Retain samples must be stored for the whole production period of the machine.	monthly	

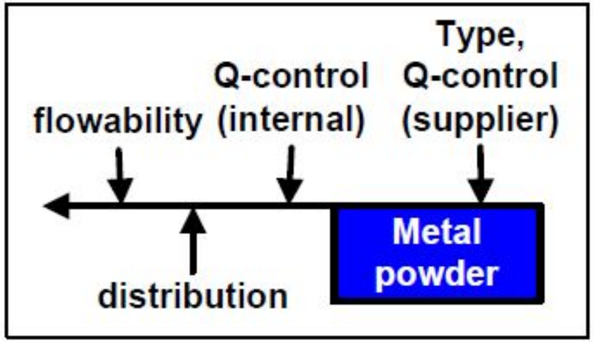
* = F =Frequency; R = Responsibility

b)

a) Q-elements of Equipment; b) Recommended Q-activities Equipment/ System

Schmid, M., & Levy, G. (2012). Quality management and estimation of quality costs for additive manufacturing with SLS. In *Fraunhofer Direct Digital Manufacturing Conference 2012*. ETH-Zürich.

Equipment/System metal powder



a)

Action	*Documentation*	*Comments*	*F**	*R***
conduct a material logbook	collect any material documentation	no particular Q-check of metal material	--	The quality of fresh metal powder must be guaranteed by the material supplier;
check delivered material data sheet regarding guaranteed value (according to agreement with material supplier)	Following data to be given at least for new batch: - Production identification (e.g. chargen number) - Powder distribution (e.g. d10 / d50 / d90)	Preferebly further data are disclosed by supplier: - chemical composition - REM / microscope picture - powder density	as needed	
sieving	type and mesh size of sieve	prefered mesh size: 48 μm	every batch	

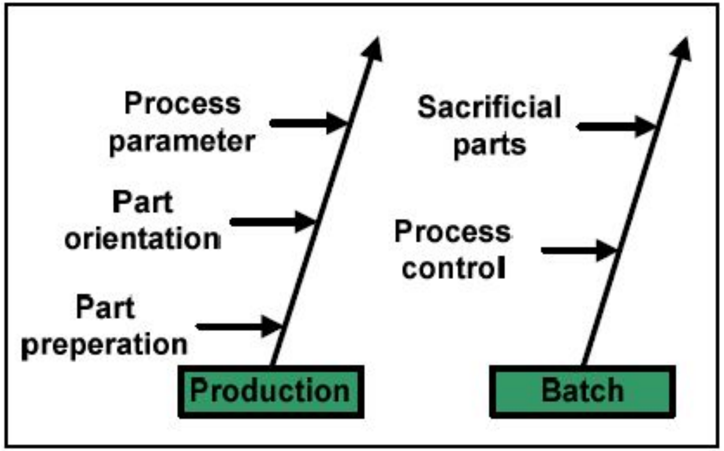
*F =Frequency; **R = Responsibility

b)

a) Q-elements of Metal Powder; b) Recommended Q-activities of Metal Powder

Schmid, M., & Levy, G. (2012). Quality management and estimation of quality costs for additive manufacturing with SLS. In *Fraunhofer Direct Digital Manufacturing Conference 2012*. ETH-Zürich.

Equipment/System Production and Batch



a)

Action	*Documentation*	*Comments*	*F**	*R***
record relevant production/batch parameter for every single part	part orientation within build; build parameter: laser power, scan spacing, temperature profile, scan strategy, layer thickness, laser exposure style, scan speed, hatch distance scan vector length, atmosphere	the recording and storing of these data should be preferably realised with specialized production software; e.g. eRP-System of Materialise or EOSTAT of EOS;	daily	The part production process is under the responsibility of the part producer;
comment: <u>no</u> standardised production of test bars for every build		production of special test bars for every build is to much effort and costs as well	--	

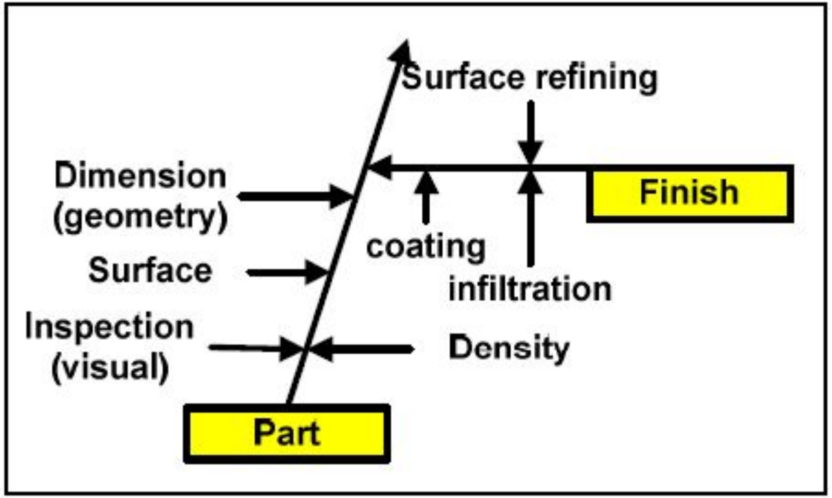
*F =Frequency; **R = Responsibility

b)

a) Q-elements of Production and Batch; b) Recommended Q-activities of Production and Batch

Schmid, M., & Levy, G. (2012). Quality management and estimation of quality costs for additive manufacturing with SLS. In *Fraunhofer Direct Digital Manufacturing Conference 2012*. ETH-Zürich.

Equipment/System Part and Finishing



a)

Action	Documentation	Comments	F*	R**
conduct a part protocol	collect any part specification		--	The final part quality and the desired finishing is under the responsibility of the part producer;
perform quality check (qualitative)	- optical inspection & dimension check - surface control (roughness) - weight (density)		as needed	
check comparison to order specification	- part quantity - on time delivery - special requirements - pre-assambly			
perform defined finishing	- infiltration (which infiltrate) - coating (e.g. colour) - surface optimization (vibratory grinding)			

*F =Frequency; **R = Responsibility

b)

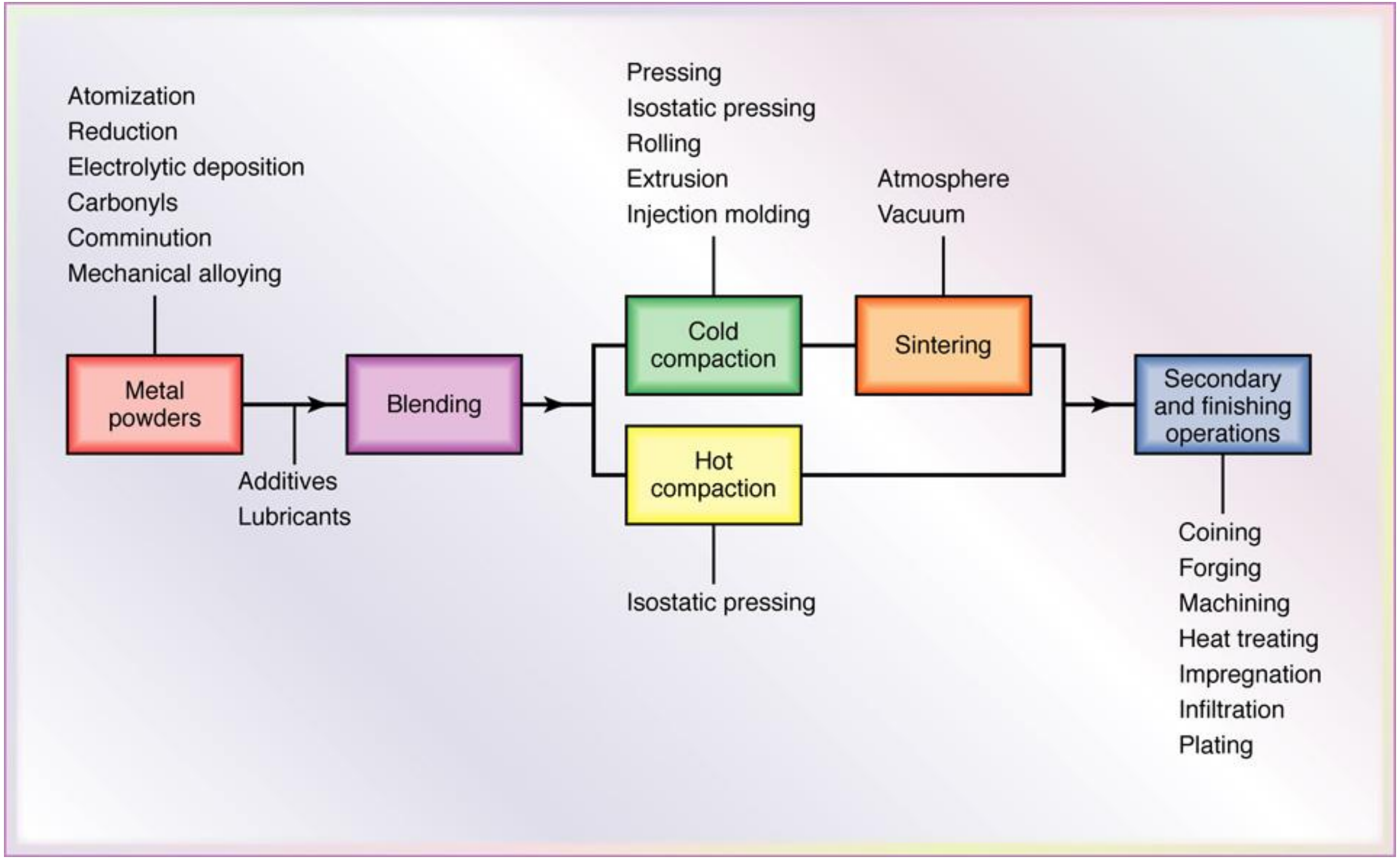
a) Q-elements of Part and Finishing; b) Recommended Q-activities of Part and Finishing

Schmid, M., & Levy, G. (2012). Quality management and estimation of quality costs for additive manufacturing with SLS. In *Fraunhofer Direct Digital Manufacturing Conference 2012*. ETH-Zürich.

Selective laser sintering

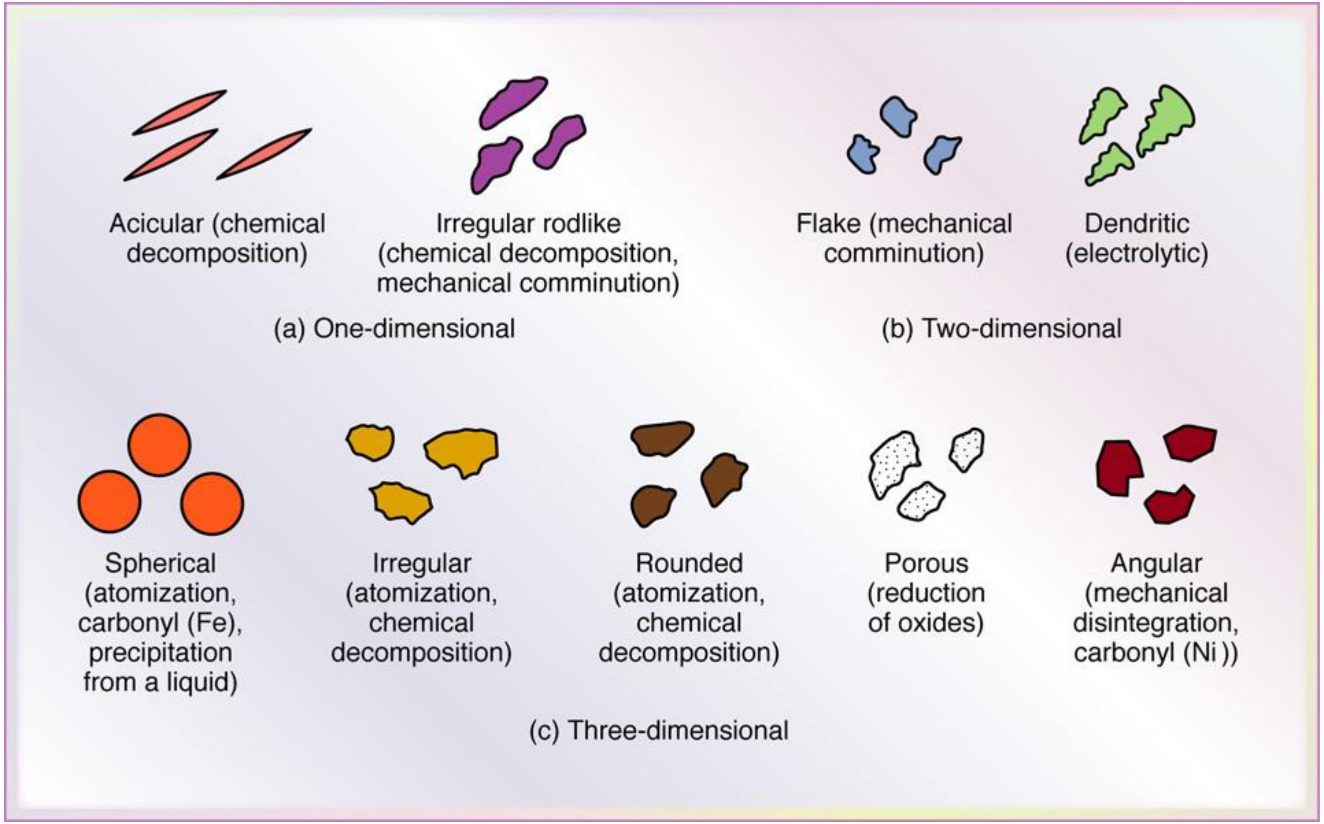
powder agglomeration by laser

Steps in Making Powder-Metallurgy Parts



Outline of processes and operations involved in making powder-metallurgy parts

Particle Shapes in Metal Powders



Particle shapes in metal powders, and the processes by which they are produced. Iron powders are produced by many of these processes.

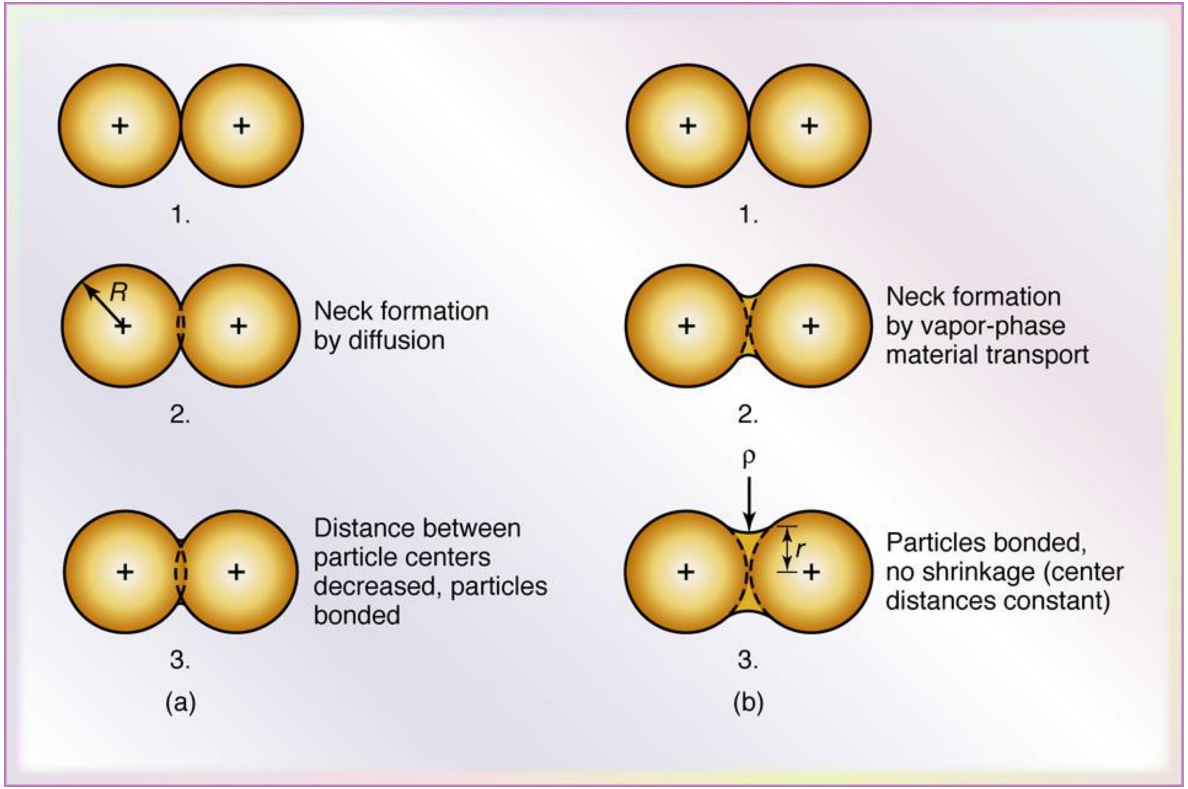
Sintering Time and Temperature for Metals

TABLE 17.2

Sintering Temperature and Time for Various Metals

Material	Temperature (°C)	Time (min)
Copper, brass, and bronze	760-900	10-45
Iron and iron-graphite	1000-1150	8-45
Nickel	1000-1150	30-45
Stainless steels	1100-1290	30-60
Alnico alloys (for permanent magnets)	1200-1300	120-150
Ferrites	1200-1500	10-600
Tungsten carbide	1430-1500	20-30
Molybdenum	2050	120
Tungsten	2350	480
Tantalum	2400	480

Mechanisms for Sintering Metal Powders



Schematic illustration of two mechanisms for sintering metal powders: (a) solid-state material transport; and (b) vapor-phase material transport. *R* = particle radius, *r* = neck radius, and *p* = neck-profile radius.

Manufacturing, Engineering & Technology, Fifth Edition, by Serope Kalpakjian and Steven R. Schmid. ISBN 0-13-148965-8.

ELSEVIER

Journal of Cleaner Production

Volume 18, Issues 16–17, November 2010, Pages 1722-1730

Experimental analysis of selective laser sintering of polyamide powders: an energy perspective

Alessandro Franco [a], Michele Lanzetta [b], Luca Romoli [b]

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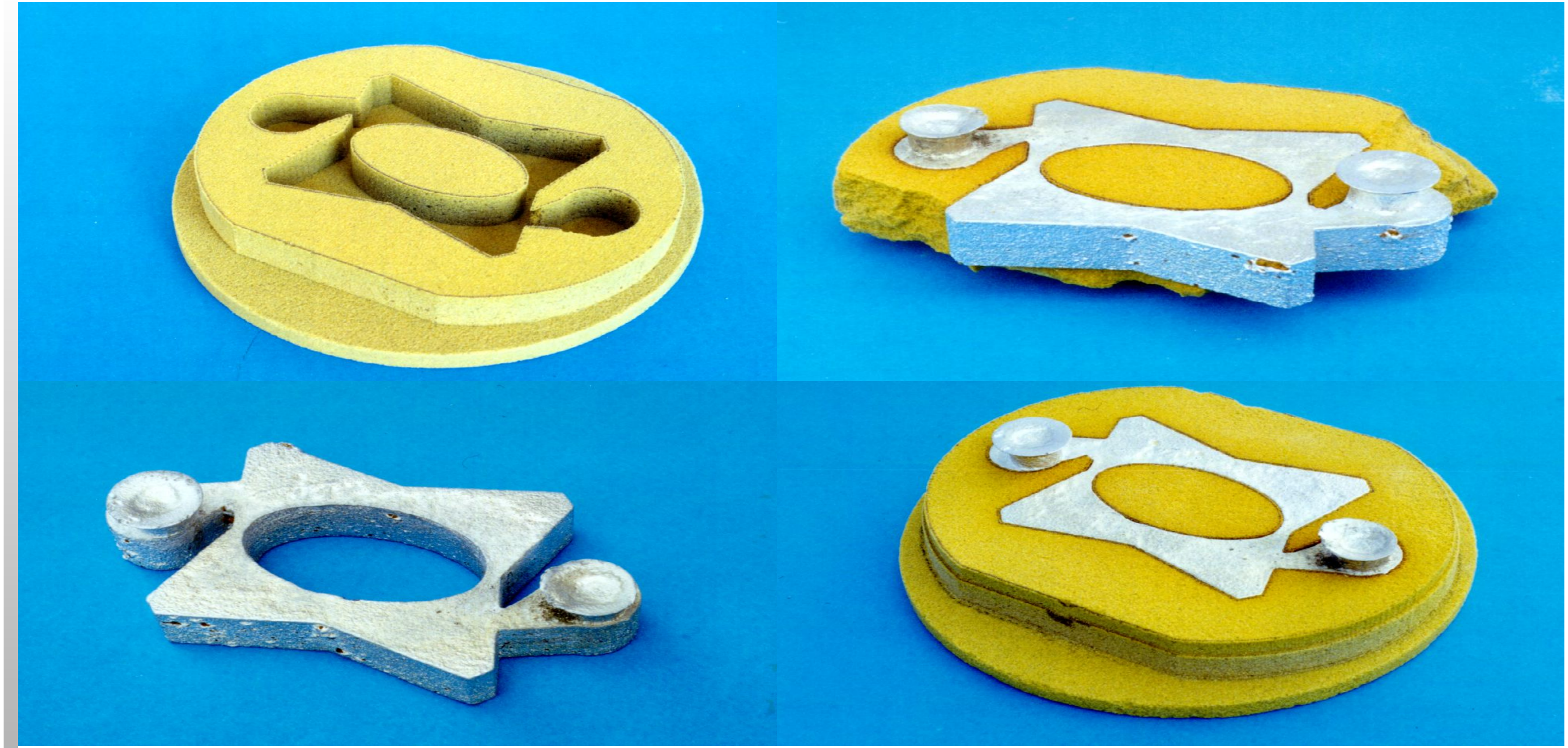
Abstract

This paper presents an analysis of Selective Laser Sintering (SLS) from an energy standpoint. Selective Laser Sintering (SLS) has a potential as an environmental benign alternative to traditional processes but only few authors deal with the process optimisation including energy aspects. In the present paper an analysis of

https://www.sciencedirect.com/science/article/pii/S0959652610002763

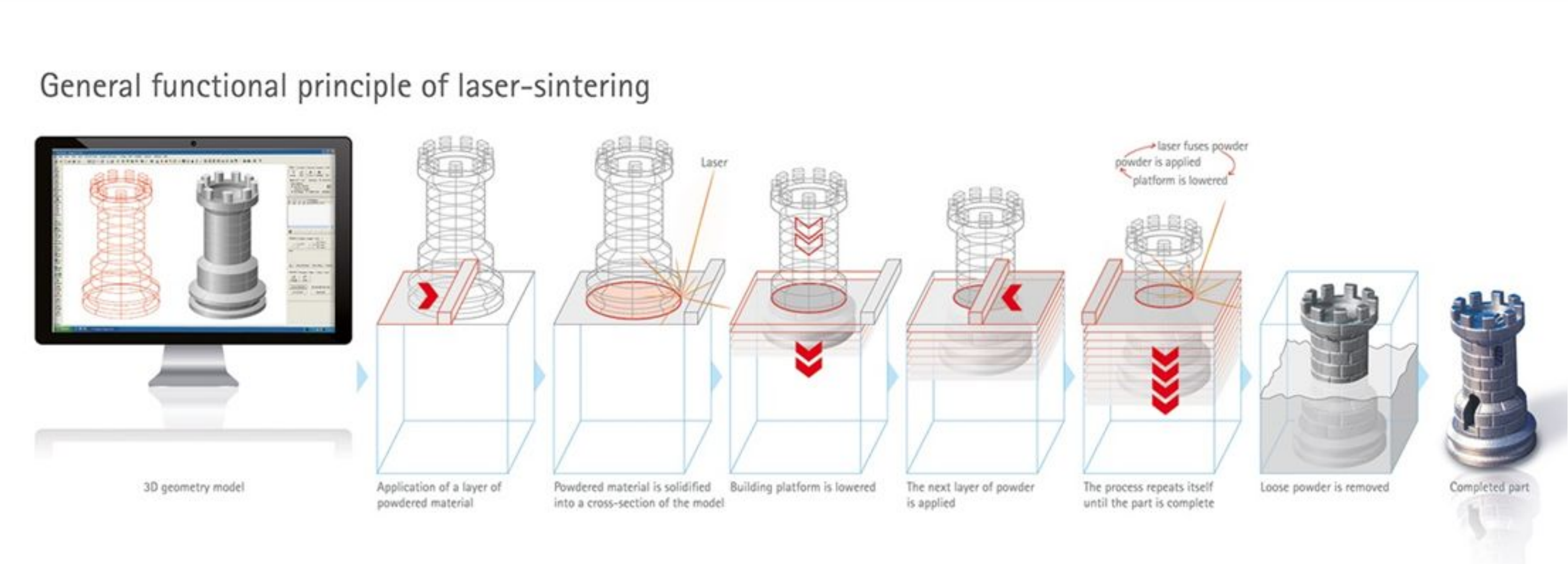


Monitoring

Direct Metal Laser Sintering

DEFECTS ANALYSIS AND MONITORING STRATEGIES

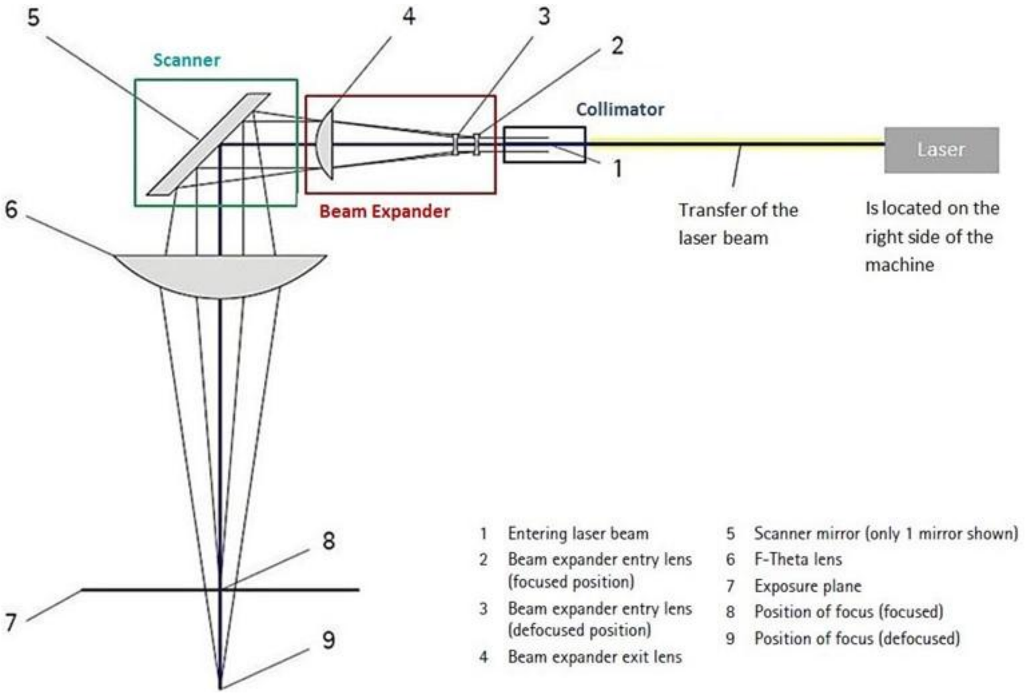
Direct Metal Laser Sintering (DMLS) Process



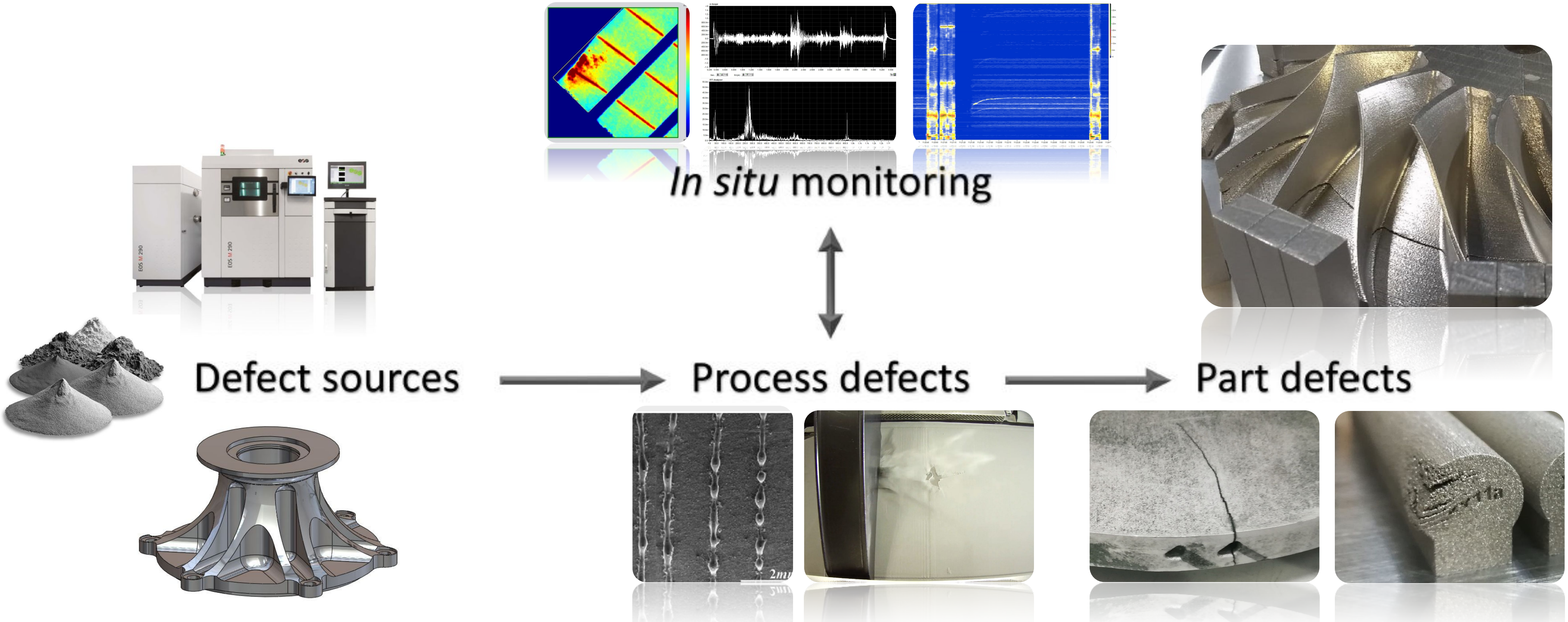
Direct Metal Laser Sintering (DMLS) Process

Optical system

- Laser: Ytterbium 1064 nm
- Optical fiber: bring the radiation from the laser
- Collimator: collimate the laser radiation
- Beam expander: increase the beam diameter
- Scanner: with high dynamic mirrors to direct the beam
- F-Theta lens: focus the beam

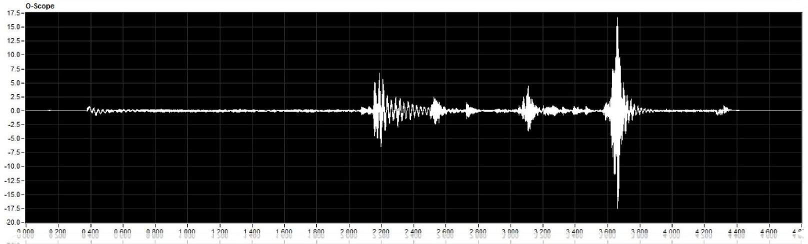


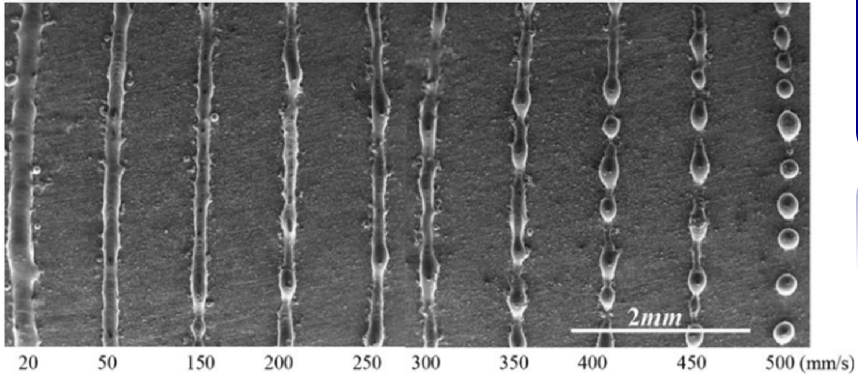
Defects classification



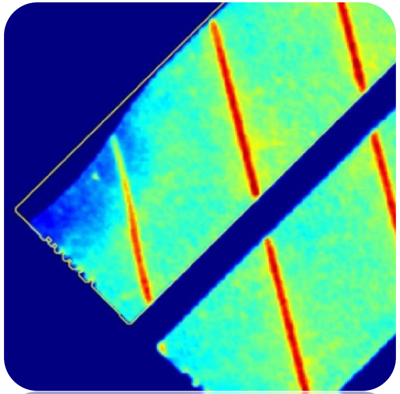
Defects classification

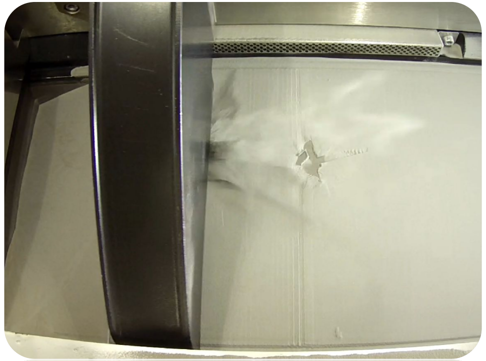
Process defects

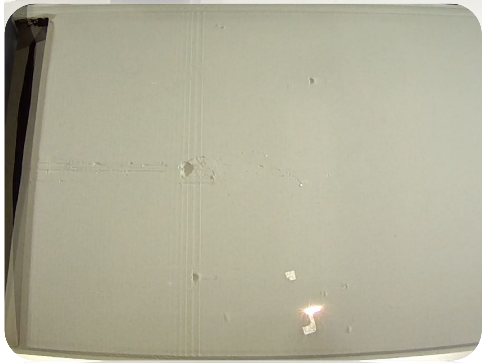




R. LI et al. 2012

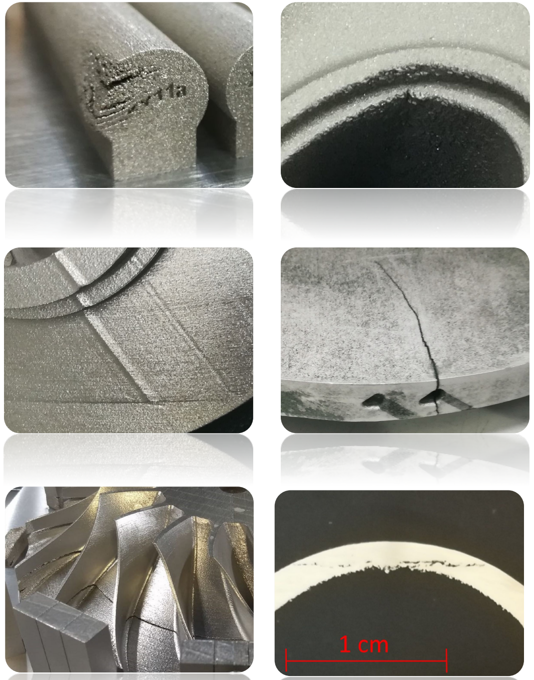






Defects classification

Part defects



Process defects	Part defects					
	Incompleted parts	Geometric defects	Surface defects	Residual stress, cracks and delamination	Porosity	Microstructural inhomogeneity and impurity
Powder bed						
Lack of powder	●	●	●	●	●	●
Recoater collision	●	●	●		●	●
Recoater vibration			●			
Particle drag		●	●		●	●
Melting						
MeltPool instability			●		●	●
Spatter emission			●		●	●
Hot/Cold spot			●	●	●	●
Balling		●	●		●	●
Gas flow						
Instability			●		●	●
Dishomogeneity			●	●	●	●
Laser scanning						
Geom. deformation		●				
Lack of power			●		●	●
Thermal						
Deformation	●	●		●		

Defects classification

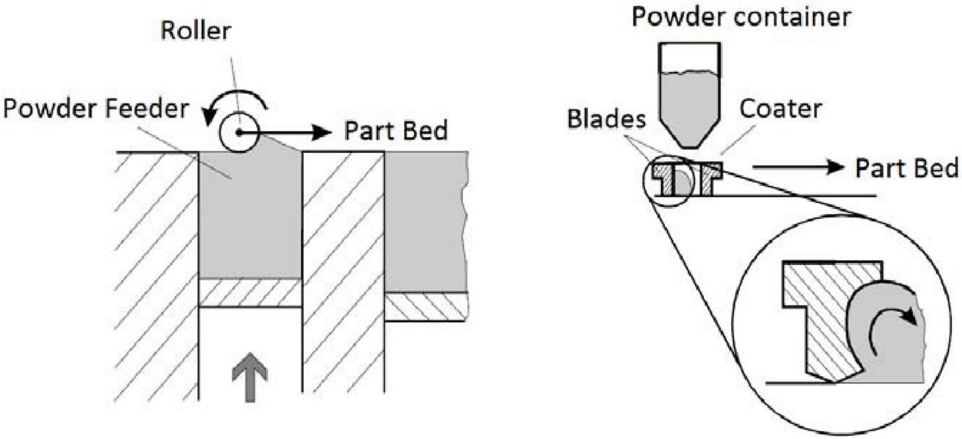
Defect sources

	Defects cause														
	Machine							Design							Powder
Process defects	Optical chain	Building platform	Machine calibration	Laser	Filtration system	Recoating system	Software	Layer thickness	Process parameters	Part orientation	Supports	Part shape	Powder bed parameters	Gas flow parameters	
Powder bed															
Lack of powder						●							●		
Recoater collision		●	●			●		●	●	●	●	●			
Recoater vibration		●				●		●	●		●	●	●		●
Particle drag		●				●		●	●		●	●			●
Melting															
MeltPool instability	●		●	●	●		●	●	●					●	●
Spatter emission			●	●	●		●	●	●					●	●
Hot spot			●	●	●		●		●		●	●		●	
Cold spot	●		●	●			●		●			●		●	
Balling			●	●			●	●	●						
Gas flow															
Instability					●									●	
Dishomogeneity					●									●	
Laser scanning															
Geom. deformation	●		●				●								
Lack of power	●		●	●	●		●								
Thermal															
Deformation		●			●			●	●	●	●	●		●	

Direct Metal Laser Sintering (DMLS) Process

Recoating system

- Today two different spreading system are present on the market
- A roller or a blade spread the powder on the bed

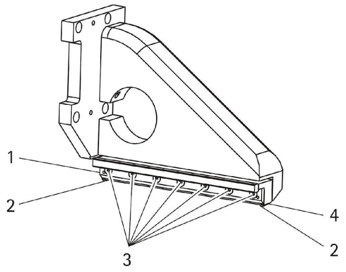


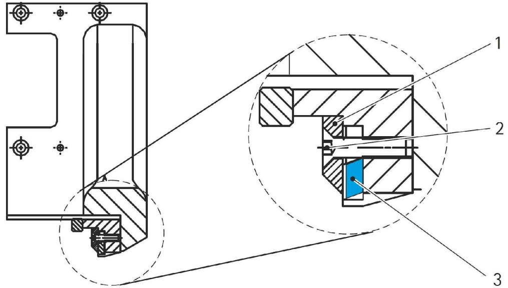
A. Amado et al. 2011

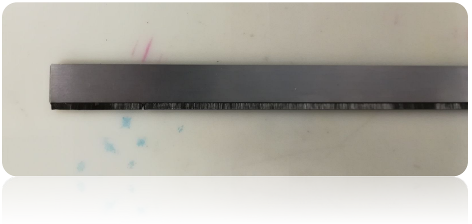
Direct Metal Laser Sintering (DMLS) Process

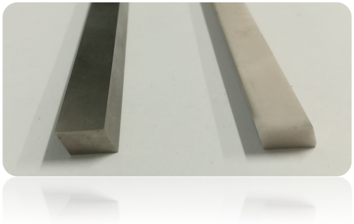
Recoating system

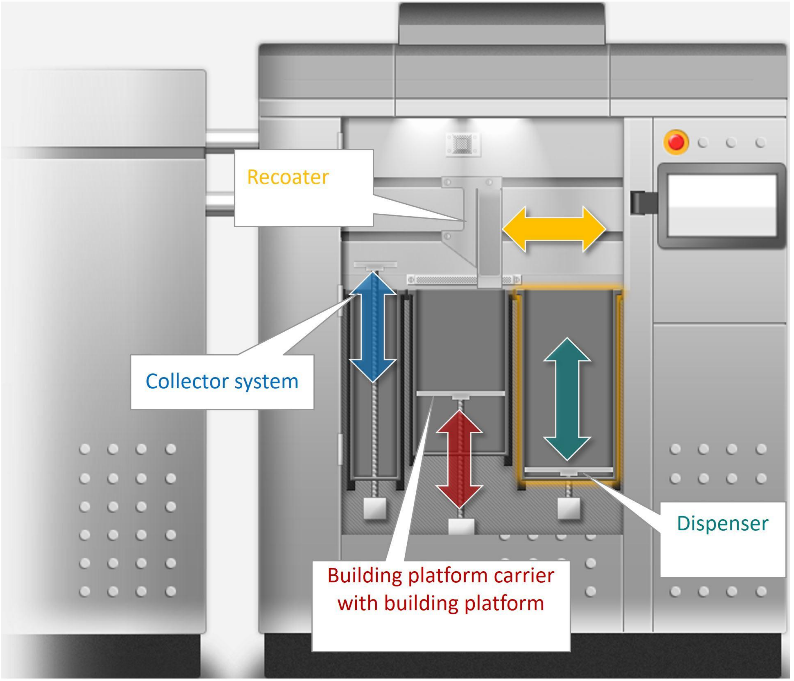
- 3 platform on EOS® M280 e M290
- Recoater with changeable blade



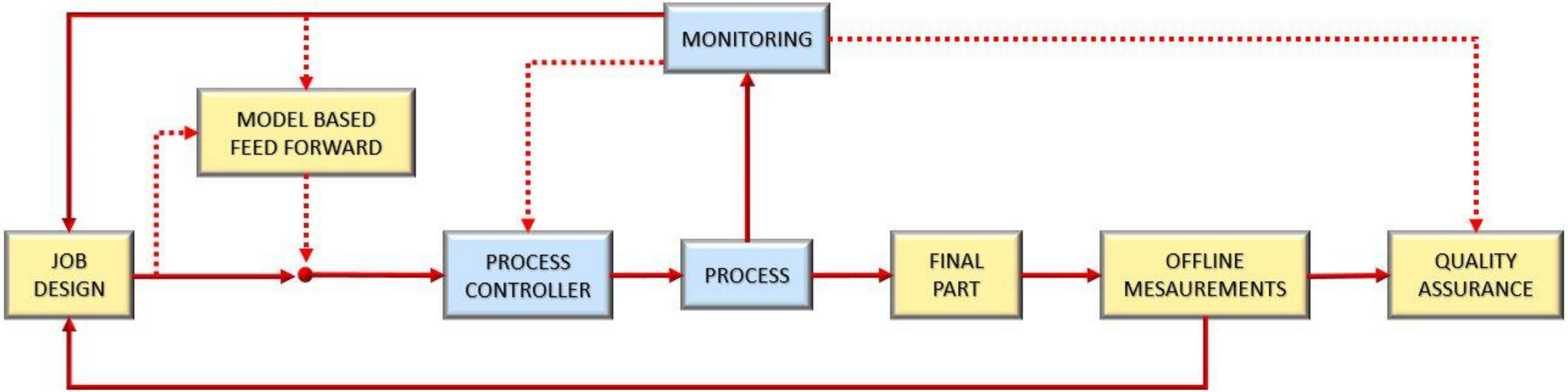






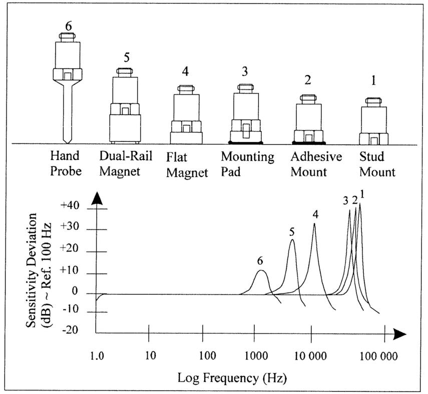


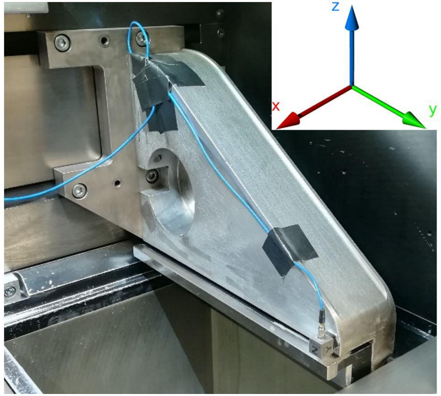
DMLS *in situ* Monitoring

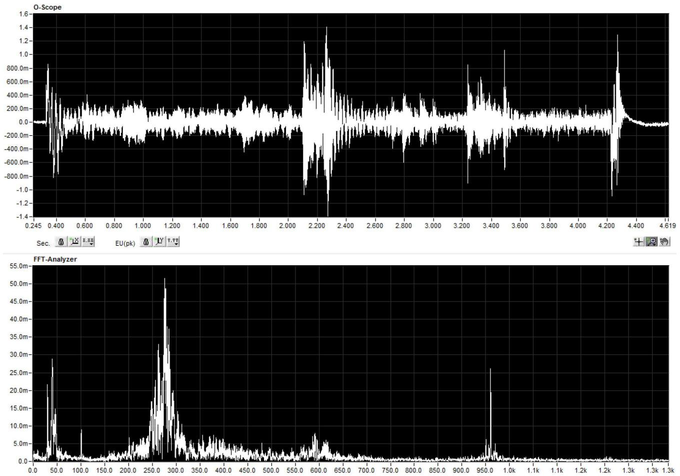


Accelerometer monitoring

- Recoating system vibration
- Powder bed quality analysis
- Threshold alarm setting



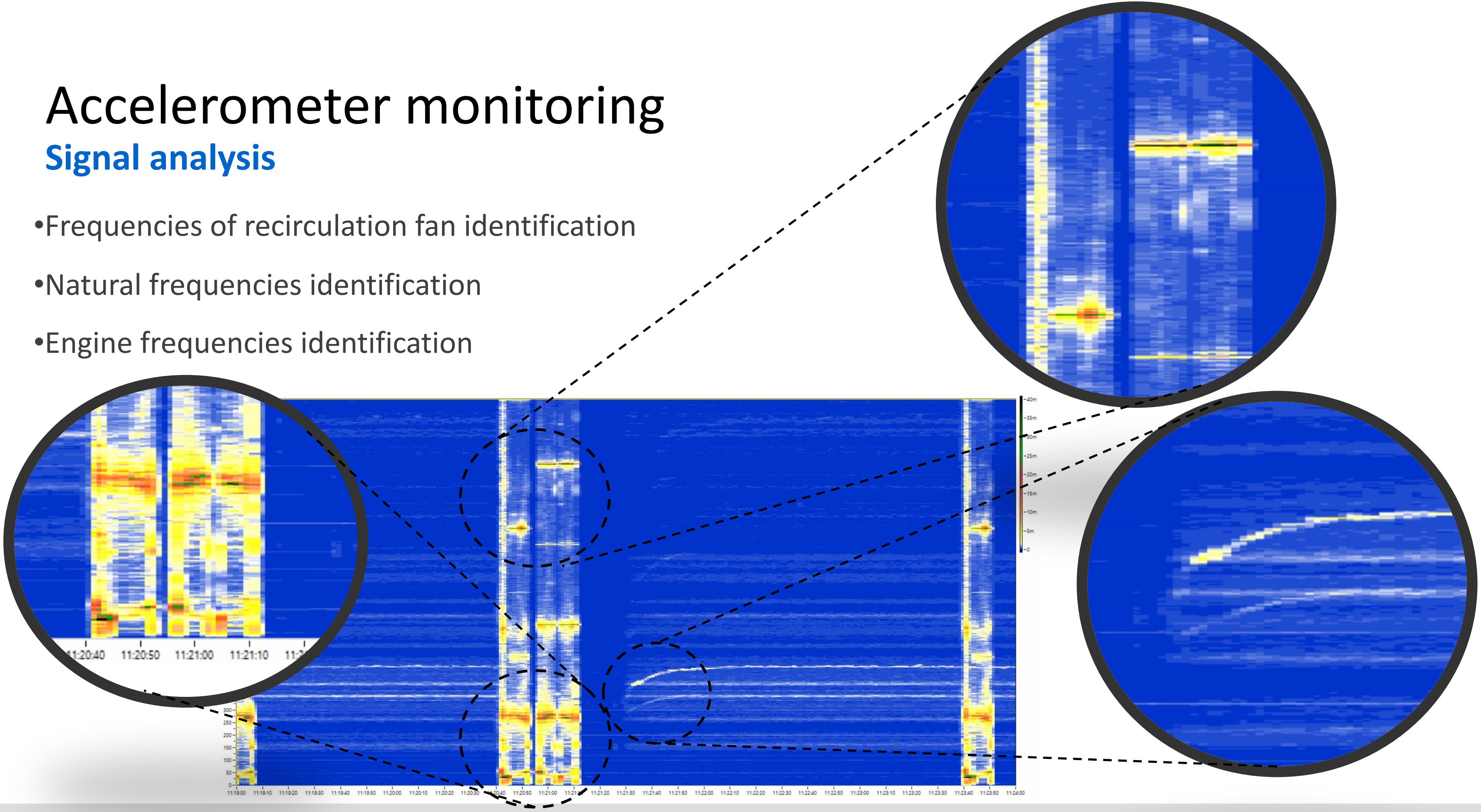




Accelerometer monitoring

Signal analysis

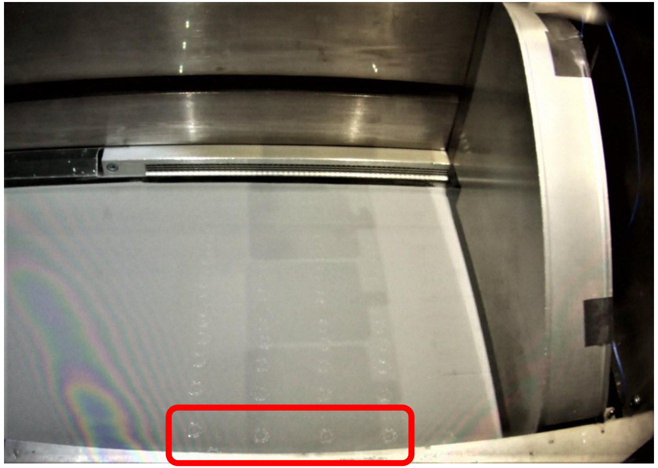
- Frequencies of recirculation fan identification
- Natural frequencies identification
- Engine frequencies identification

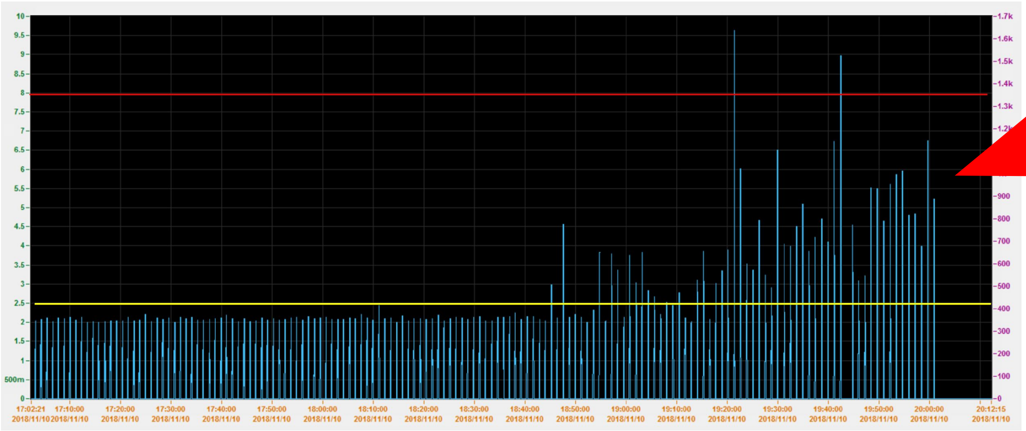


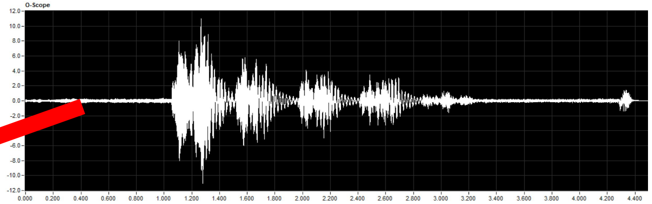
Accelerometer monitoring

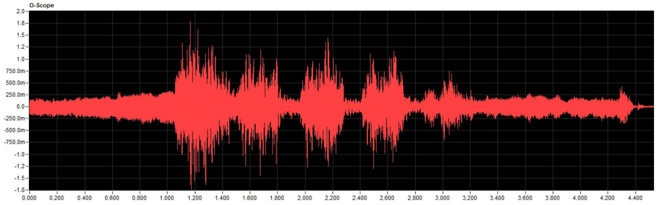
Recoater system collision with parts

- Parts collision detection
- Acceleration max detection
- Threshold alarm setting to prevent recoater stop



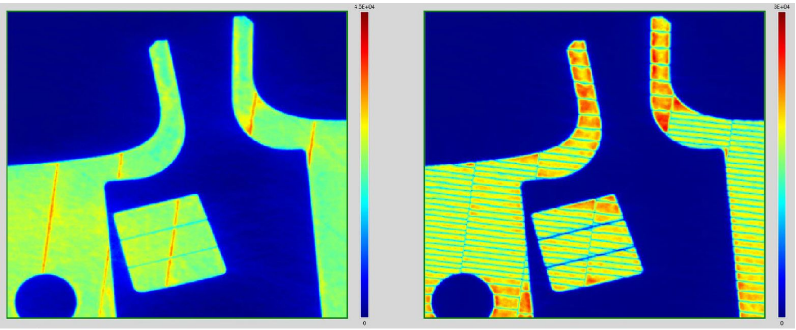


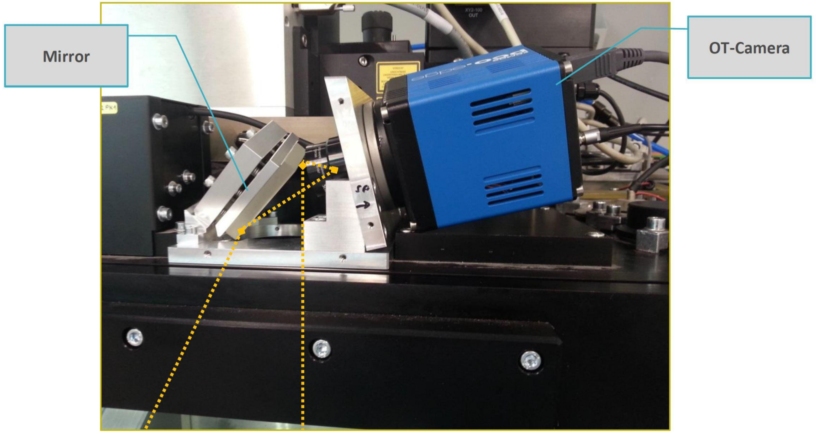




Optical Tomography Monitoring

- *CMOS Full HD Camera 10 fps*
- *Filter @960 nm*
- *Elaboration software with three different algorithms*

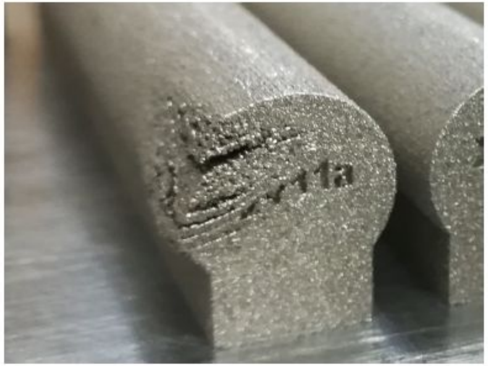




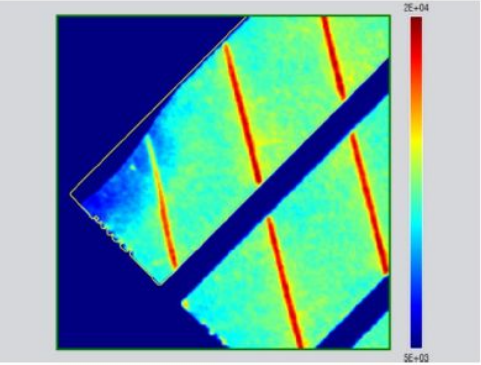
Optical Tomography monitoring

Lack of powder

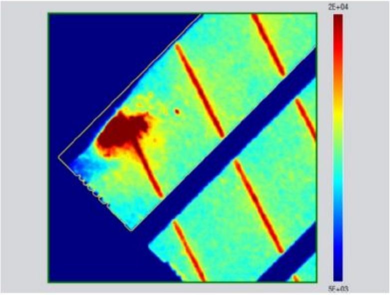
- Cold area during lack of powder
- Hot area during thicker layer melting



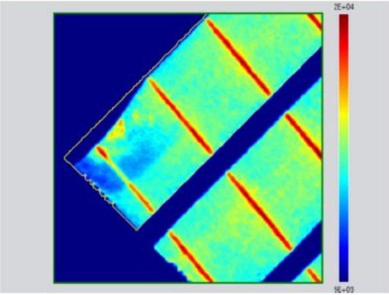
(a) *Parte finale stampata*



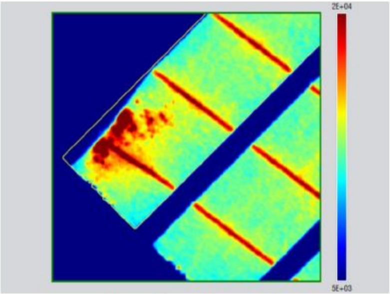
(b) *layer* 272 - h = 10.88 mm



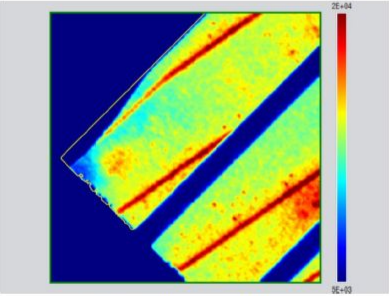
(c) *layer* 274 - h = 10.96 mm



(d) *layer* 276 - h = 11.04 mm



(e) *layer* 278 - h = 11.12 mm

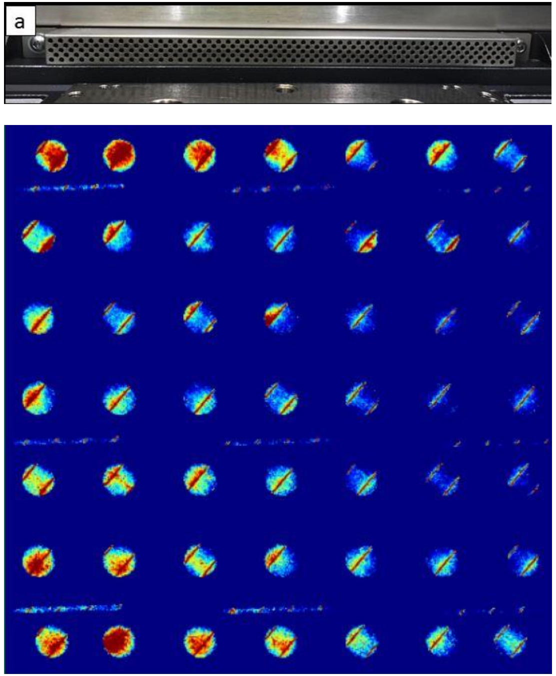


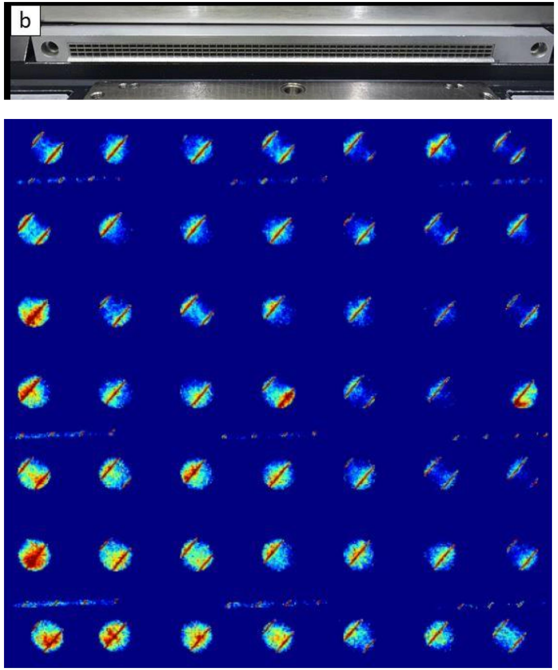
(f) *layer* 280 - h = 11.20 mm

Optical Tomography monitoring

Gas flow analysis

- Parts thermal profile with different nozzles





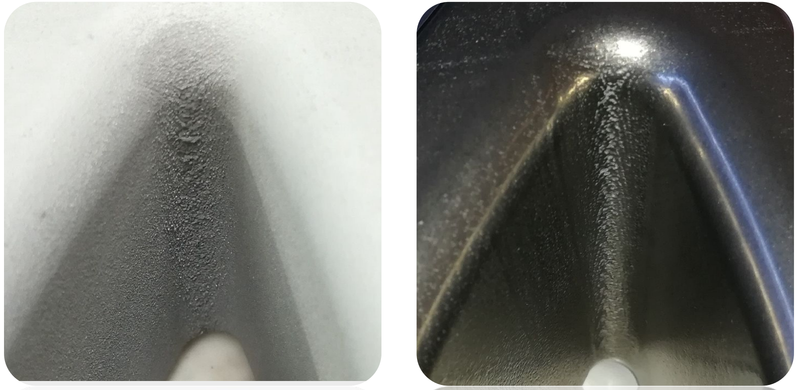
Optical Tomography monitoring

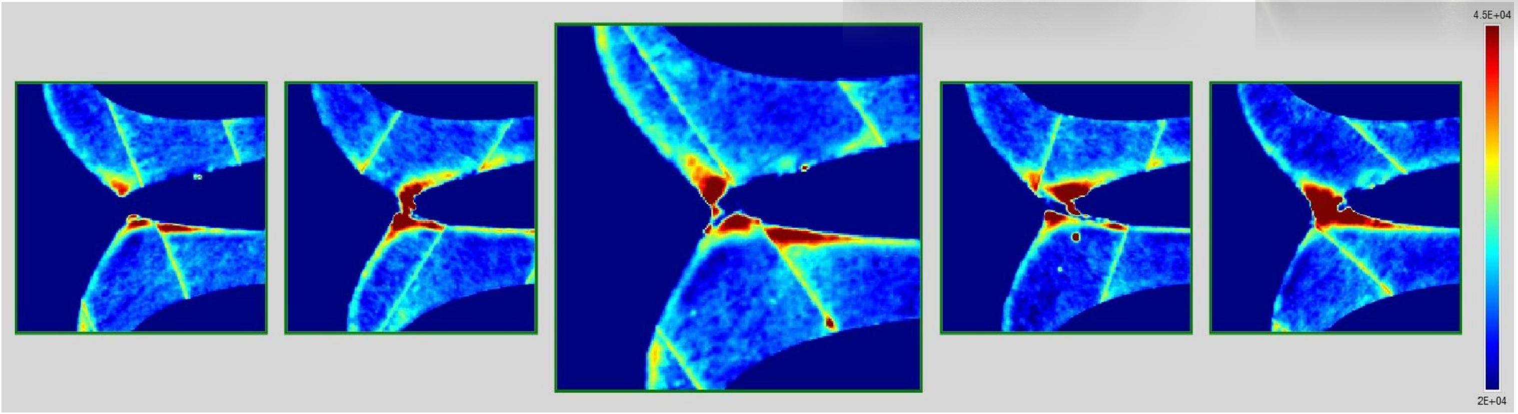
Defects identification examples

Hotspots in downskin area

↓

High roughness on the part

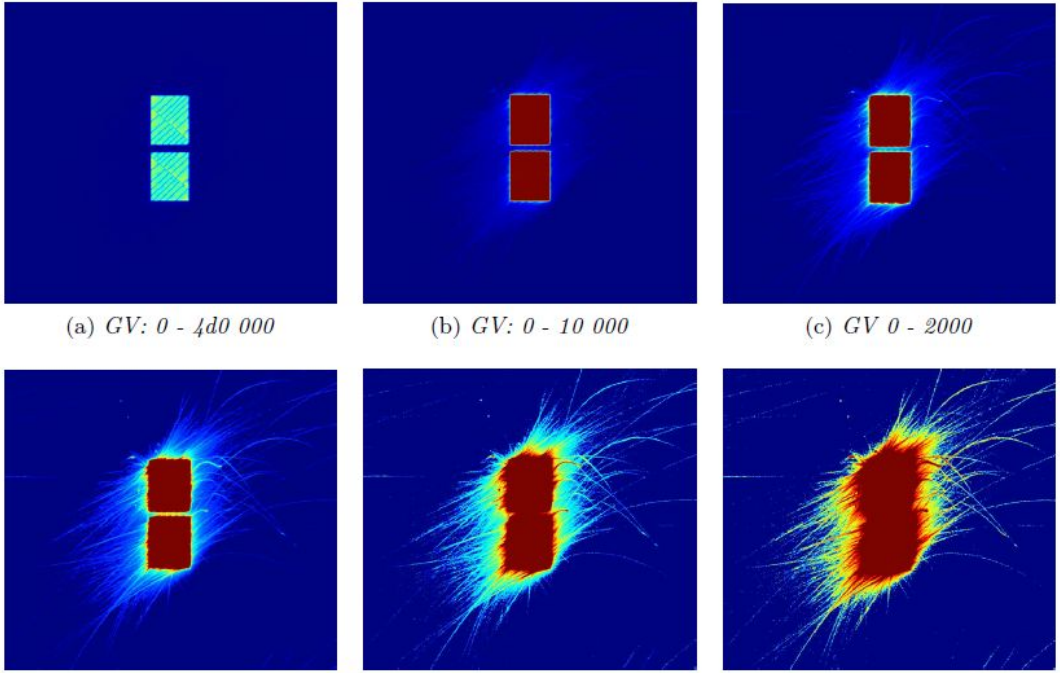




Optical Tomography monitoring

Defects identification examples

- Spatter emission visualization with different GV (Grey value)

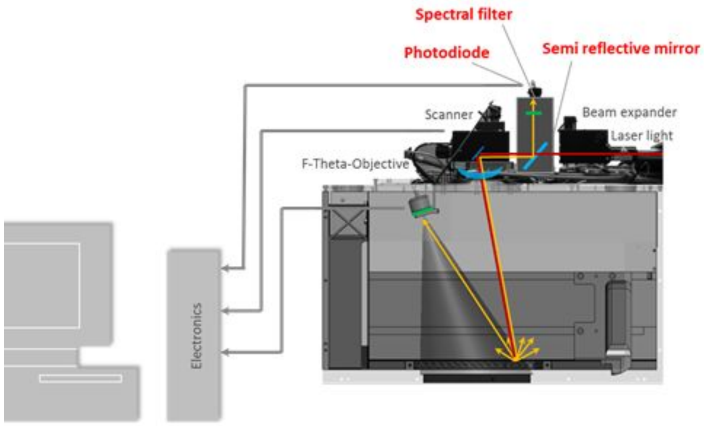


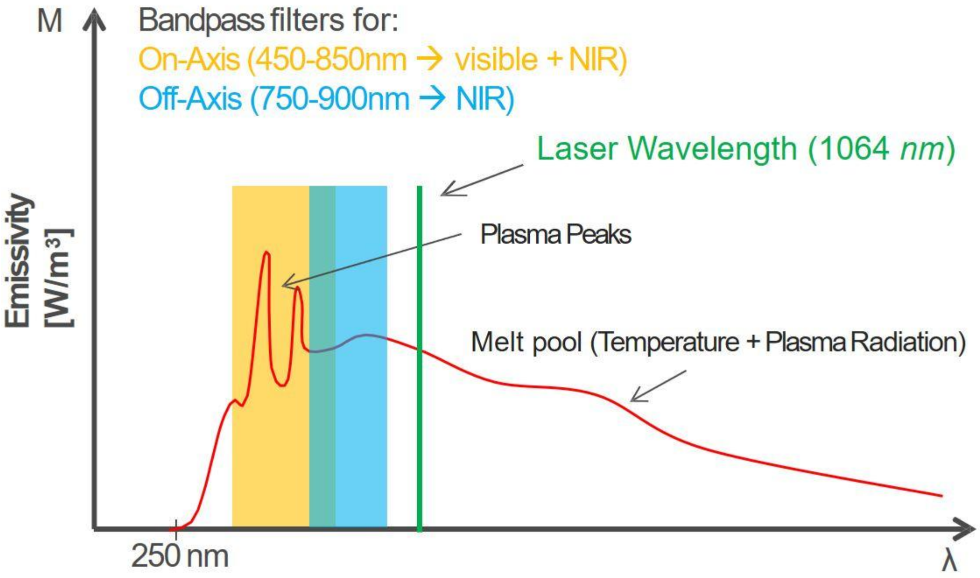
(a) *GV: 0 - 4d0 000* (b) *GV: 0 - 10 000* (c) *GV 0 - 2000*

(d) *GV 0 - 1000* (e) *GV 0 - 500* (f) *GV 0 - 300*

MeltPool Monitoring

- 2 photodiodes with different filters
- On-axis and off-axis signal
- Online and offline analysis software

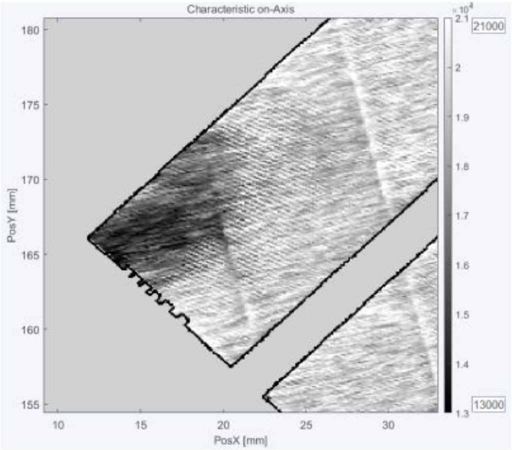




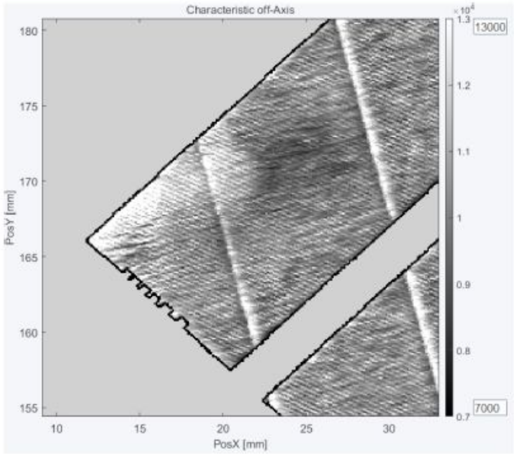
MeltPool monitoring

Lack of powder

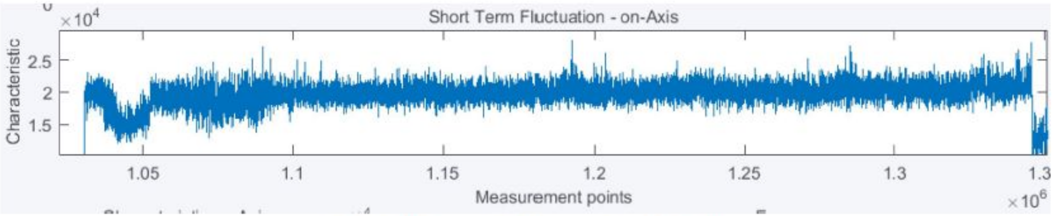
- 60 kHz signal visualization
- Differences between on- and off-axis images



(a) *Mappa della caratteristica on-axis della parte.*

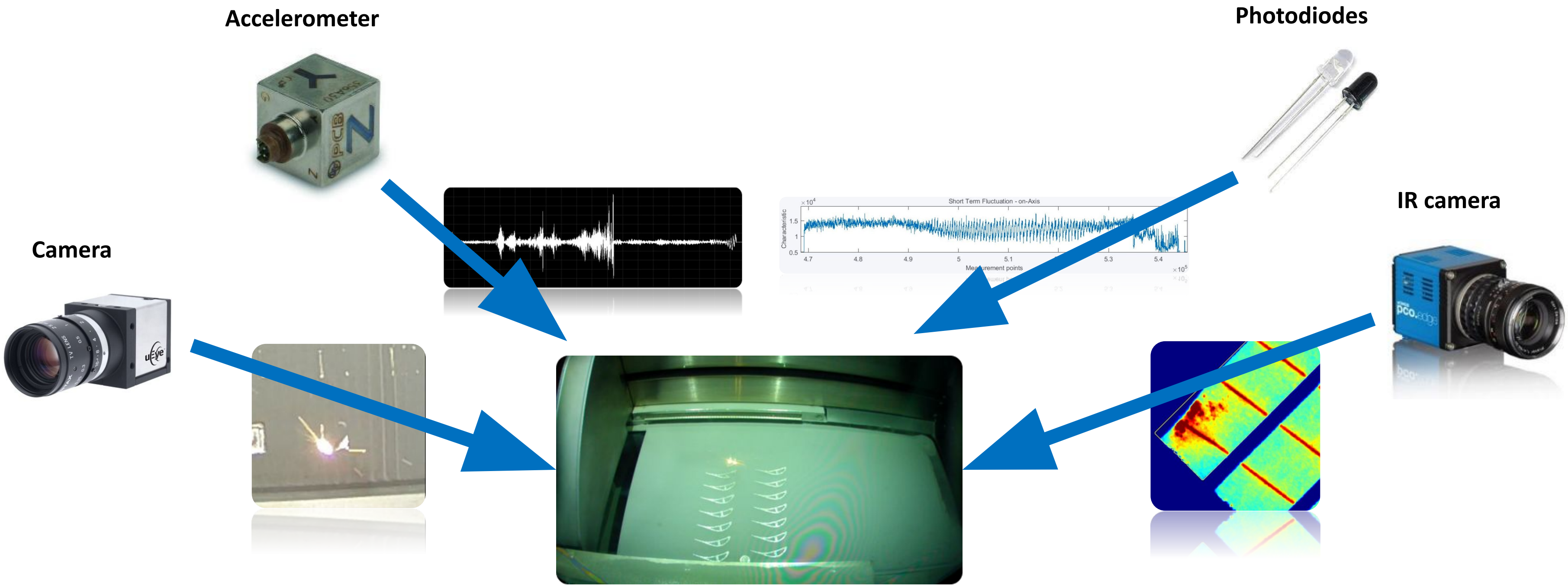


(b) *Mappa della caratteristica off-axis della parte.*



(c) *Segnale on-axis nel tempo per la parte.*

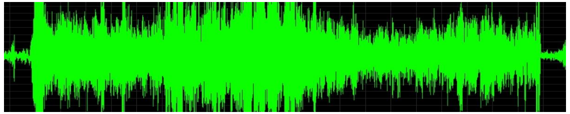
Sensors integration

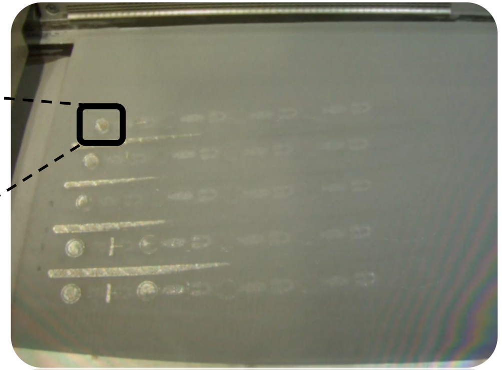


Sensor integration

Lack of powder

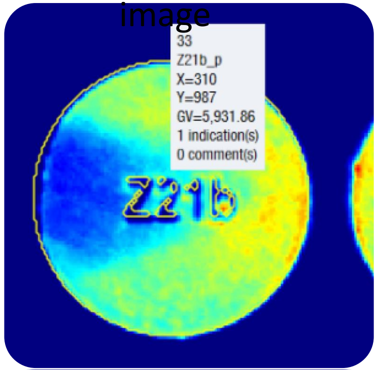
Accelerometer signal

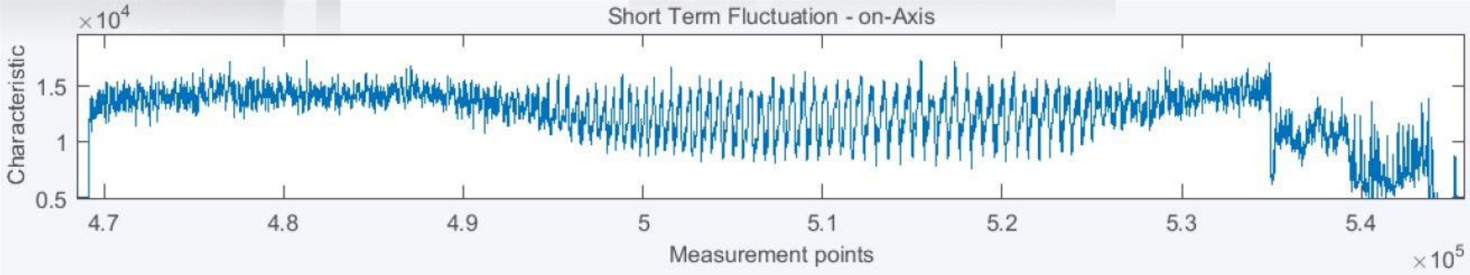




MeltPool signal and Exposure map

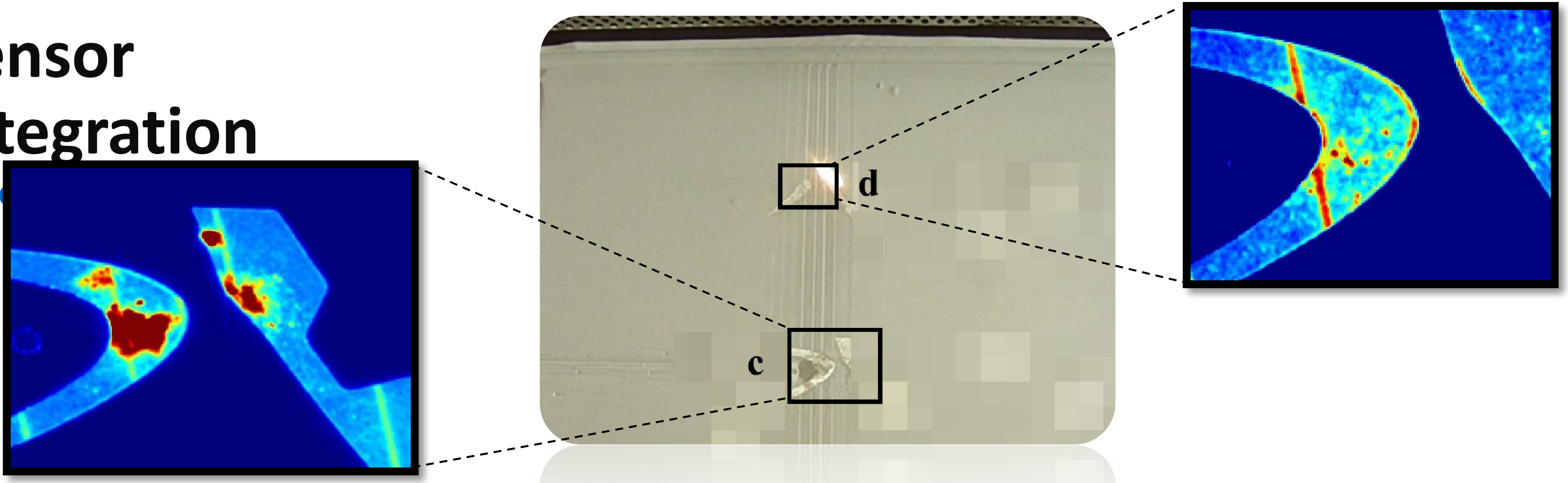
OT image



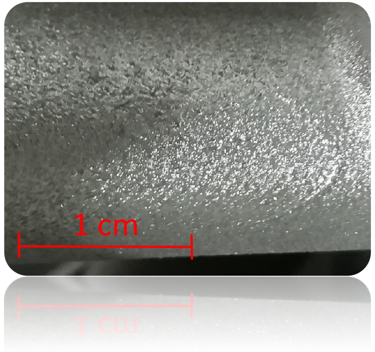


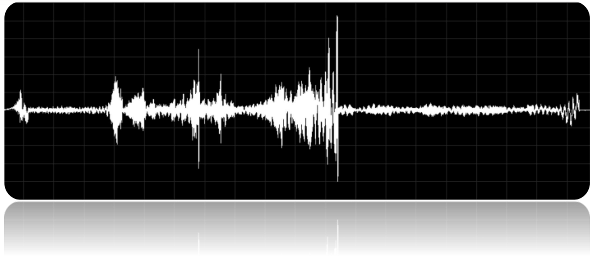
Sensor integration

Rec

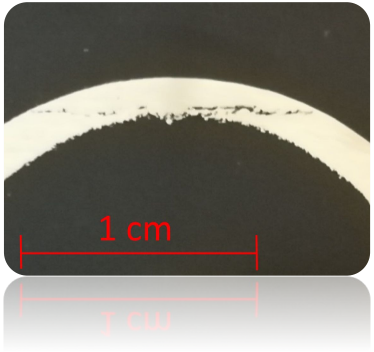


Rugosità



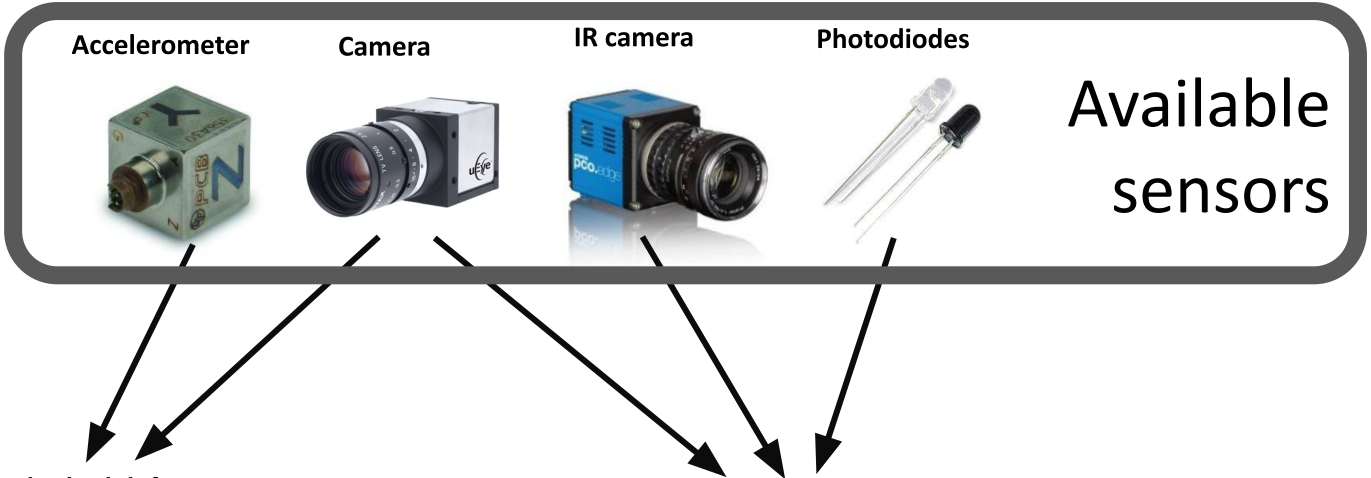


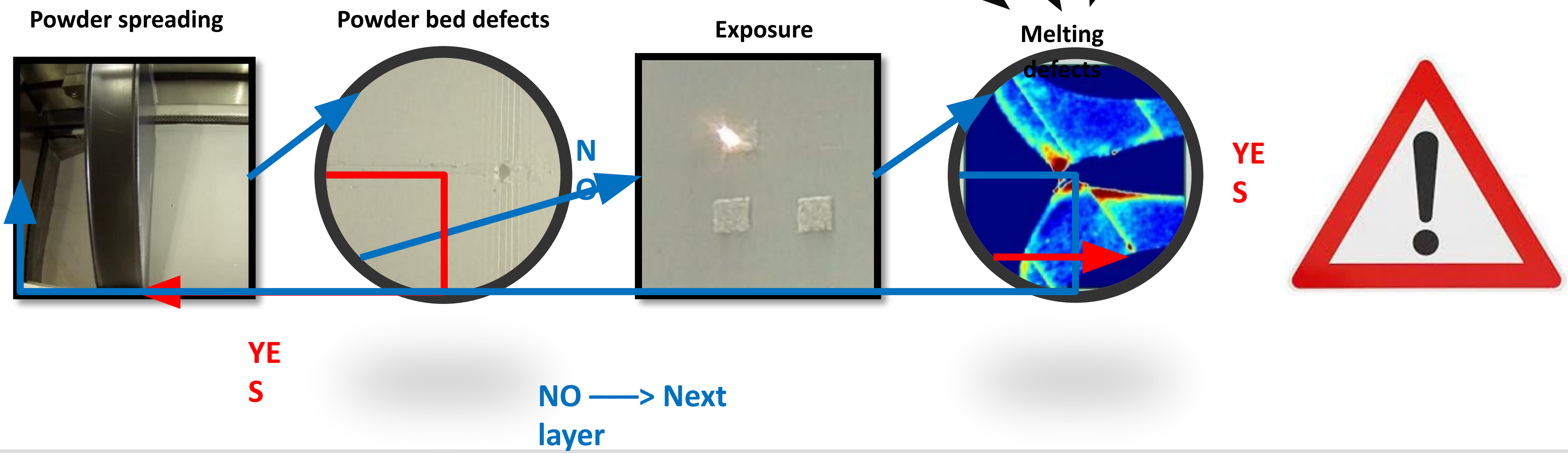
Porosità



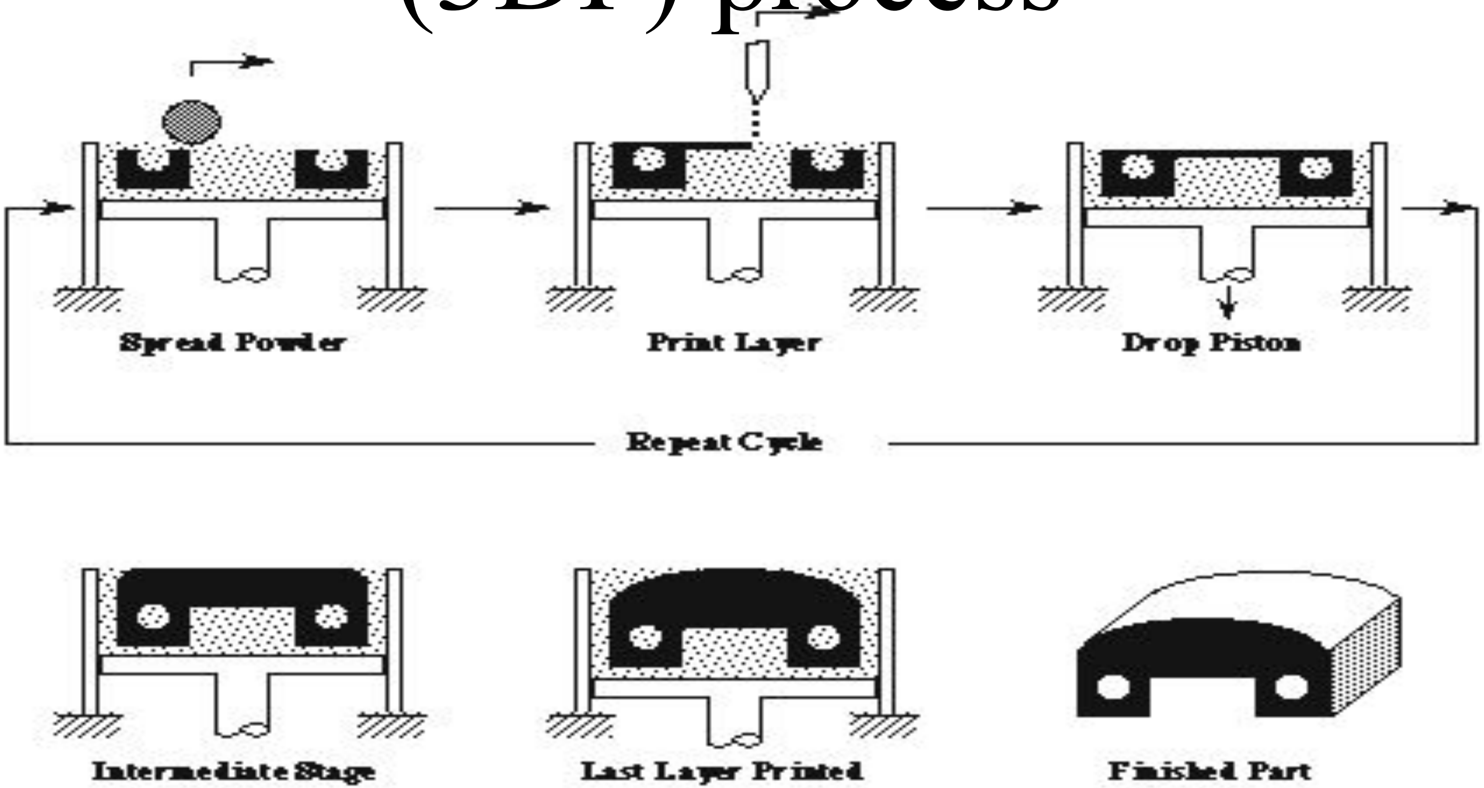
Sensors integration

Online feed-back





The Three Dimensional Printing (3DP) process



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Volume 65, 1985, Pages 91-171

Ink-Jet Printing

J. Heinzl, C.H. Hertz

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https://doi.org/10.1016/S0065-2539(08)60877-X

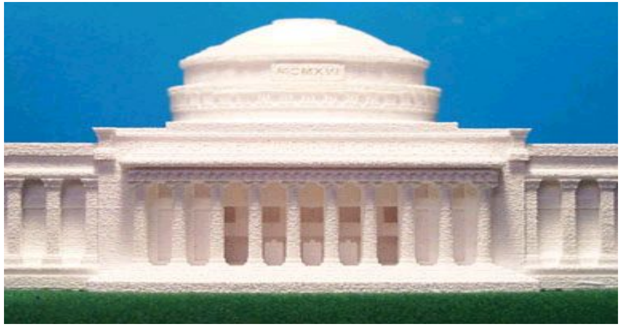
Publisher Summary

From the literature on ink jets, it is evident that extensive research has been conducted during the last two decades to make use of electrically controlled ink jets for the printing of characters and other tasks in graphic arts. In spite of this, the new technology has come into more widespread use only recently. This chapter discusses a review of the most important ink-jet printing methods so far developed. It provides an overview of the two most important classes of ink-jet systems—namely, the drop-on-demand and continuous-jet types. From the present use of ink-jet methods outside the laboratory, it is obvious that two fundamentally

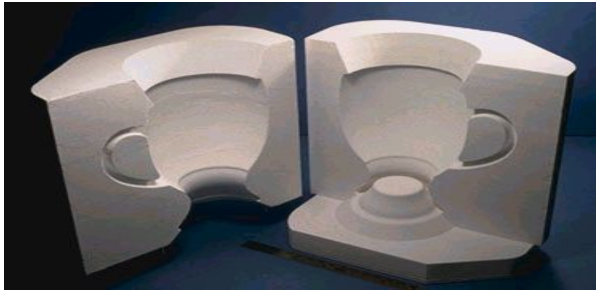
https://www.sciencedirect.com/science/article/pii/S006525390860877X

Examples of 3D Printed parts (1/3)

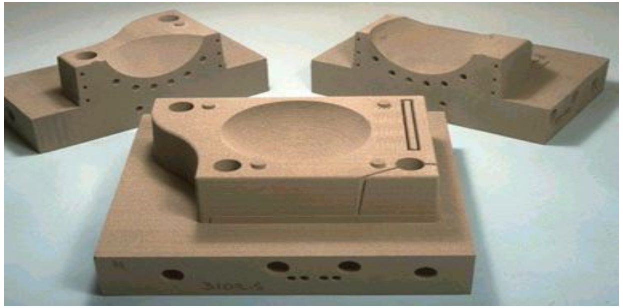
source: **web.mit.edu/tdp/www**



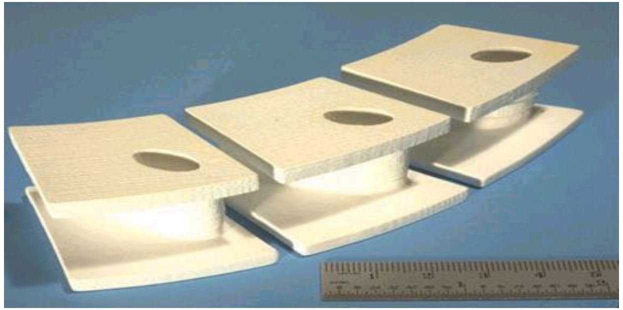
Architectural models (in ceramic)



Alumina slipcasting mold



Metal tools for injection molding



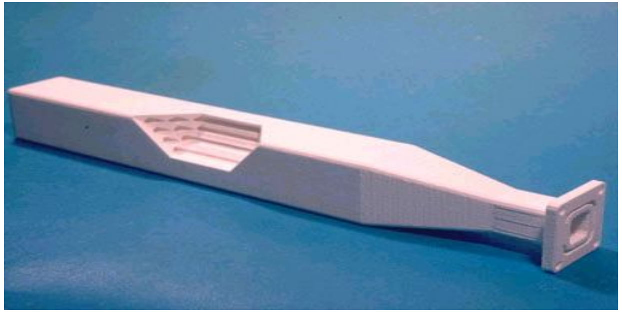
Alumina airfoils (green)

Examples of 3D Printed parts (2/3)

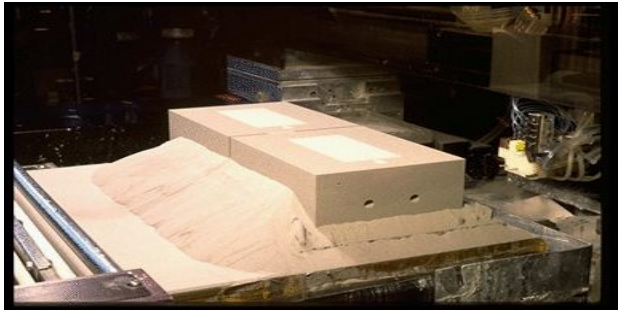
source:**web.mit.edu/tdp/www**

Ceramic appearance model

Ceramic casting (shell & casting)



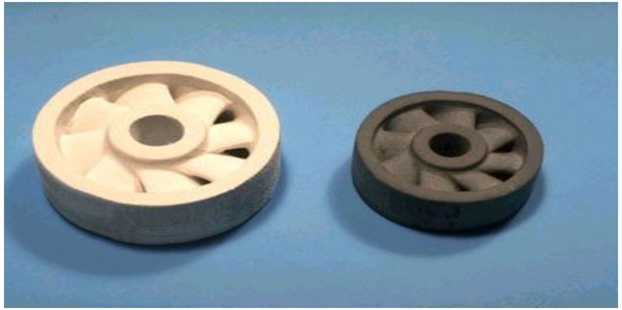
Porous ceramic filter



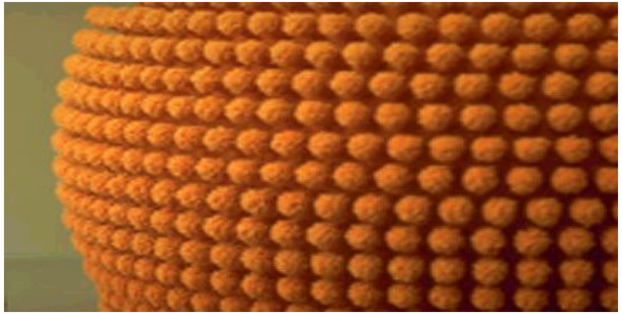
Printed part emerging from powder

Examples of 3D Printed parts (3/3)

*source:*web.mit.edu/tdp/www

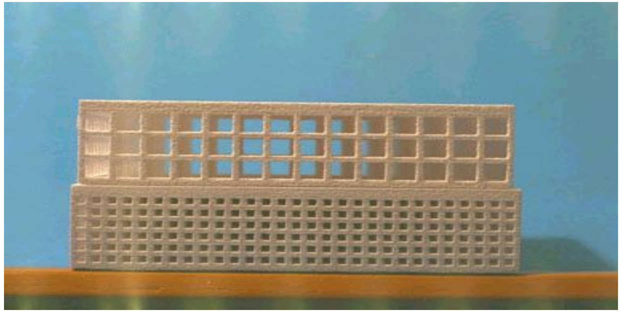


Silicon nitride rotor

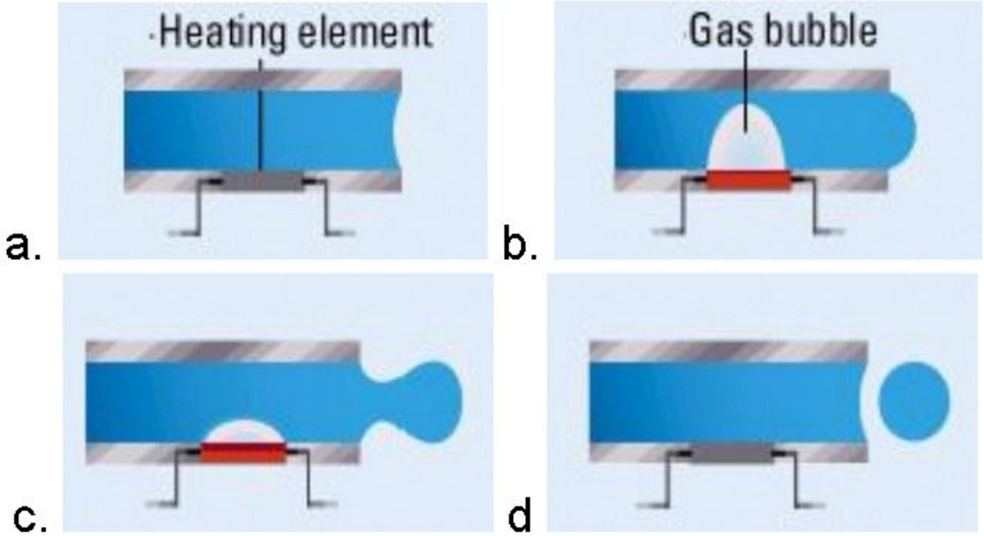


Complex surface texture

Metal injection molds

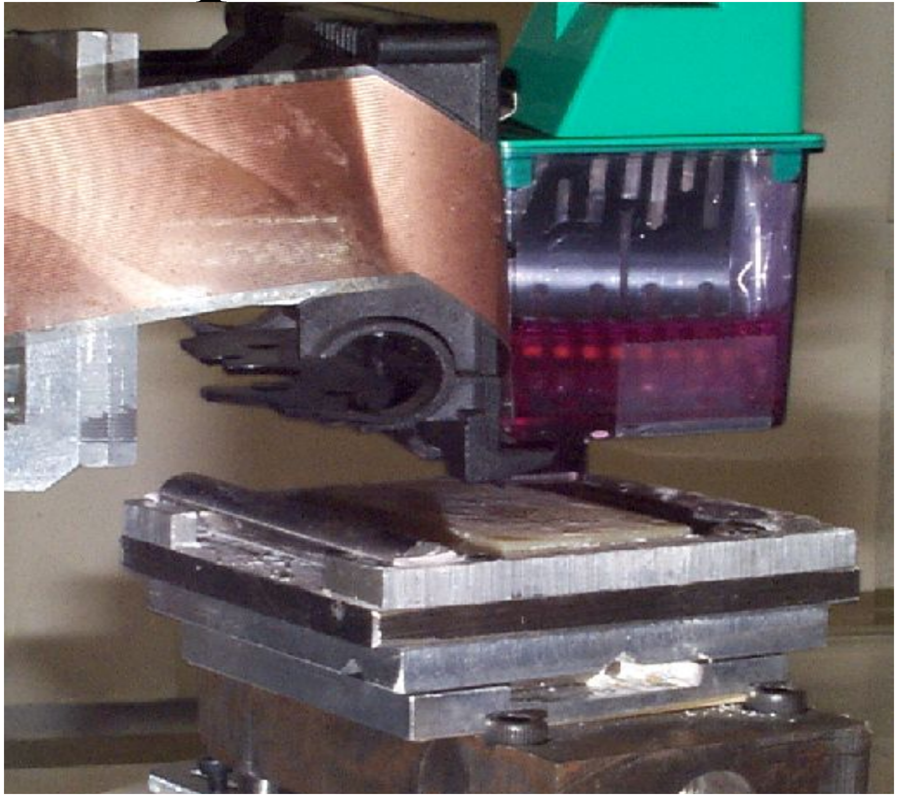


Ceramic lattice structure



The thermal and the piezo inkjet

The Experimental Set-up



<u>The control</u>

A PC driving an external electronic circuit generates a series of pulses to print drops at a given

<u>Stackable shims</u>

allow spreading beds of different thickness.

<u>The rotating platform</u>

with a switch connected to the PC to measure the actual speed and all the consequent process parameters.

<u>The printhead</u>

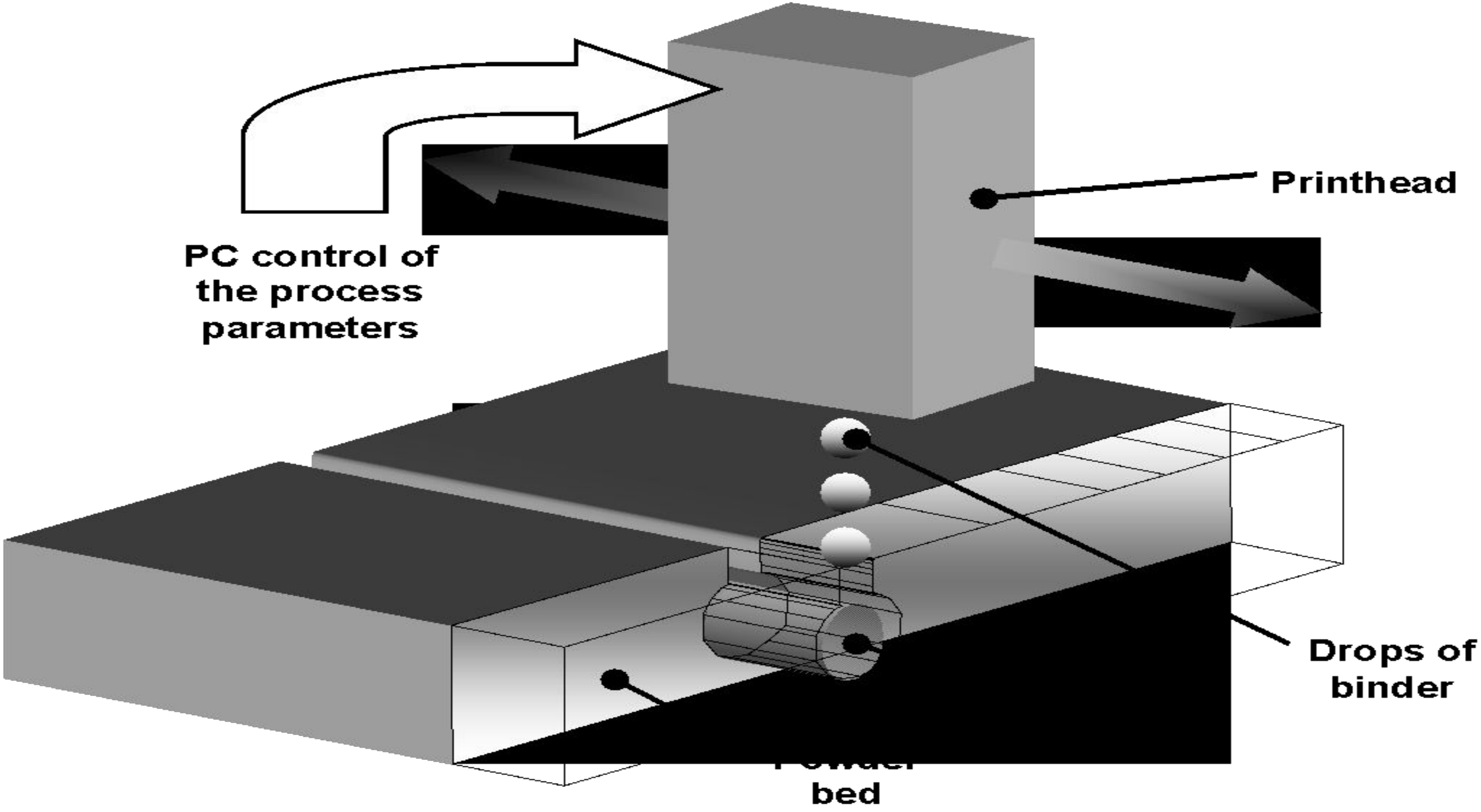
A Drop on Demand, bubble-jet commercial printhead.

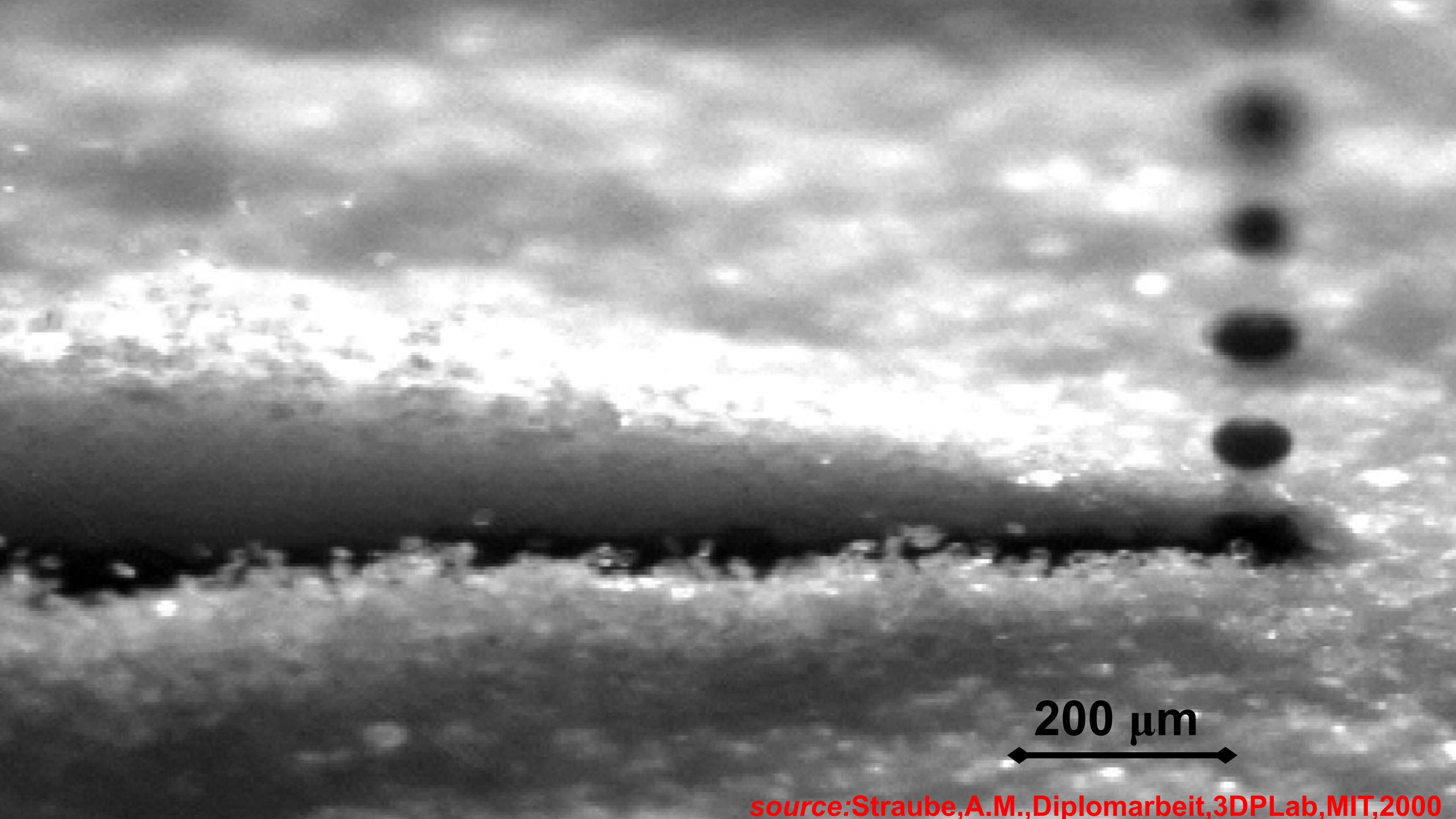
<u>The binder</u>

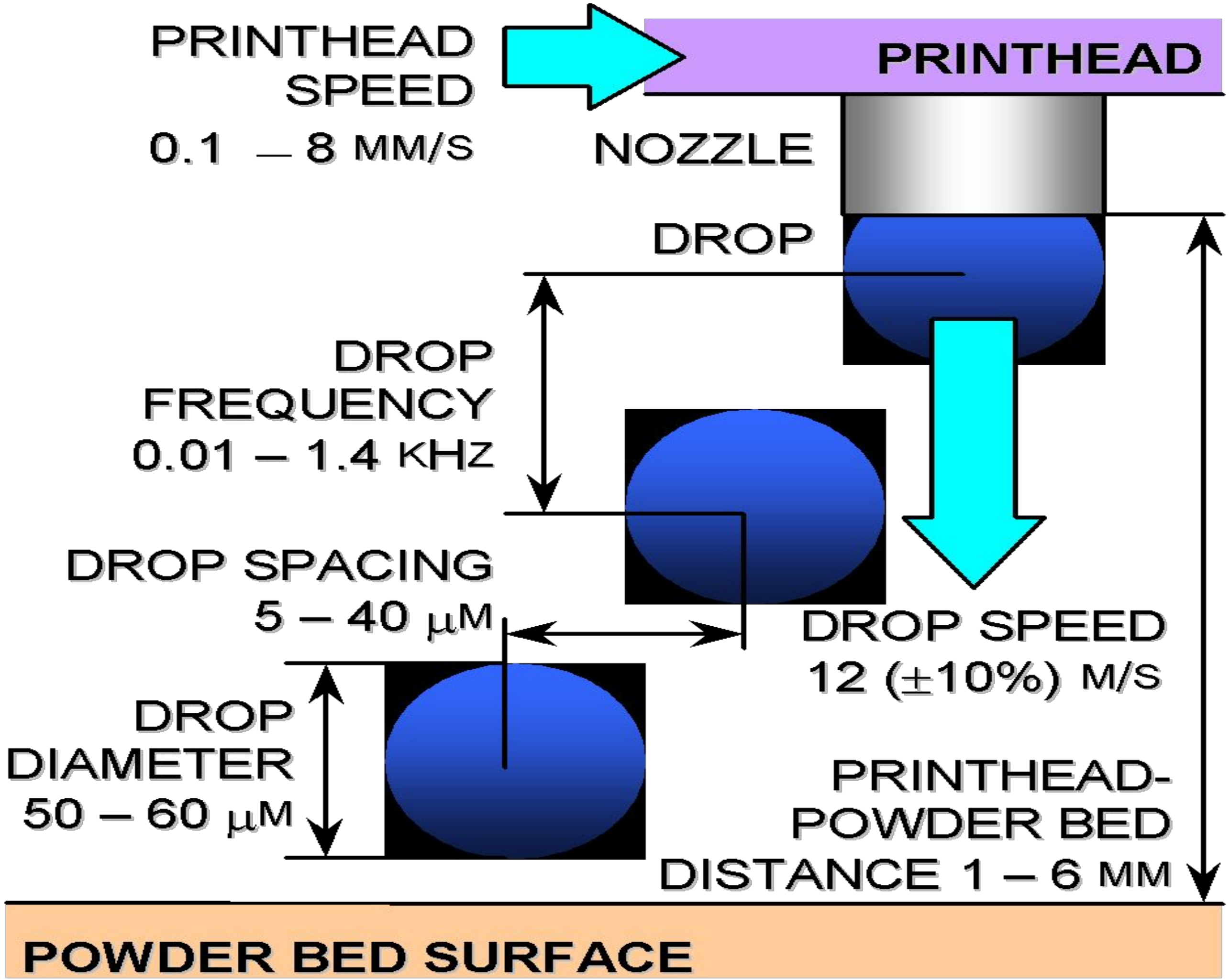
Colloidal Silica in Ethylene Glycol in water, with food colour to enhance the contrast of lines within the white Alumina

<u>The power bed</u>

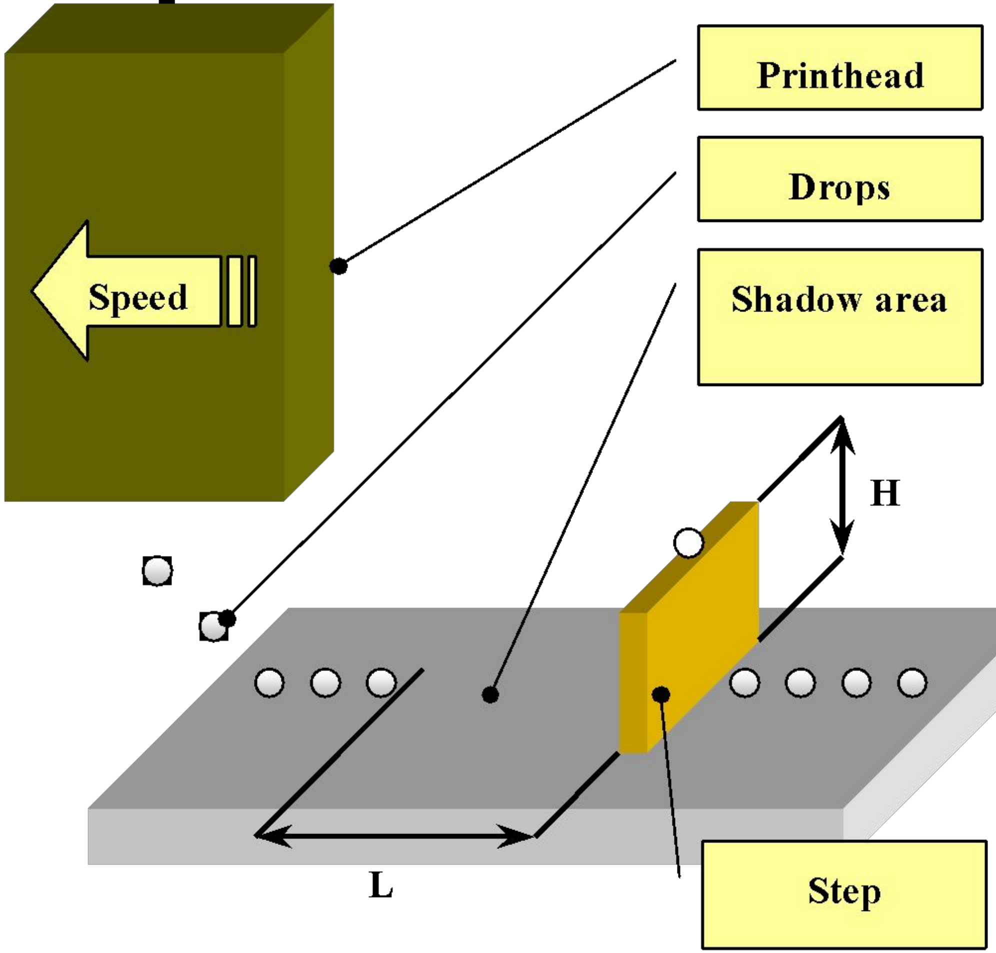
Laying on a detachable support, which allows an accurate repositioning.

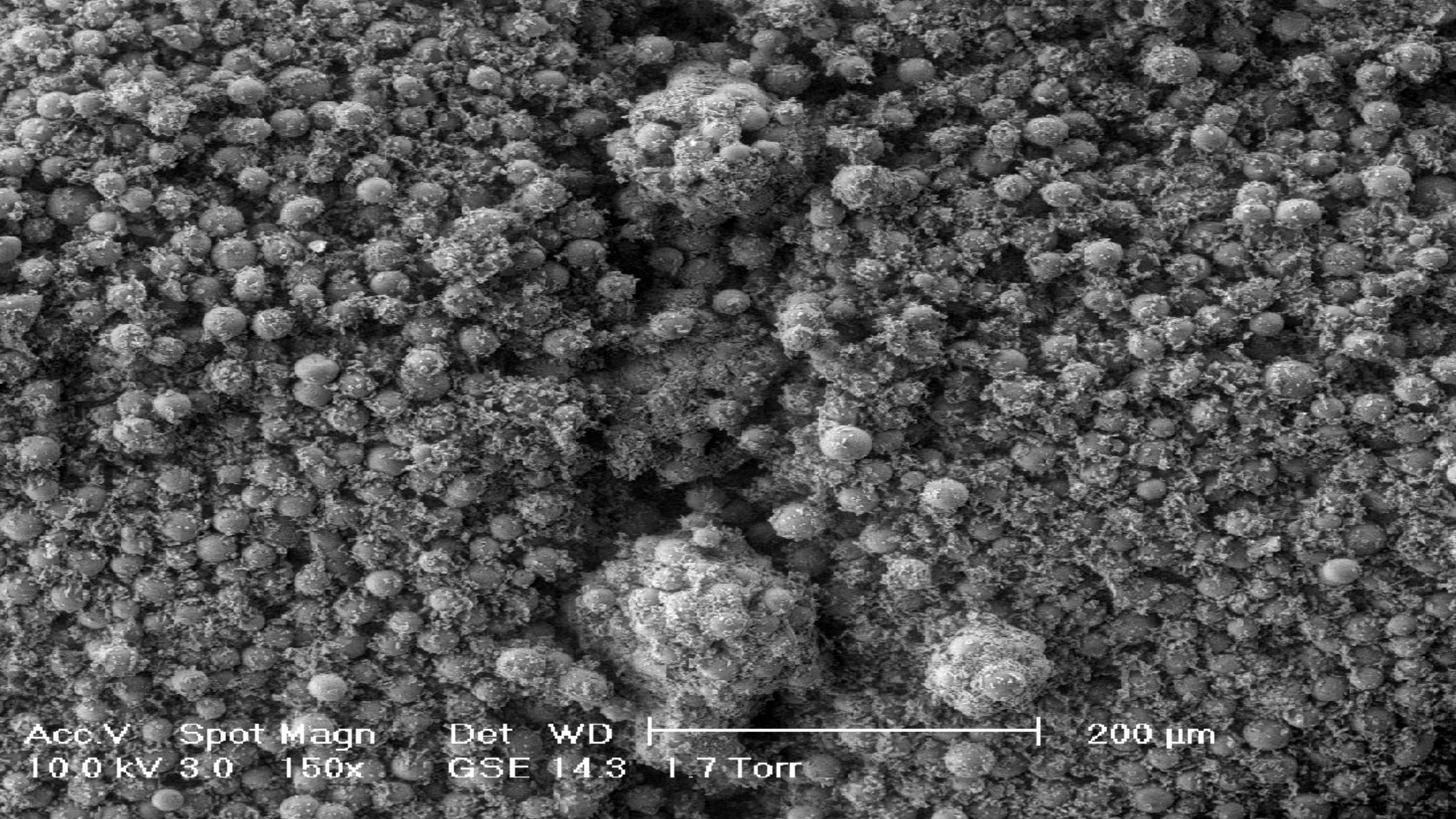

Printhead
PC control of the process parameters
Drops of binder
bed


200 µm
source:Straube,A.M.,Diplomarbeit,3DPLab,MIT,2000

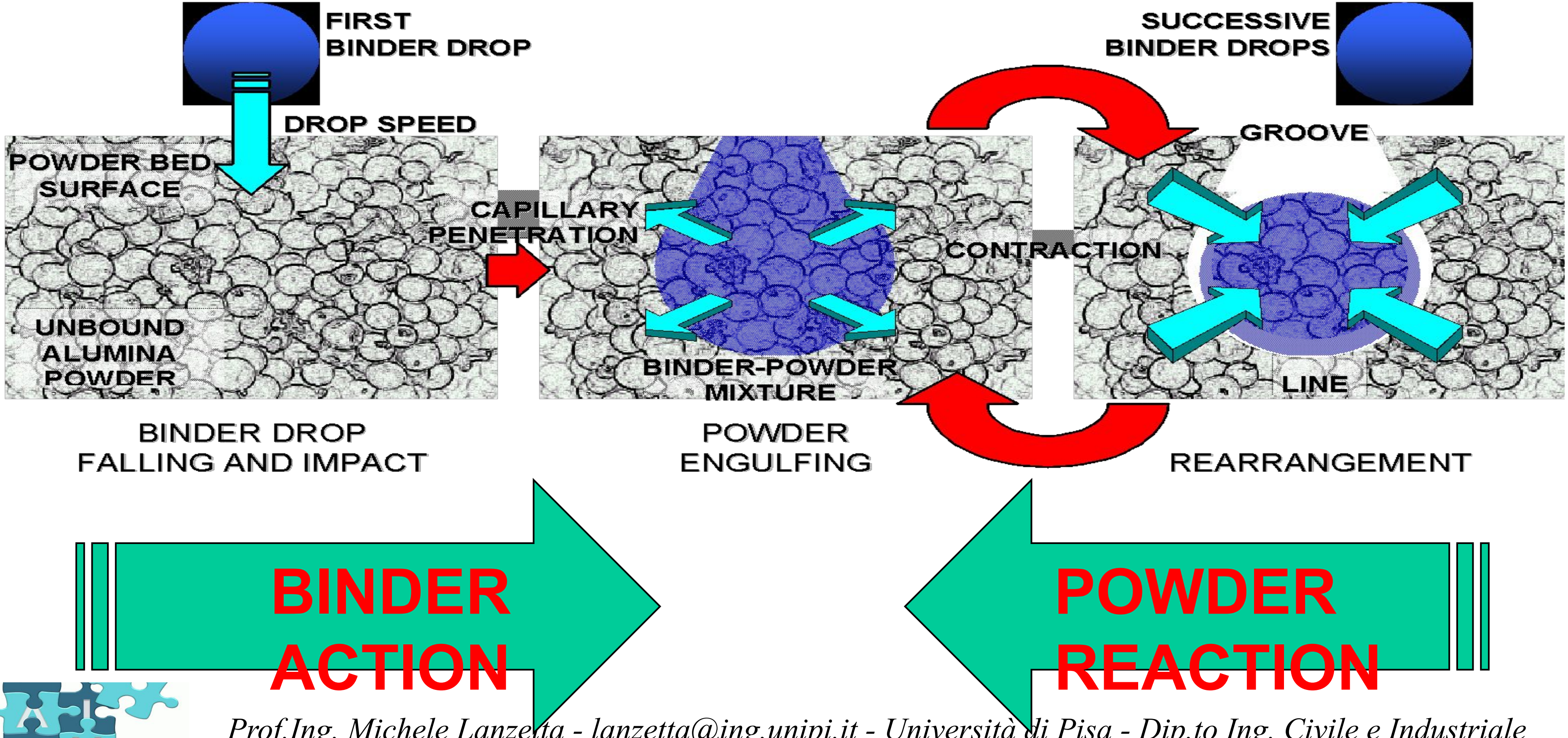

PRINTHEAD SPEED
0.1 – 8 MM/S
PRINTHEAD
NOZZLE
DROP
DROP FREQUENCY
0.01 – 1.4 KHZ
DROP SPACING
5 – 40 μM
DROP SPEED
12 (±10%) M/S
DROP DIAMETER
50 – 60 μM
PRINTHEAD-POWDER BED DISTANCE 1 – 6 MM
POWDER BED SURFACE

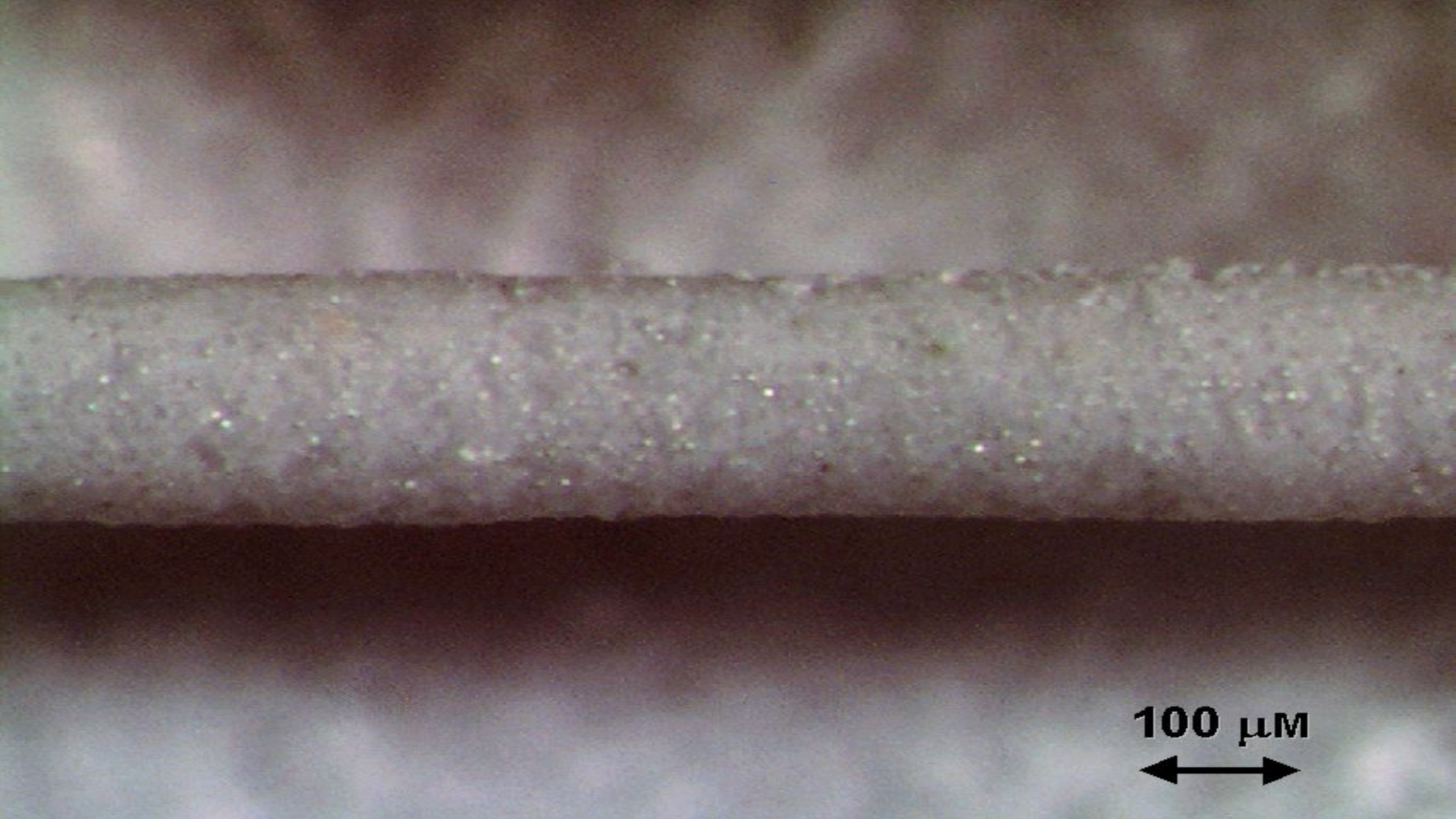
The Step Method for the Drop Speed

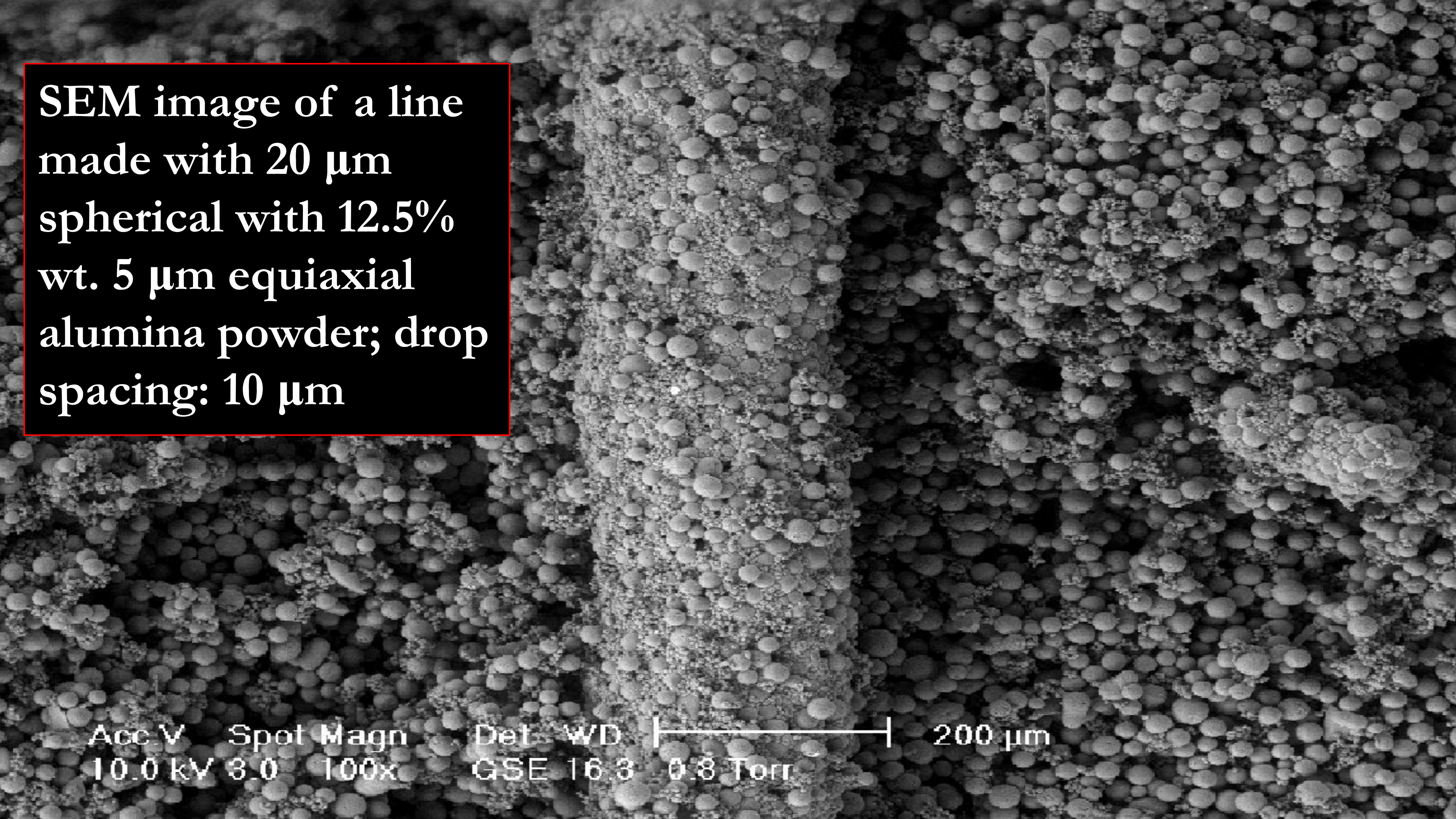



Acc.V Spot Magn Det WD
10.0 kV 3.0 150x GSE 14.3 1.7 Torr
200 µm

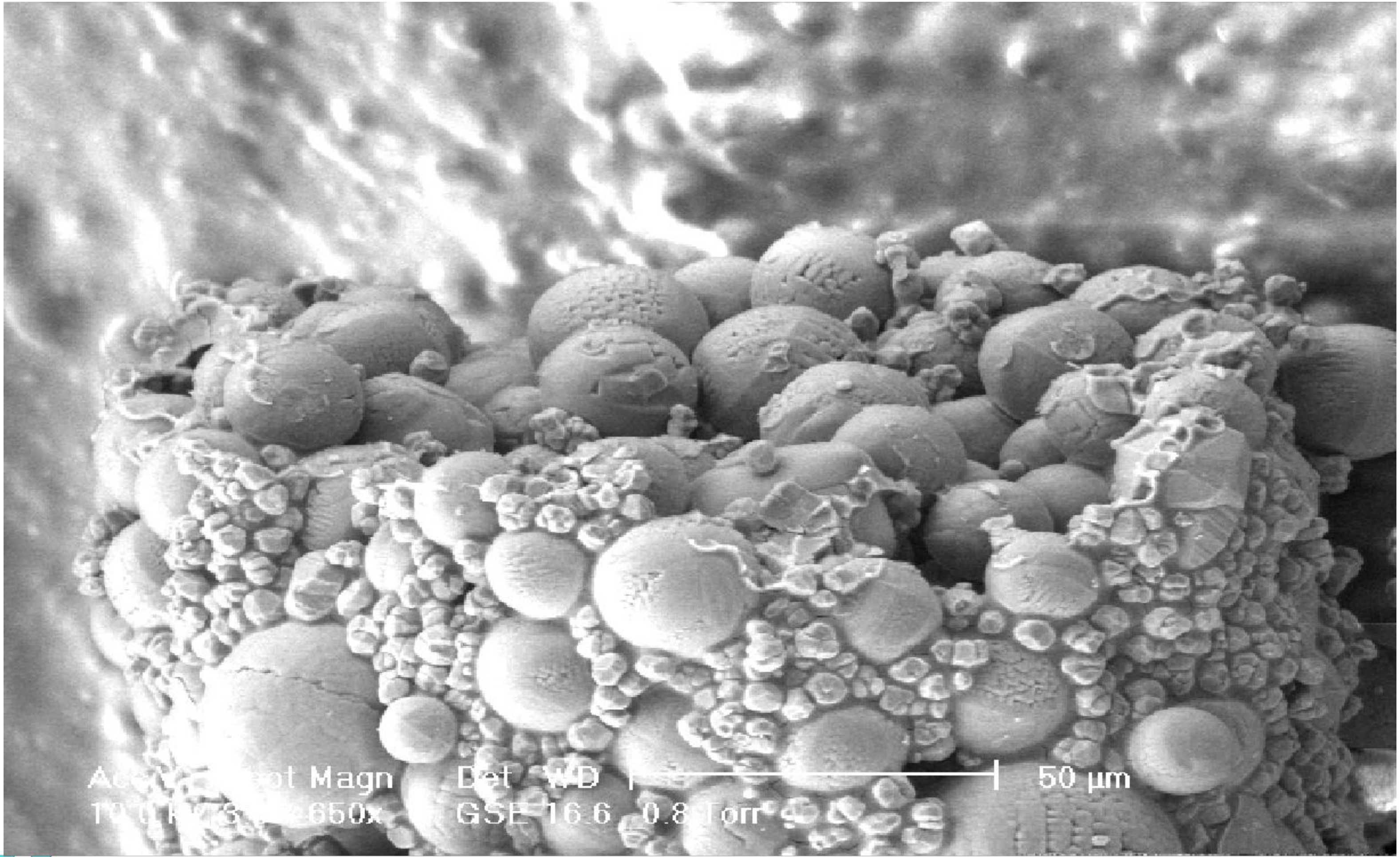
The line formation

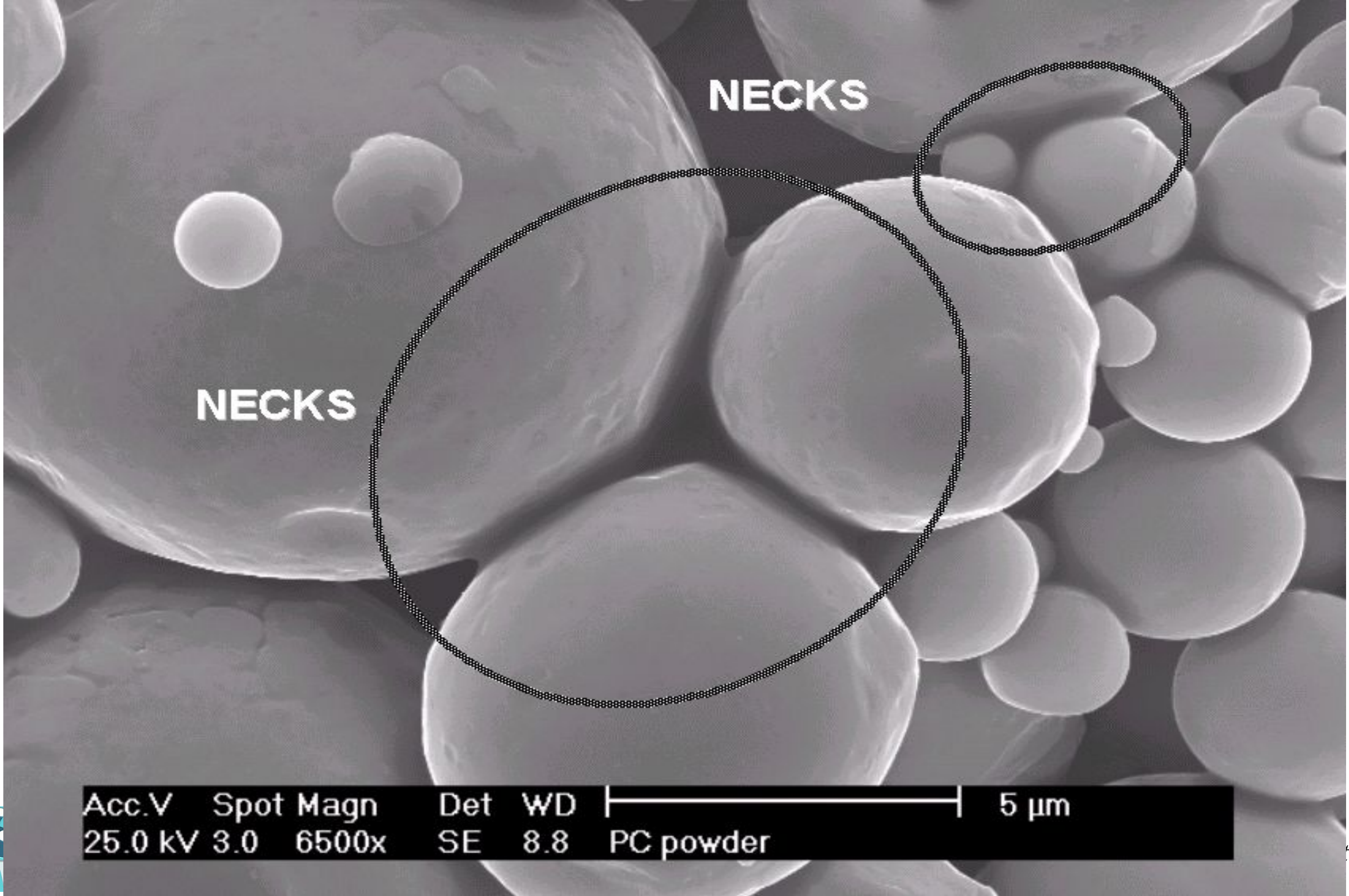



100 μM



SEM image of a line made with 20 μm spherical with 12.5% wt. 5 μm equiaxial alumina powder; drop spacing: 10 μm


50 µm


NECKS
NECKS
Acc.V Spot Magn Det WD 5 µm
25.0 kV 3.0 6500x SE 8.8 PC powder

Alumina powder line and bed

Composition:

20 µm spherical and 12.5% (wt.) of < 5 µm platelet

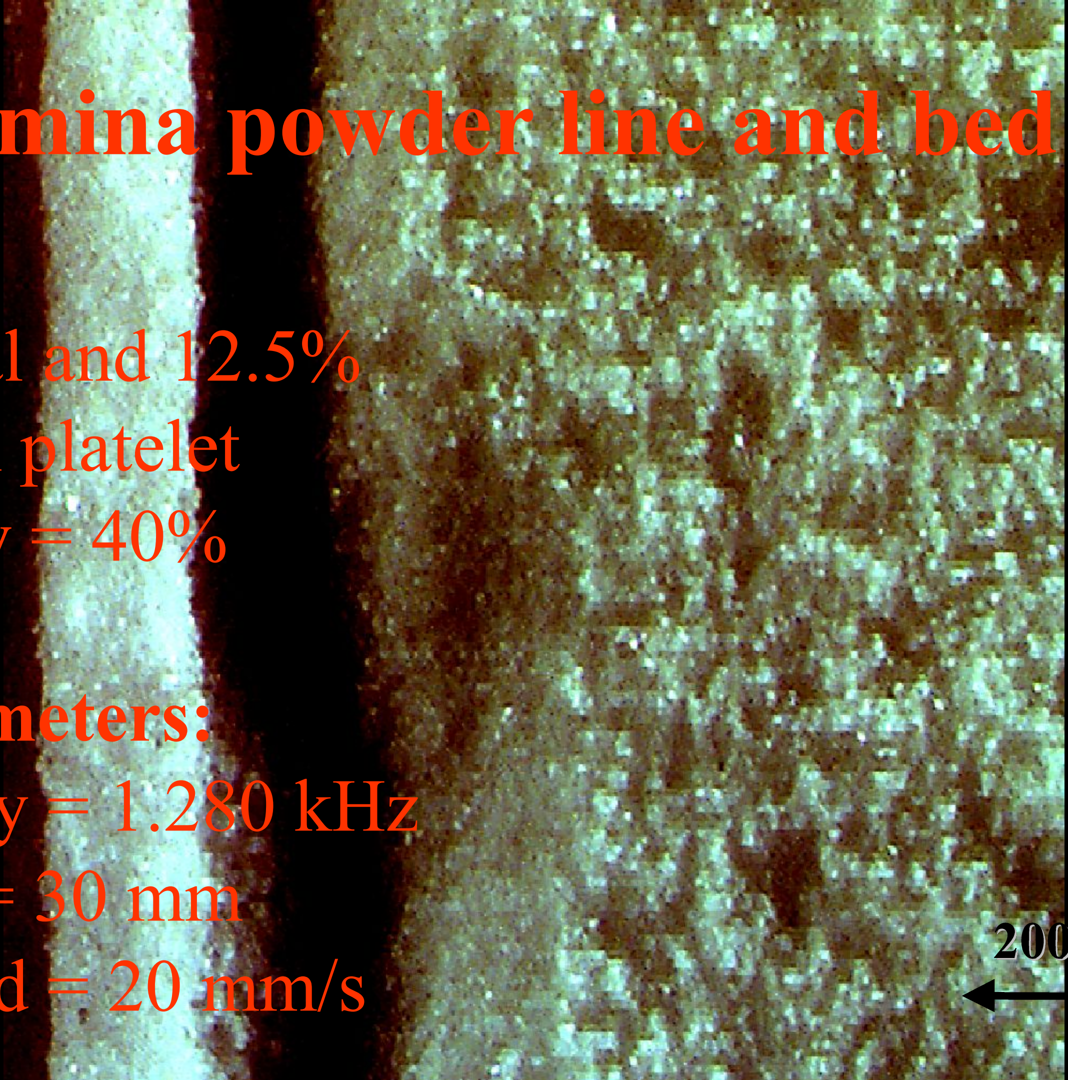
packing density = 40%

Printing parameters:

Drop Frequency = 1.280 kHz

Drop Spacing = 30 mm

Printhead Speed = 20 mm/s



Arcs of rings made with metal powder

Powder:

material = ss 17-4

average size = 15 mm

packing density = 55%

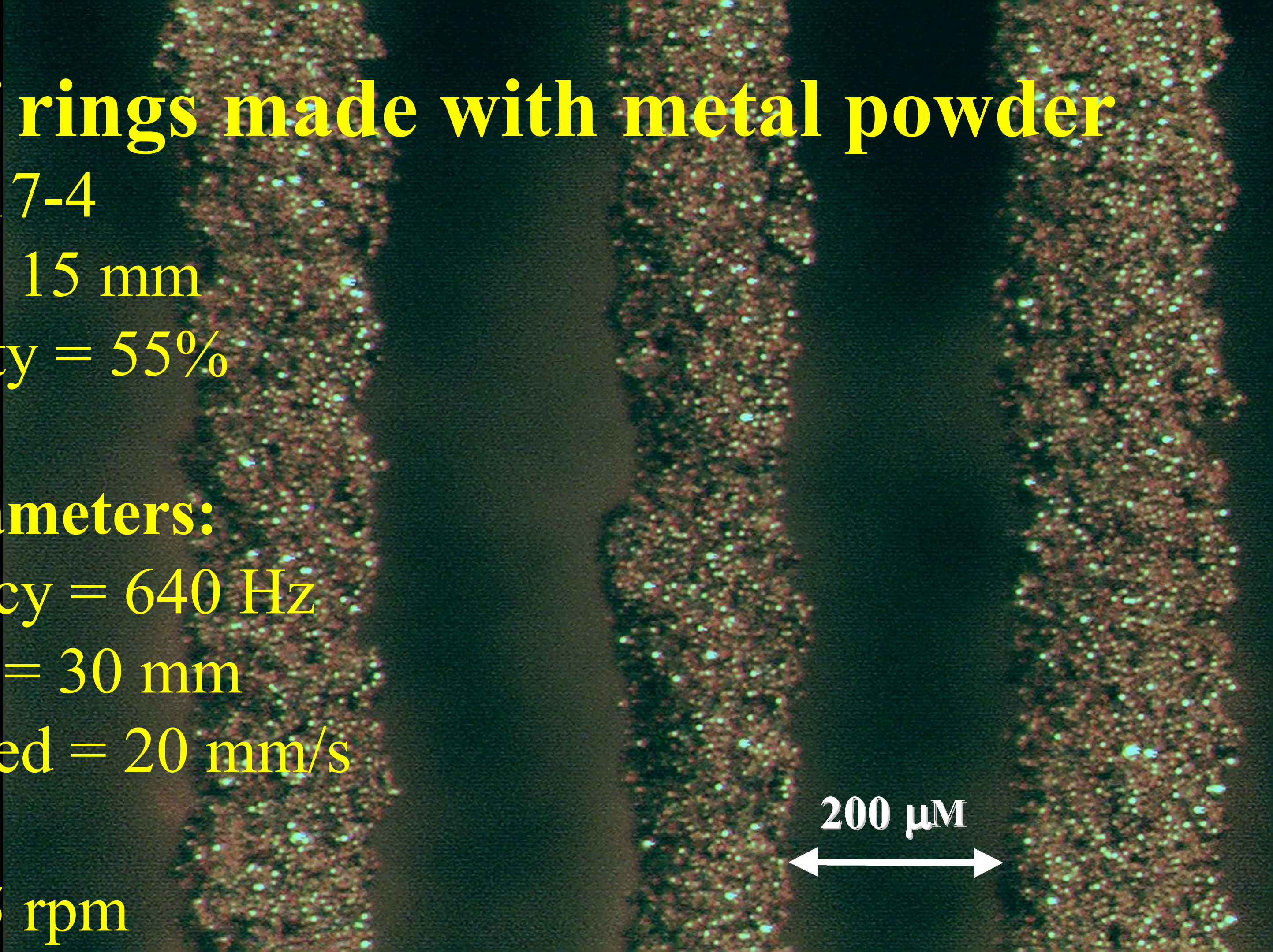
Printing parameters:

Drop Frequency = 640 Hz

Drop Spacing = 30 mm

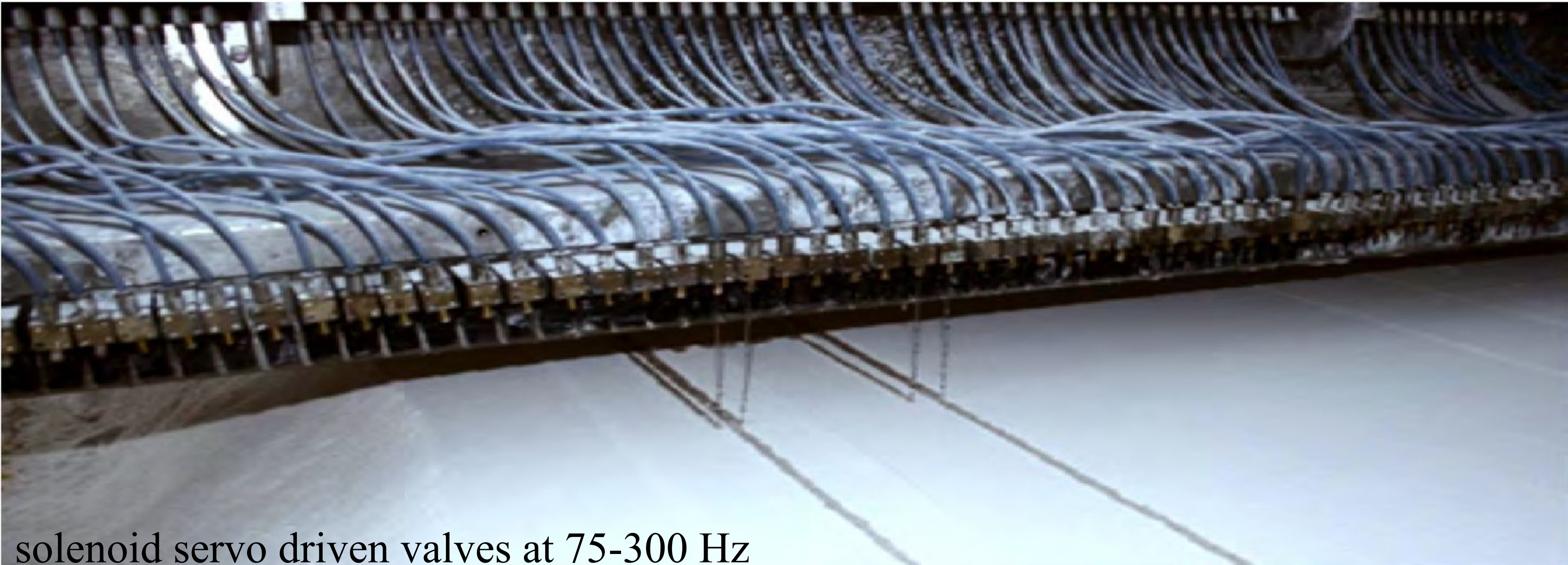
Printhead Speed = 20 mm/s

Table Spin: 25 rpm

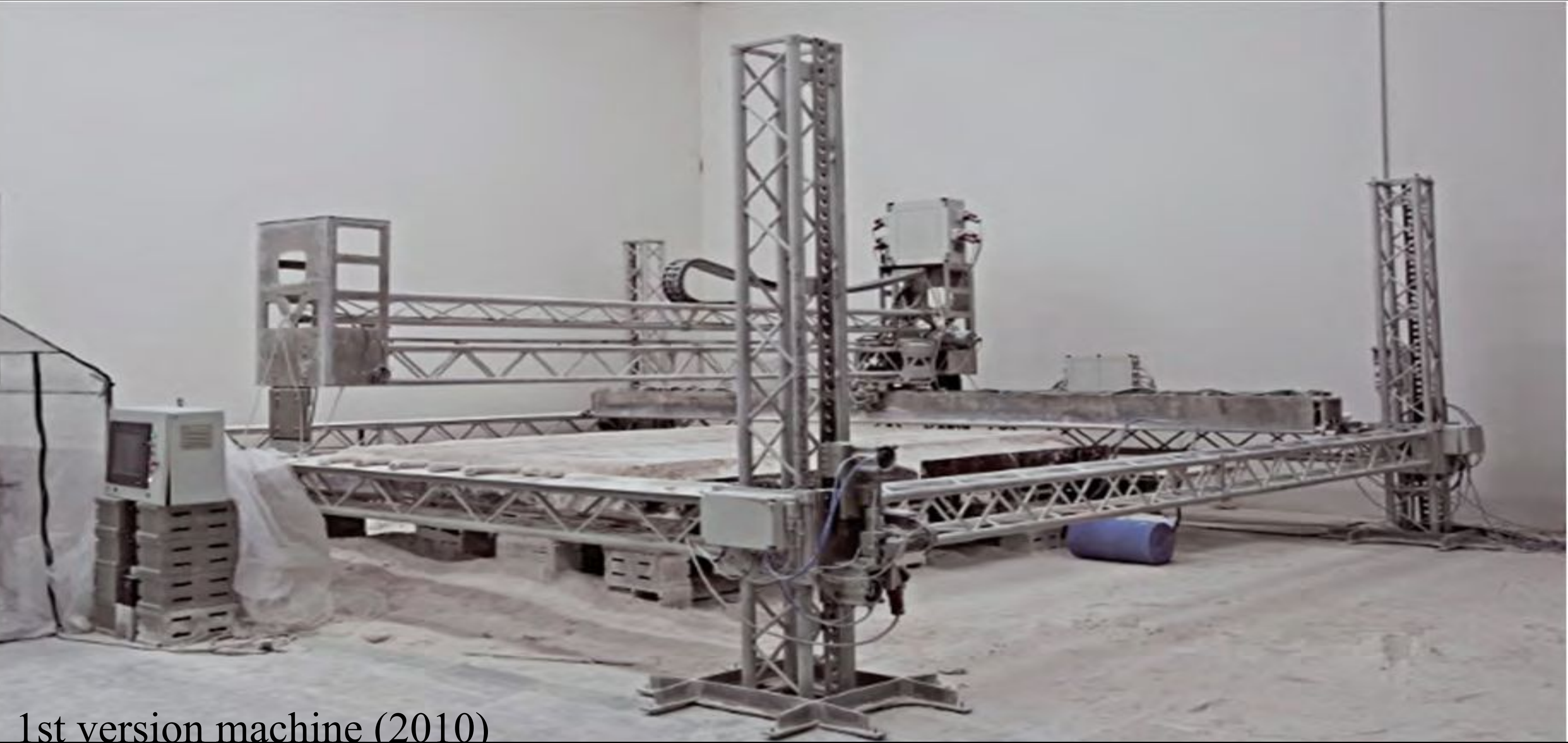


powder compaction rolls

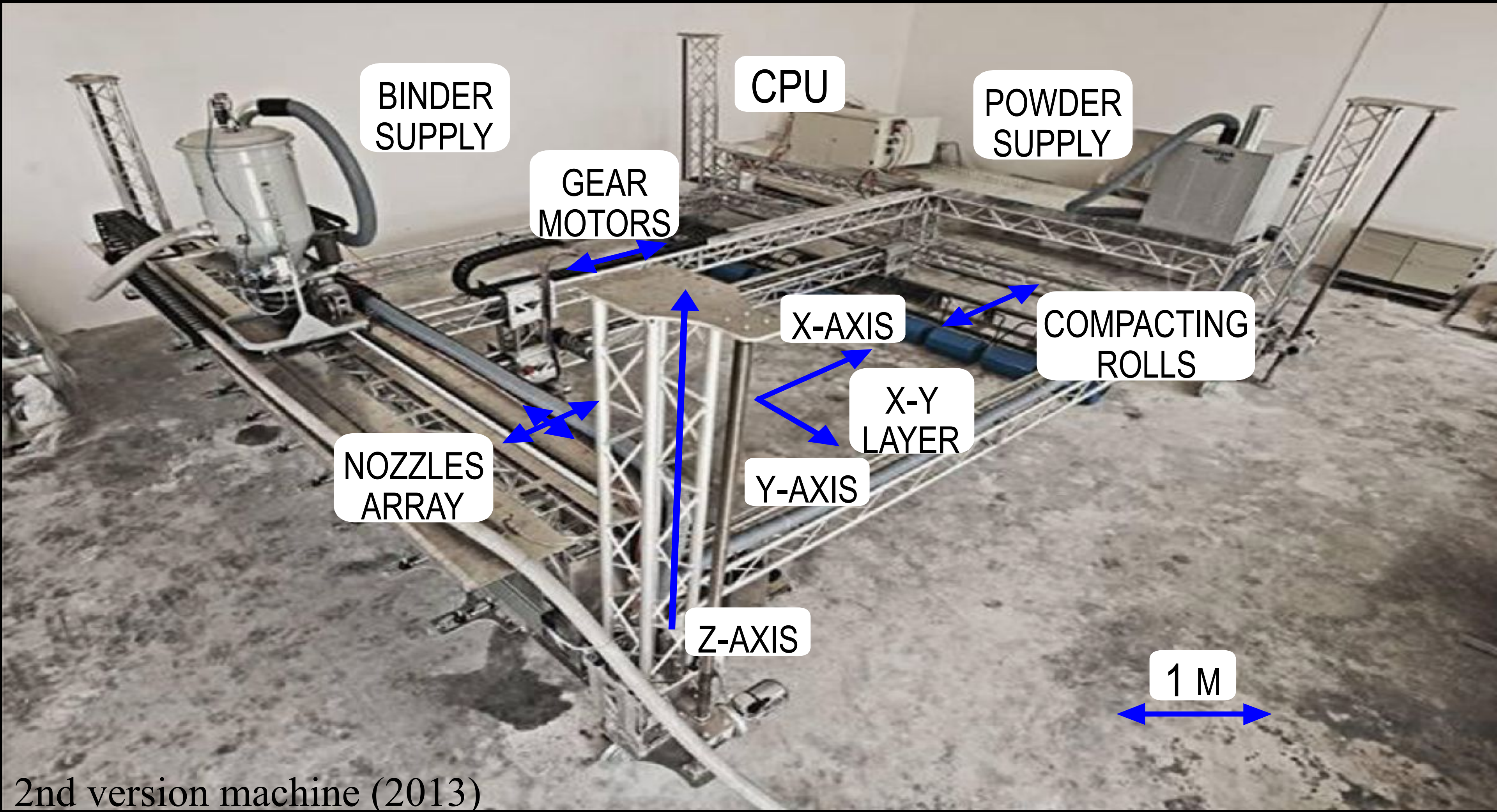
The nozzle system of the D-Shape machine



solenoid servo driven valves at 75-300 Hz



1st version machine (2010)

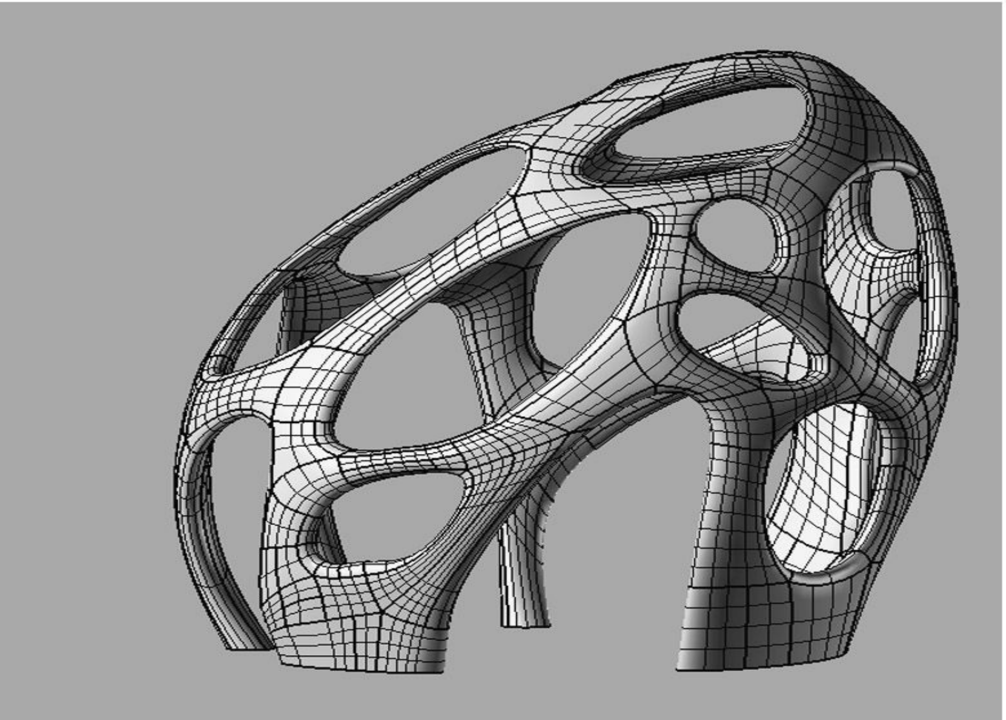


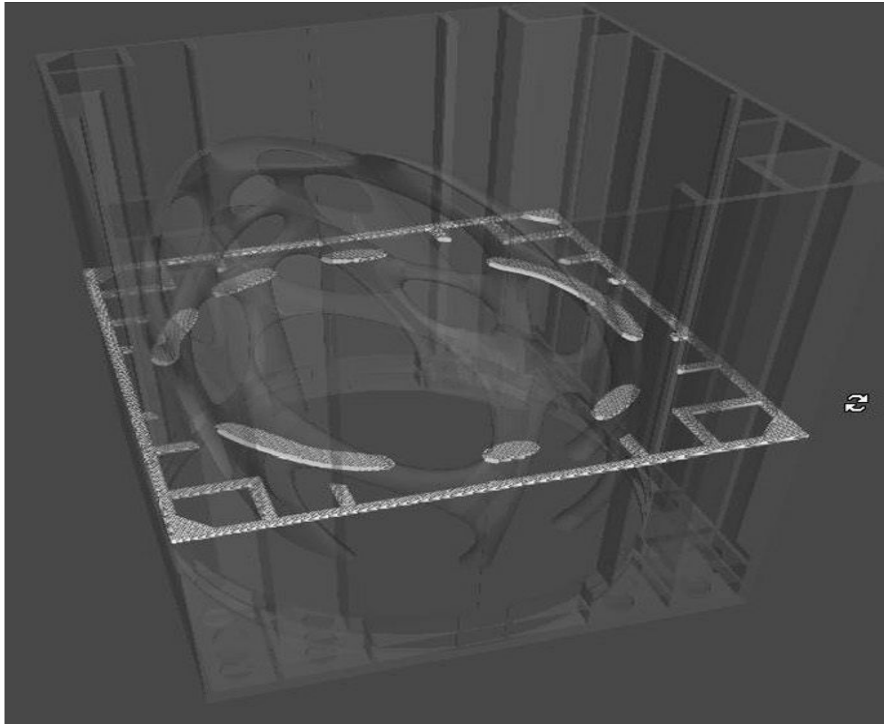
2nd version machine (2013)

3 tons full scale house www.d-shape.com

entangled concrete rings, impossible to make by traditional methods of

Conceptual design 1/3



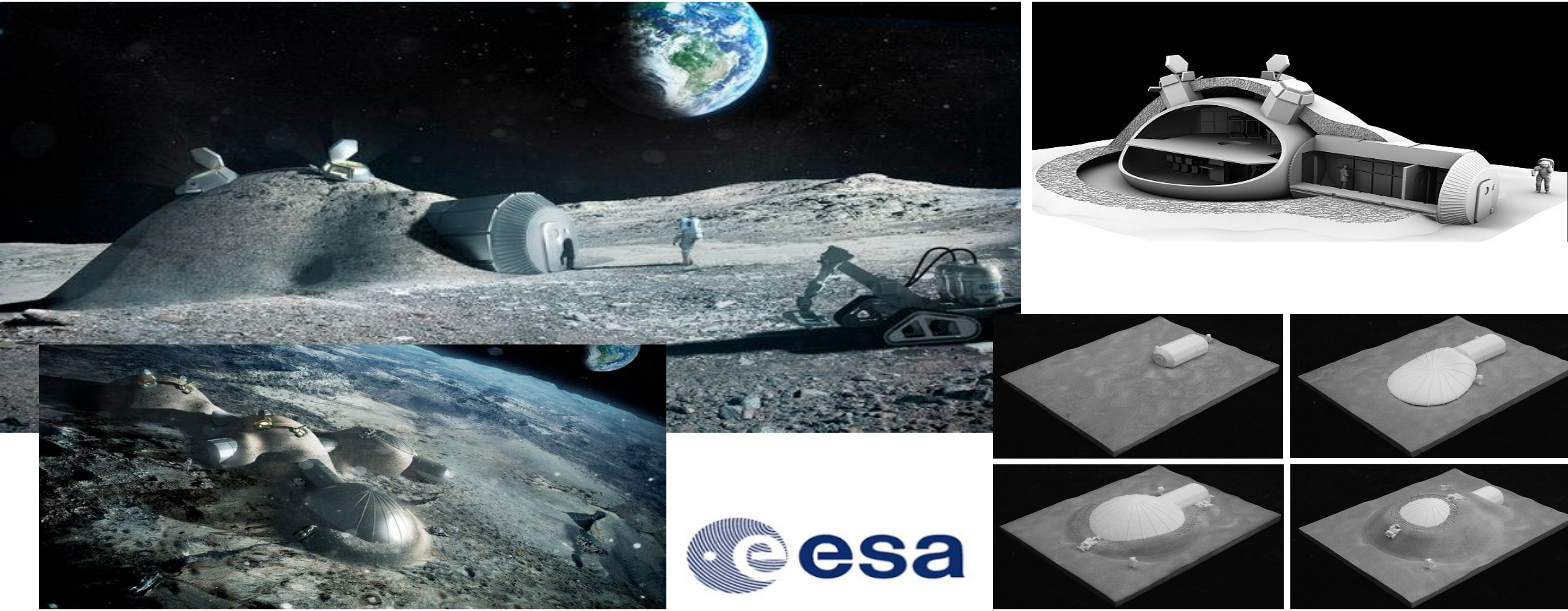


Radiolaria, 3 m^3 gazebo designed by London Architect Andrea Morgante

Conceptual design 2/3

Paolo Deiana, Tesi di laurea, Scuola di Architettura, Università di Firenze, 2015

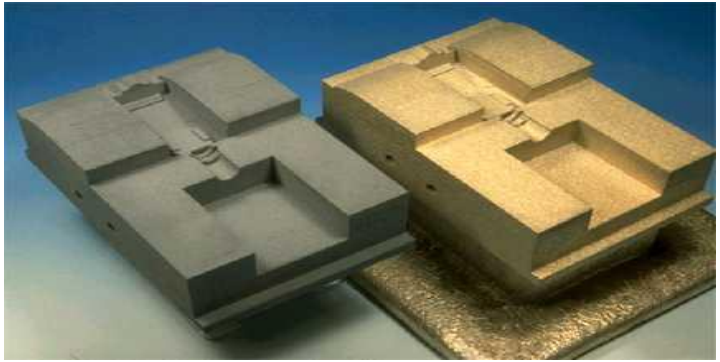
Conceptual design 3/3

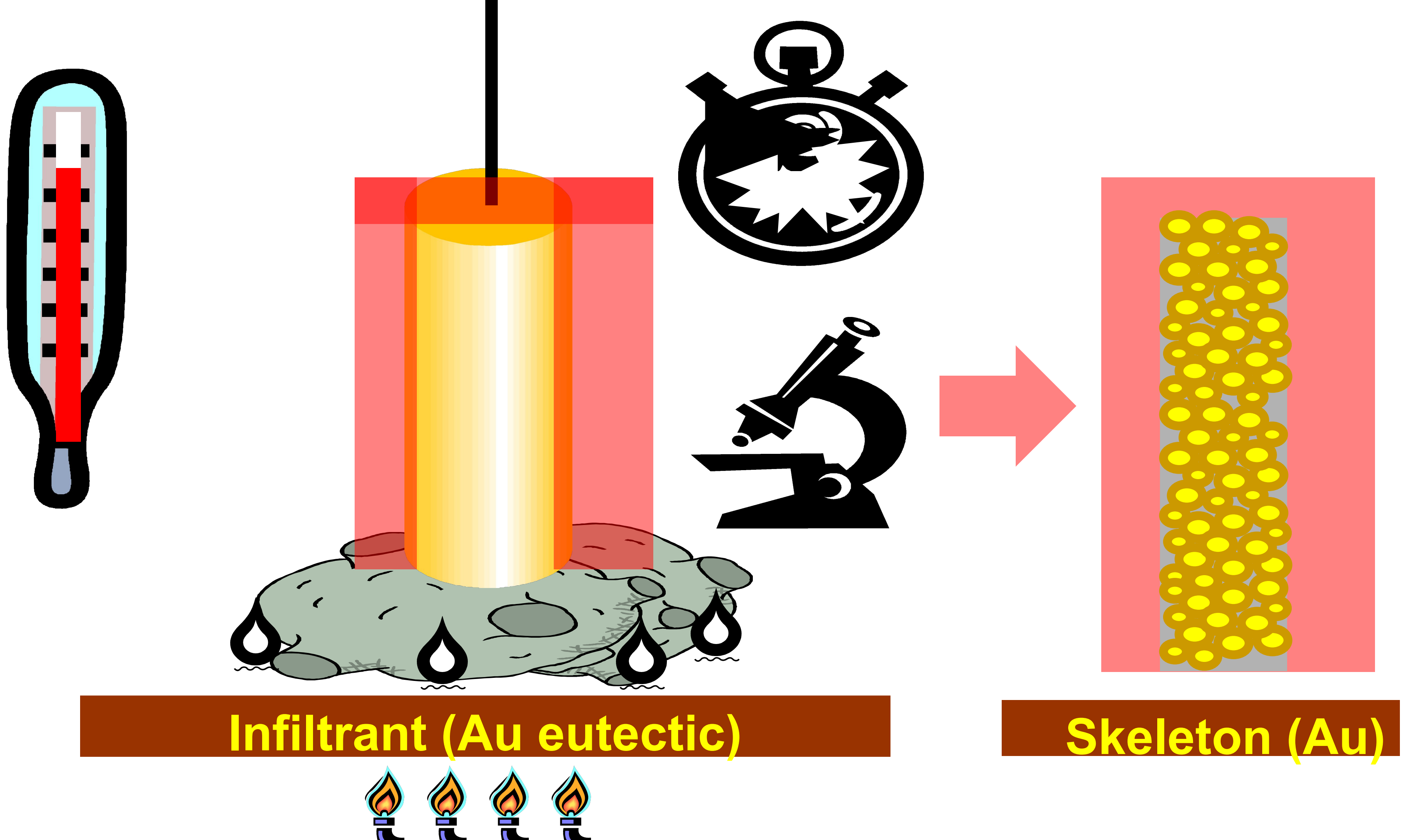


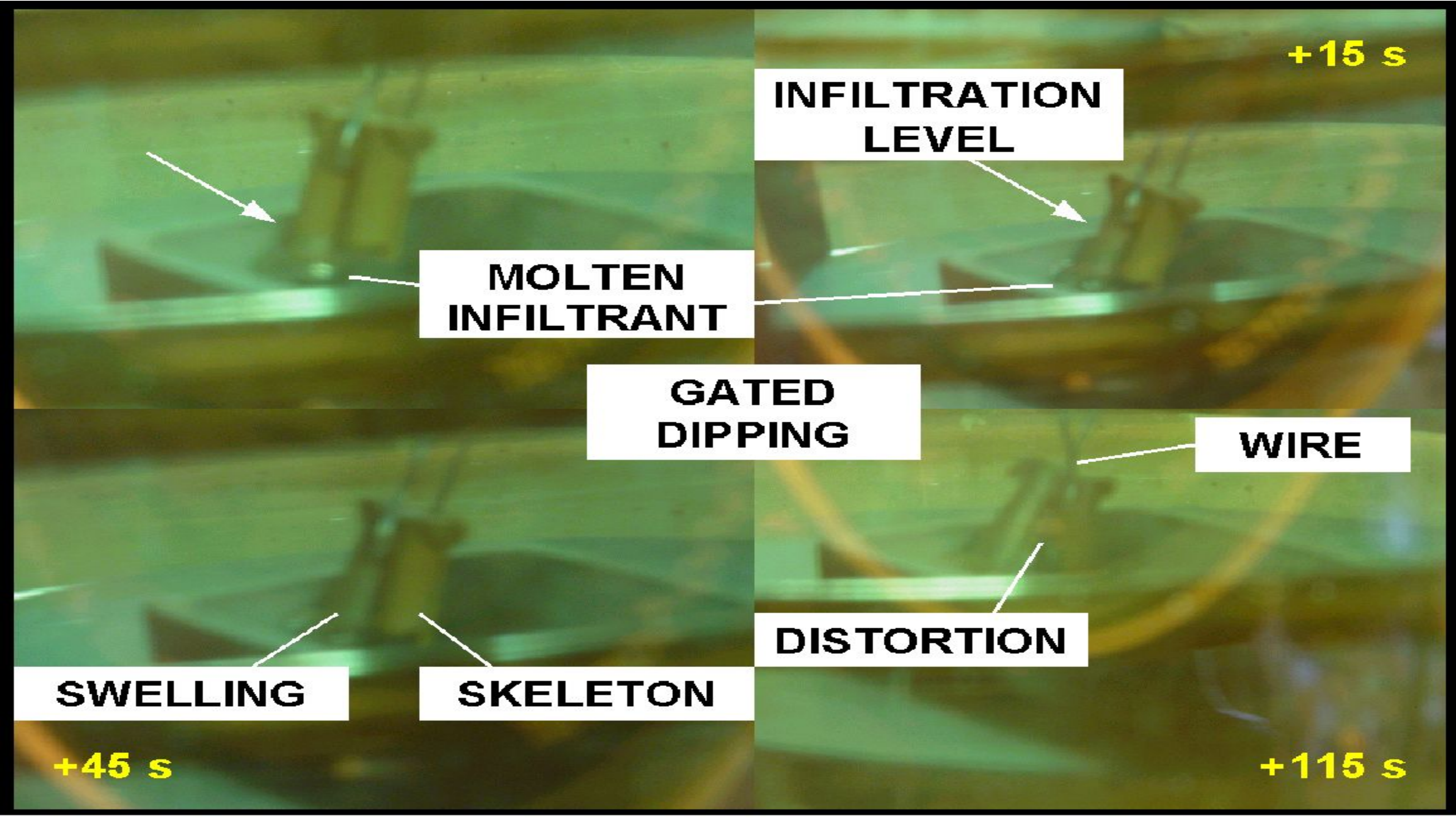
http://www.esa.int/Our Activities/Space Engineering Technology/Building a lunar base with 3D printing

Metal parts made by SFF

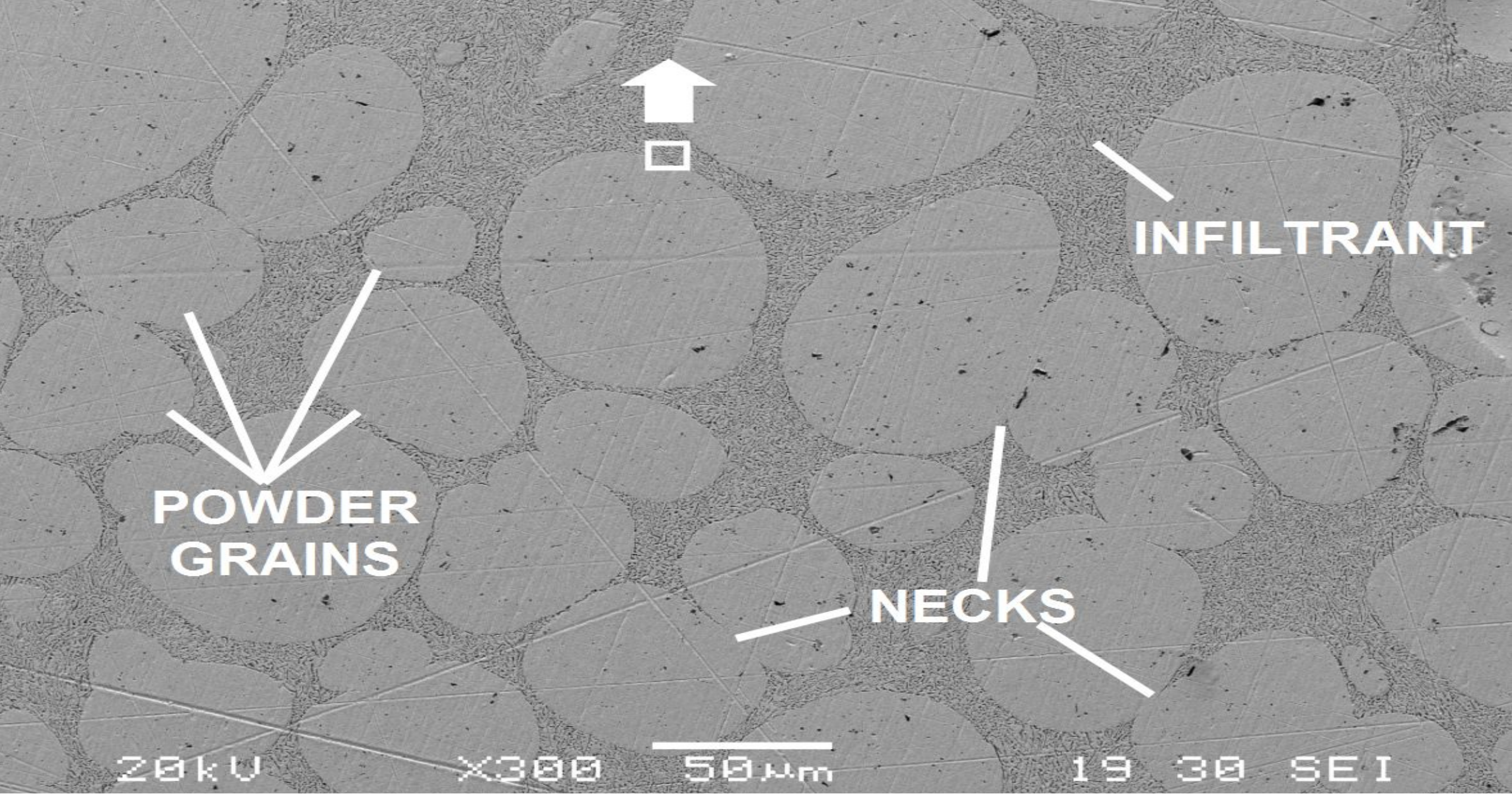
- Sinter to full density
  - choice of materials is very good
  - homogeneous final composition
- Infiltration to fill voids
  - negligible shrinkage, good for large parts
  - limited material choice
  - heterogeneous final



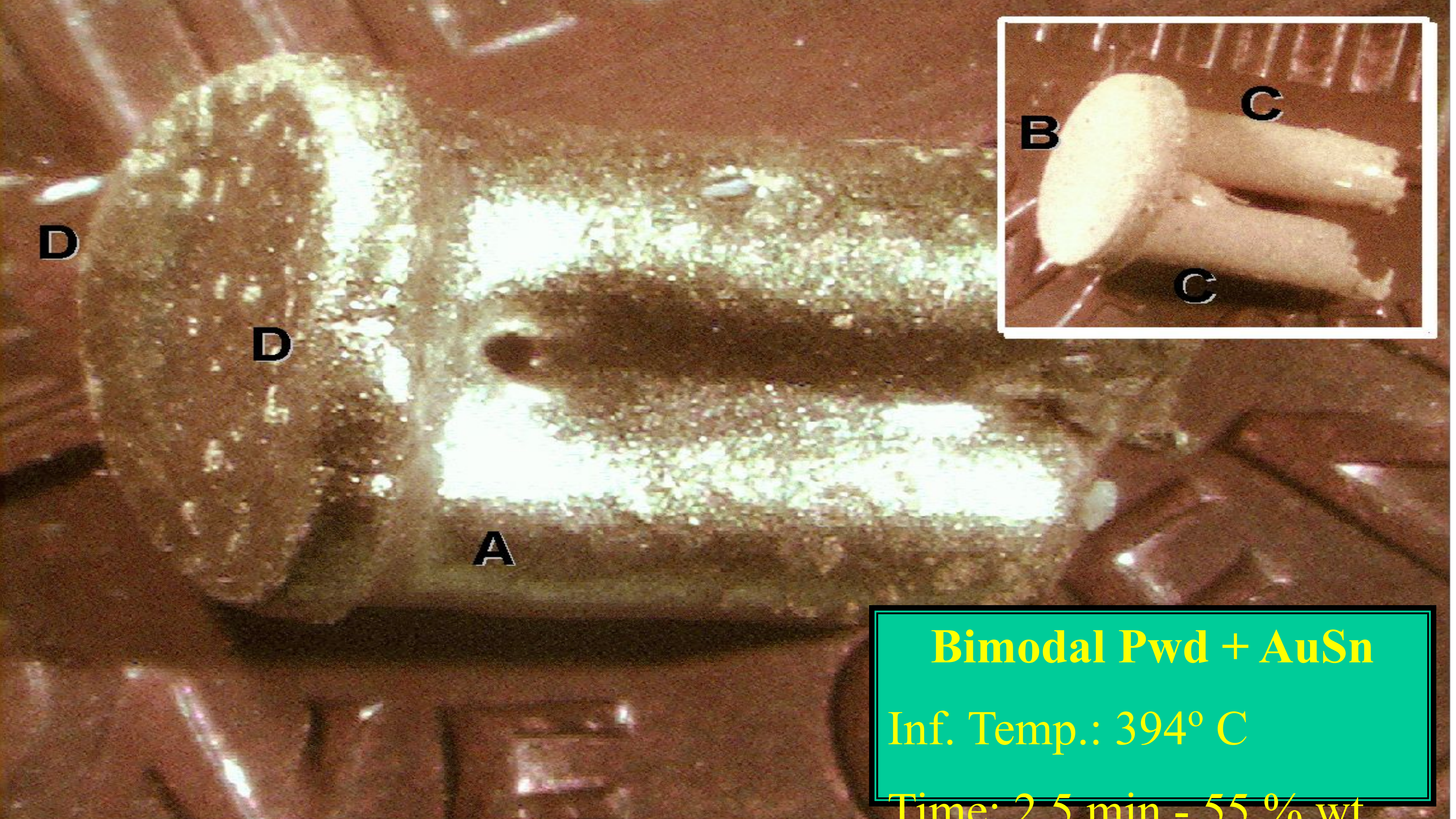

Infiltrant (Au eutectic)
Skeleton (Au)



+15 s
INFILTRATION LEVEL
MOLTEN INFILTRANT
GATED DIPPING
WIRE
DISTORTION
SWELLING
SKELETON
+45 s
+115 s

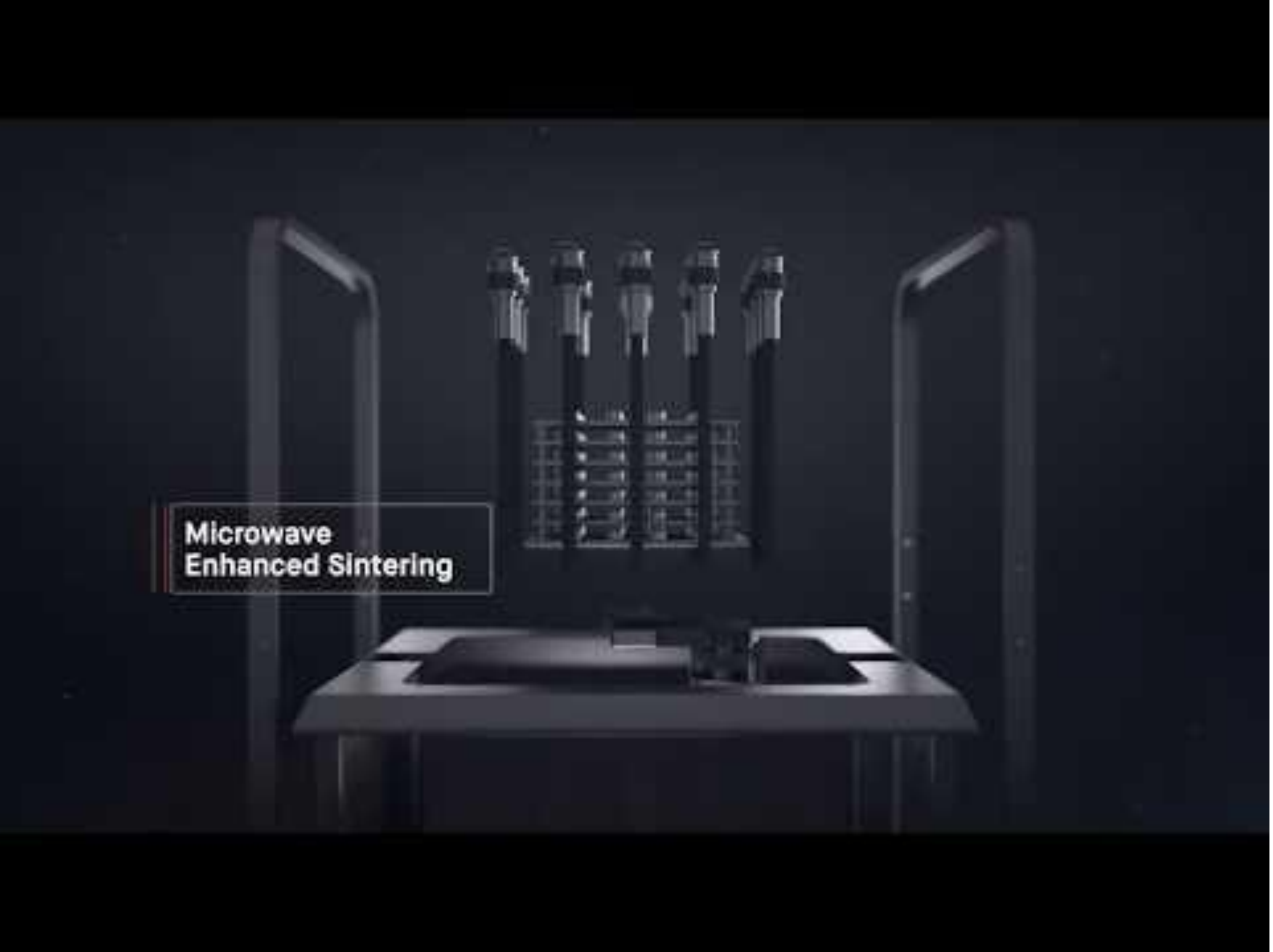


Sample Section. SEM image. Bimodal Pwd+AuSi



D
D
A
B
C
C
Bimodal Pwd + AuSn
Inf. Temp.: 394º C
Time: 2.5 min - 55 % wt

Sample Section. High porosity. Bimodal Pwd+AuSn. Inf. Temp.: 394ºC


Microwave
Enhanced Sintering

Hybrid Additive/Subtractive

58th CIRP General Assembly

Manchester (UK), August 24-30, 2008

Shape Deposition Manufacturing of biologically inspired hierarchical microstructures

Michele Lanzetta (2)

University of Pisa, Italy

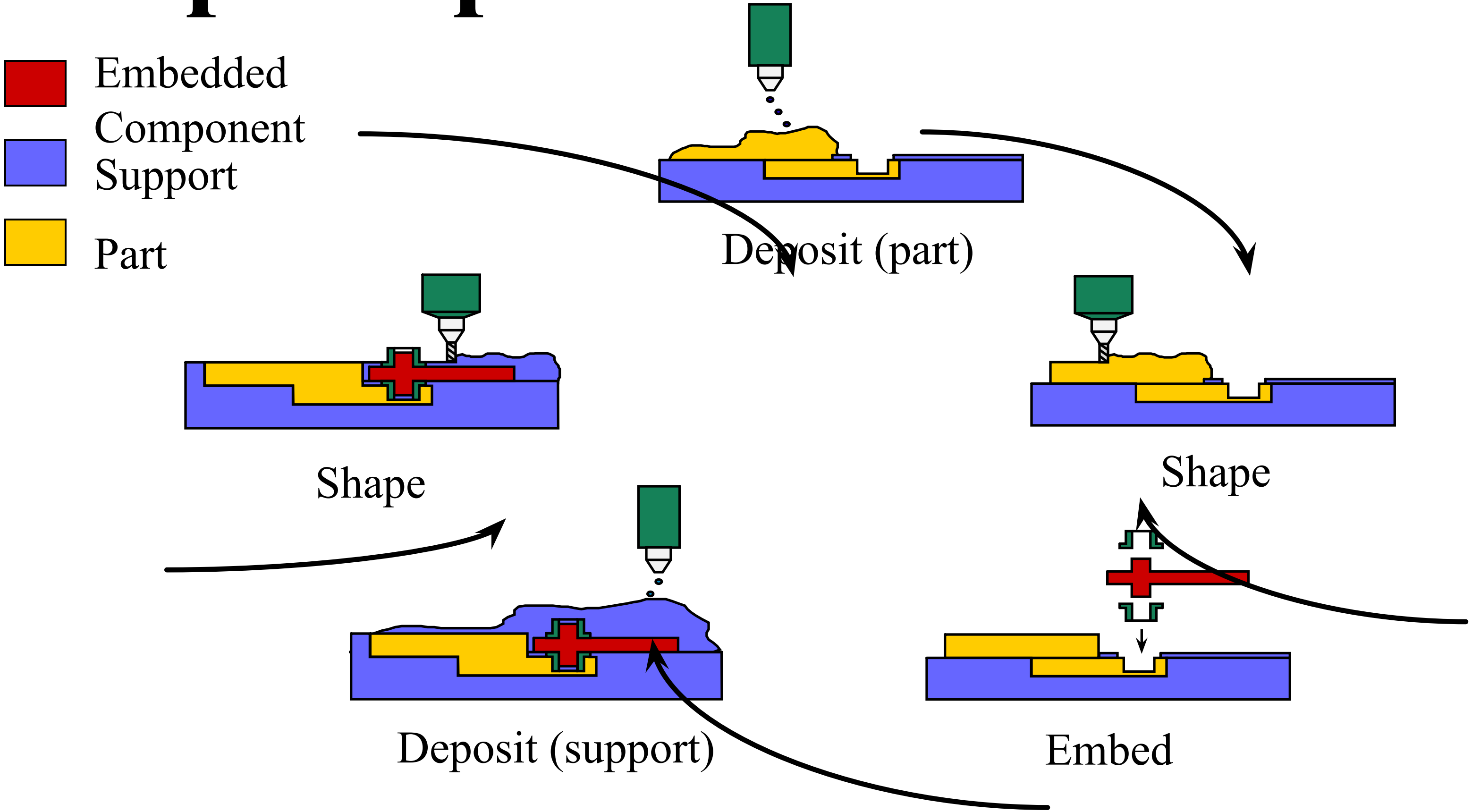
Department of Mechanical, Nuclear and Production Engineering

Mark Cutkosky

Stanford University, USA

Mechanical Engineering Research Laboratories

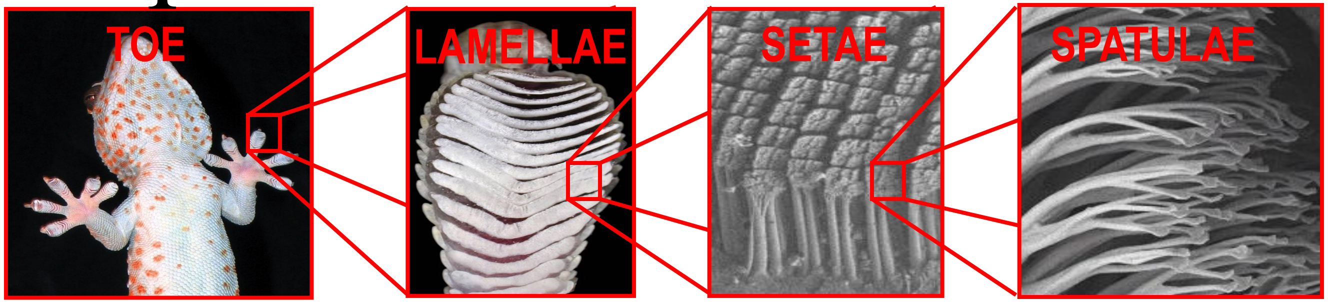
Shape Deposition Manufacturing



CLIMBING

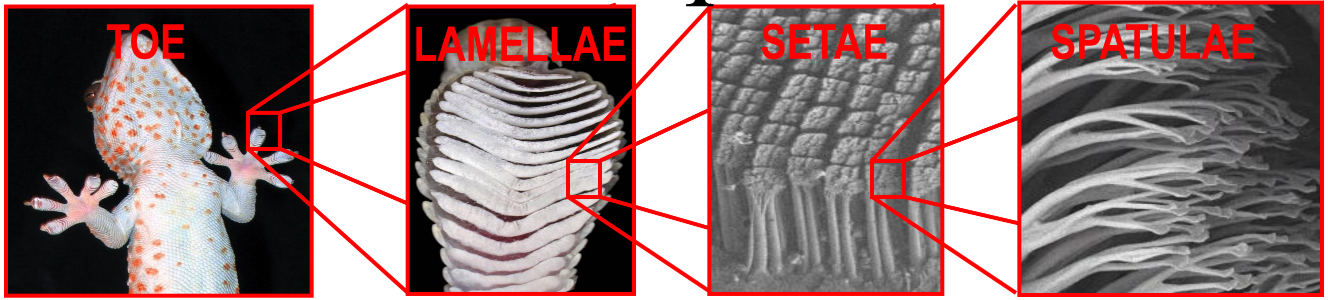
HANDLING

Inspiration: Gecko Adhesion

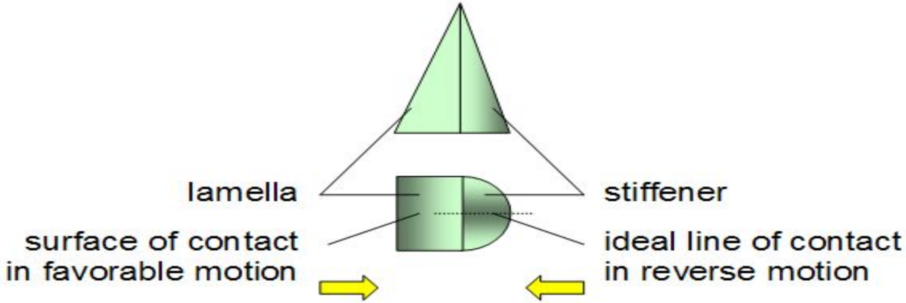


- Main features
  - **Dry** Adhesion
  - **Directional**/Controllable Adhesion
  - Hierarchical **Compliant** Structure

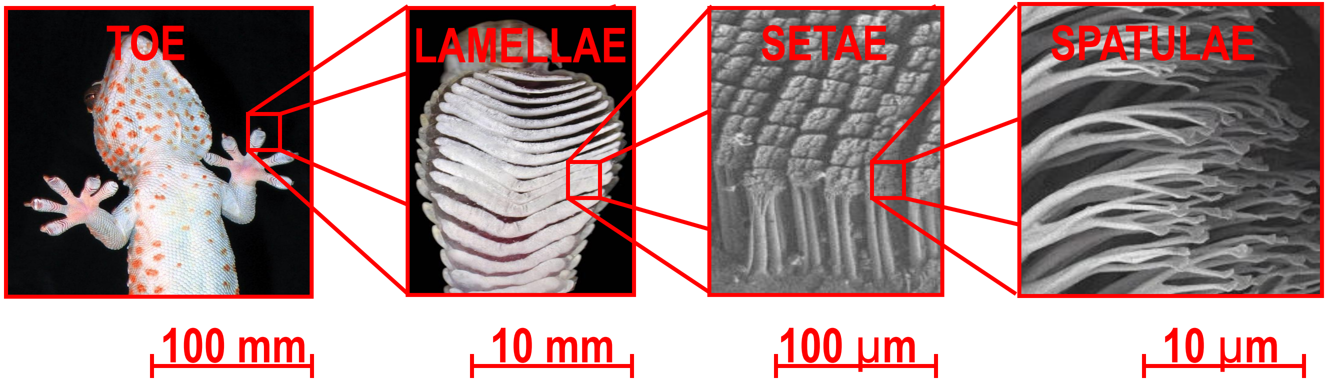
Shape?



- Angles
  - Setae 20º
  - Spatulae 45º

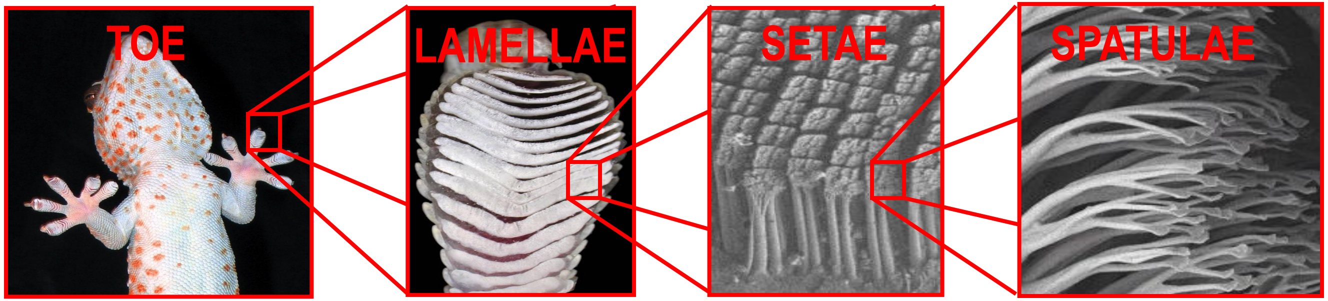


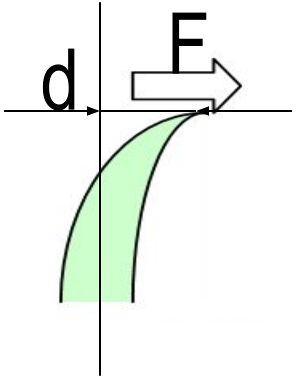
Dimensions?



- size ratio between successive layers
  - Gecko => logarithmic?
  - Theoretical (literature) => constant

Structural constraints?



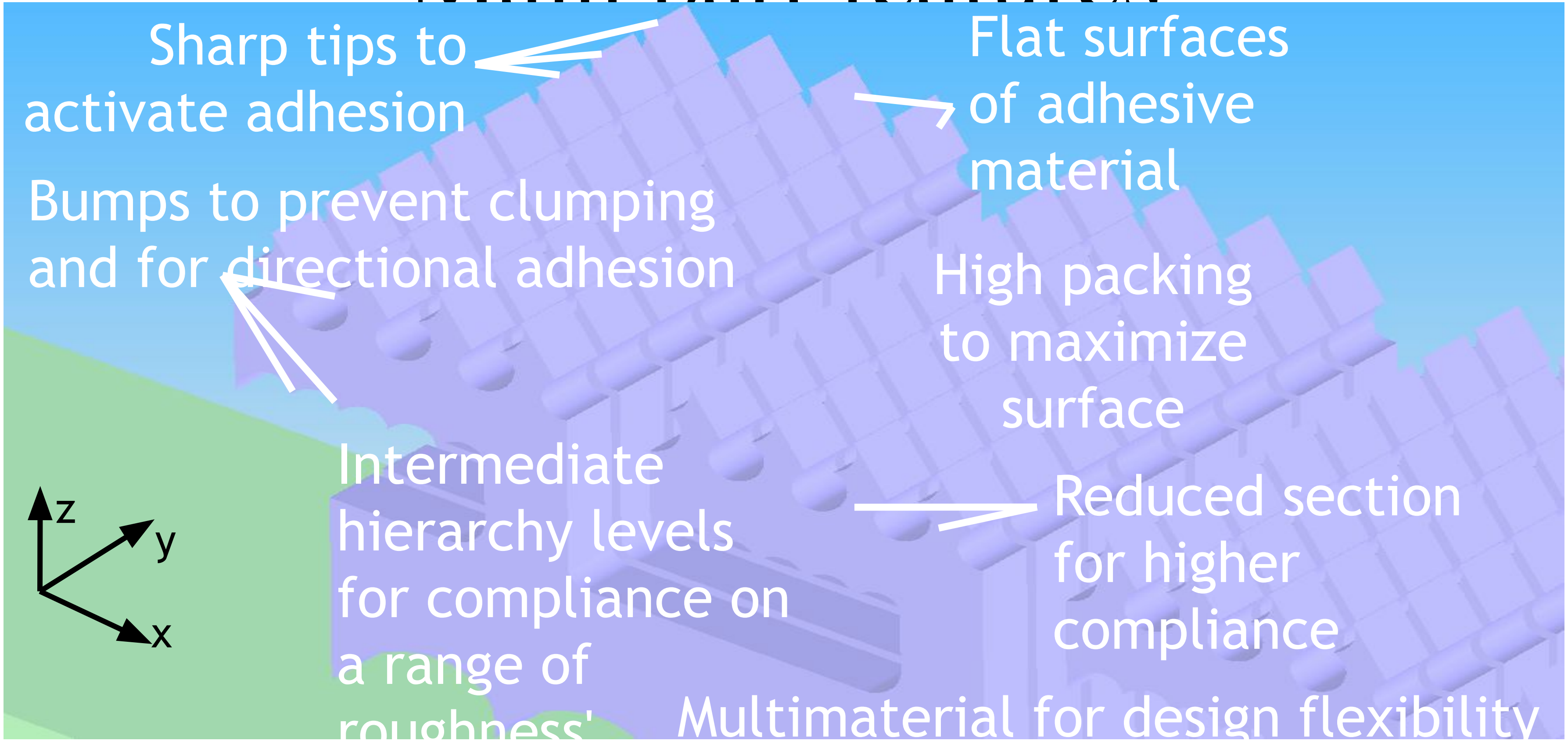


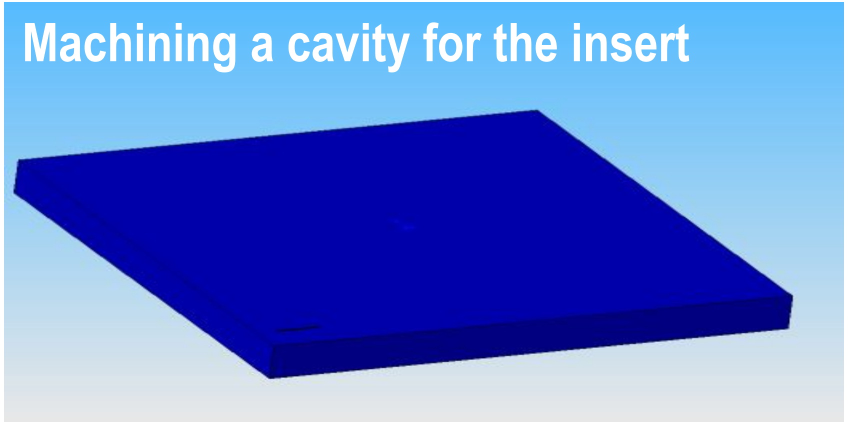
Gecko bending stiffness (defined as F/d)

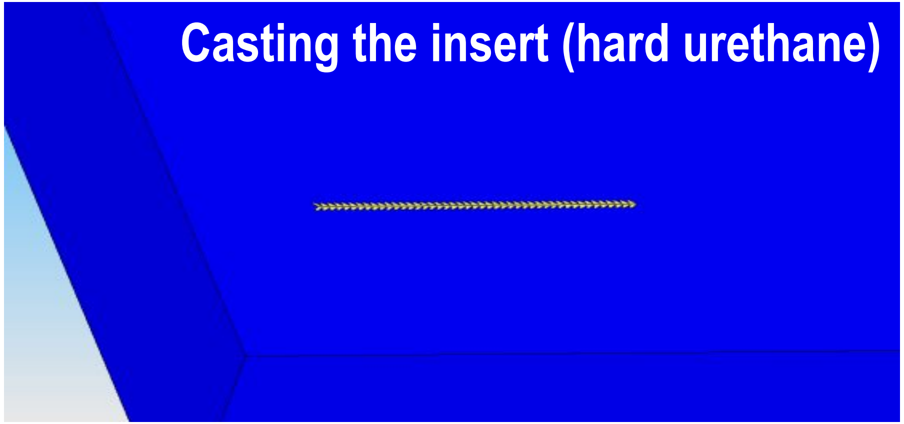
⇩

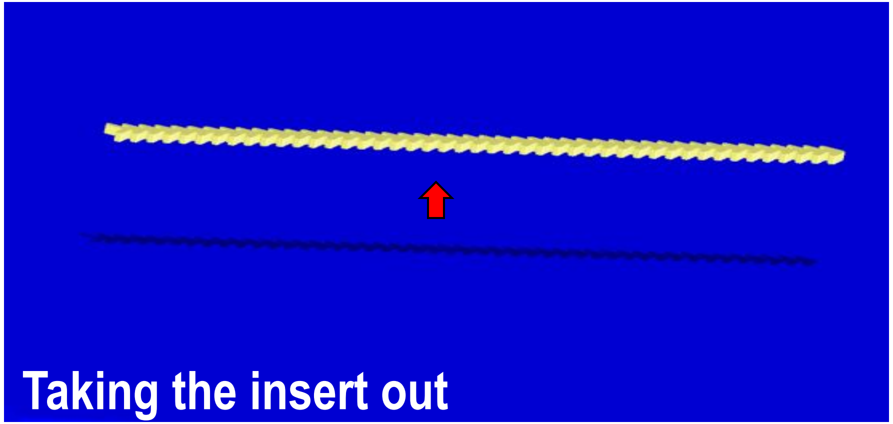
Hair length/diameter = 2

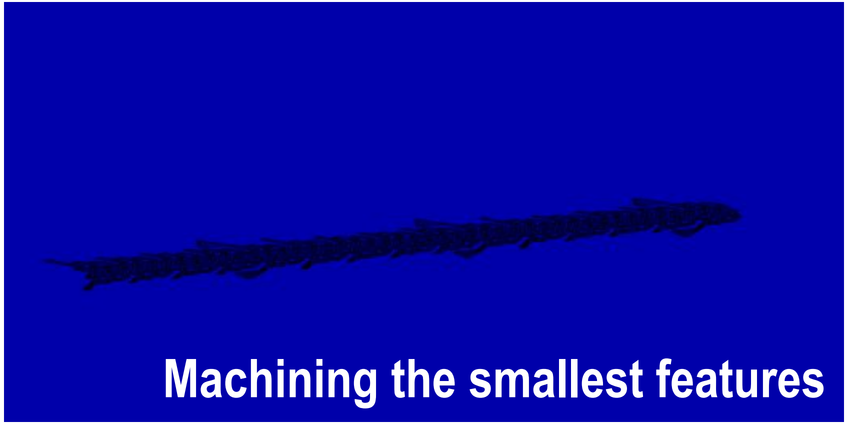
Main part features

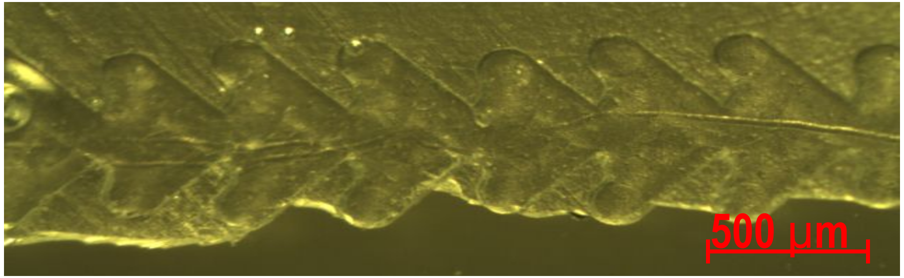


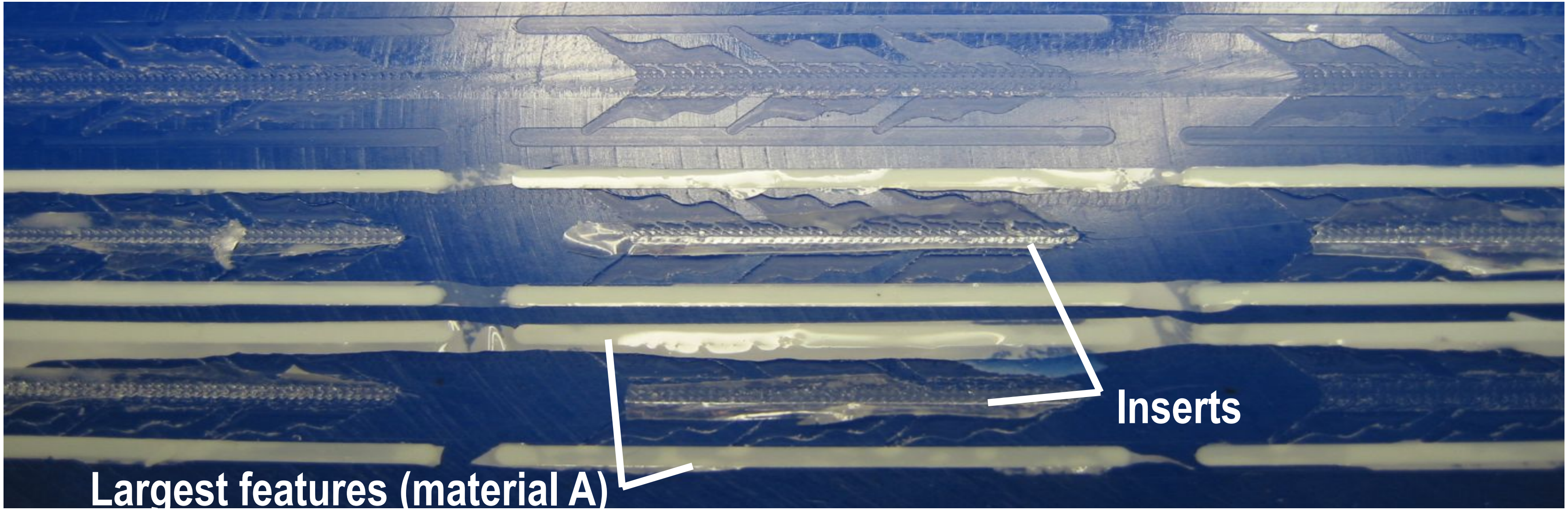

Machining a cavity for the insert

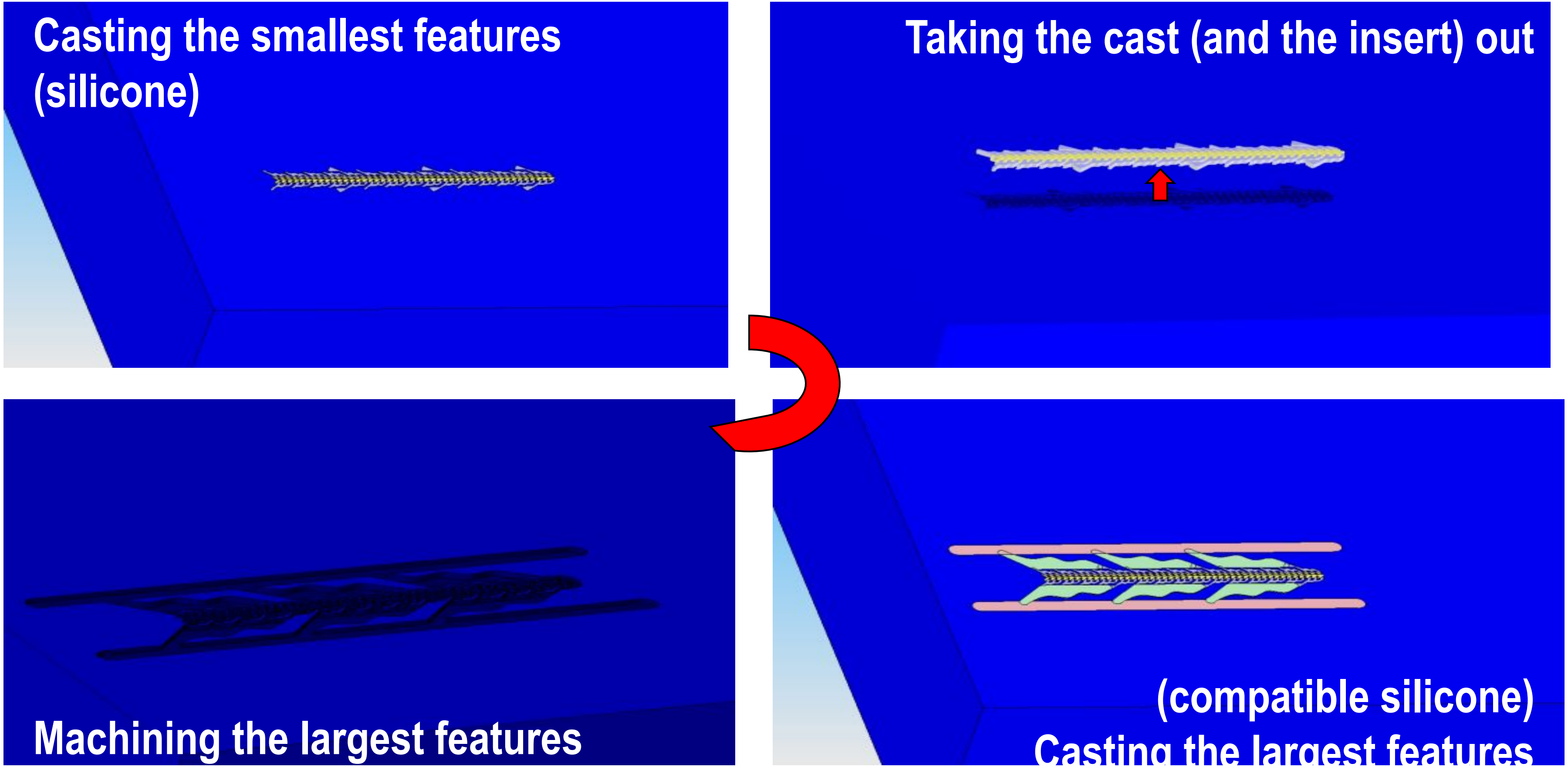

Casting the insert (hard urethane)

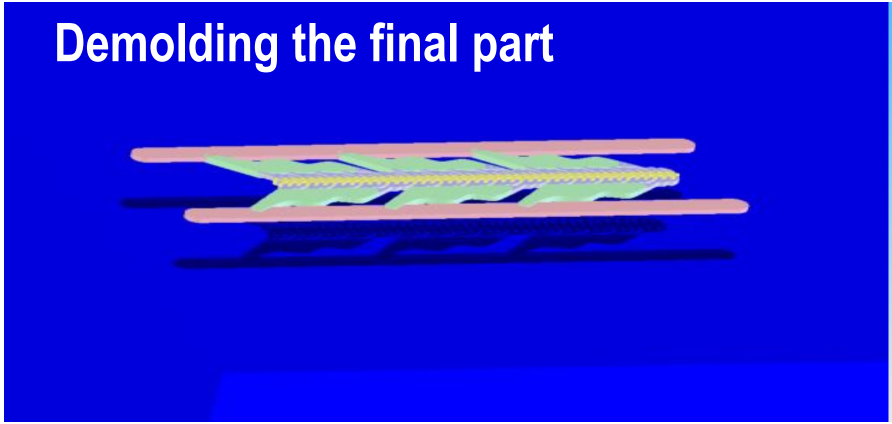

Taking the insert out

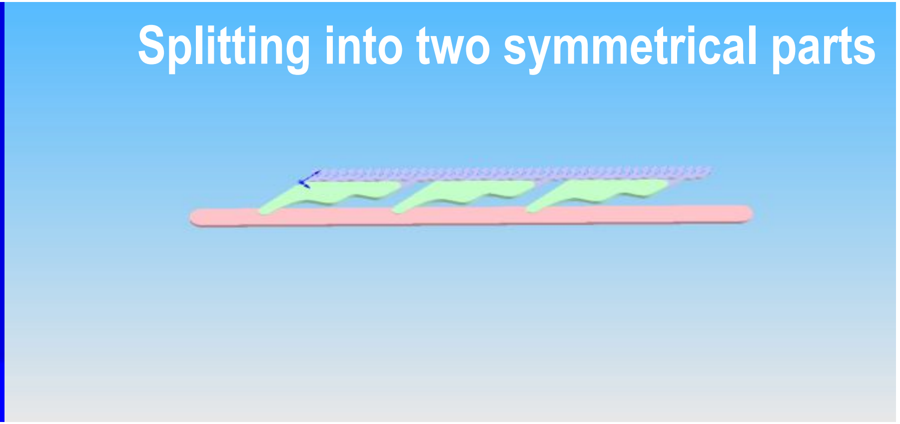

Machining the smallest features

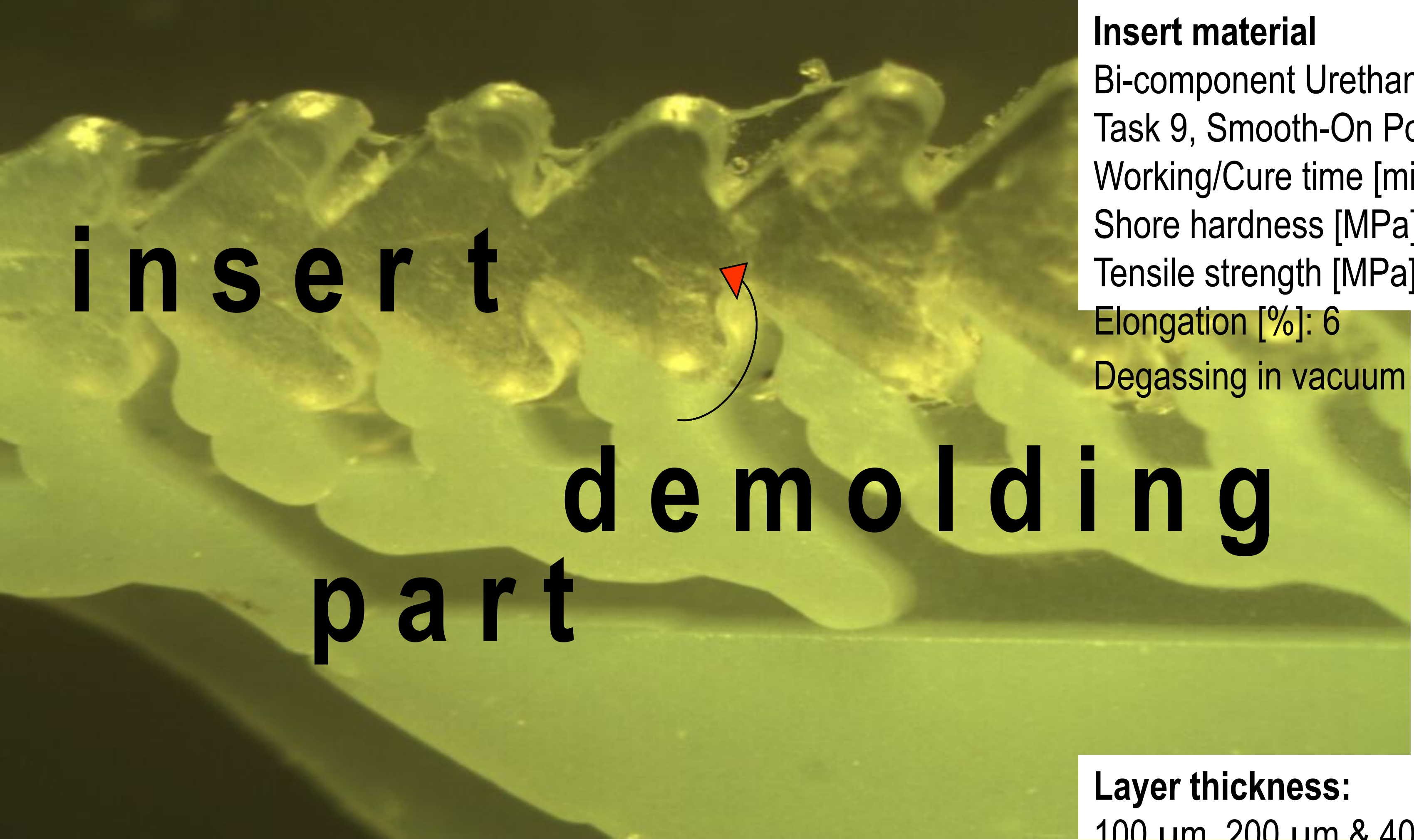

500 µm


Inserts
Largest features (material A)


Casting the smallest features (silicone)
Taking the cast (and the insert) out
Machining the largest features
(compatible silicone)
Casting the largest features


Demolding the final part


Splitting into two symmetrical parts



Insert material

Bi-component Urethane:

Task 9, Smooth-On Polymers, Inc.

Working/Cure time [min./h.]: 7/14

Shore hardness [MPa]: 85D

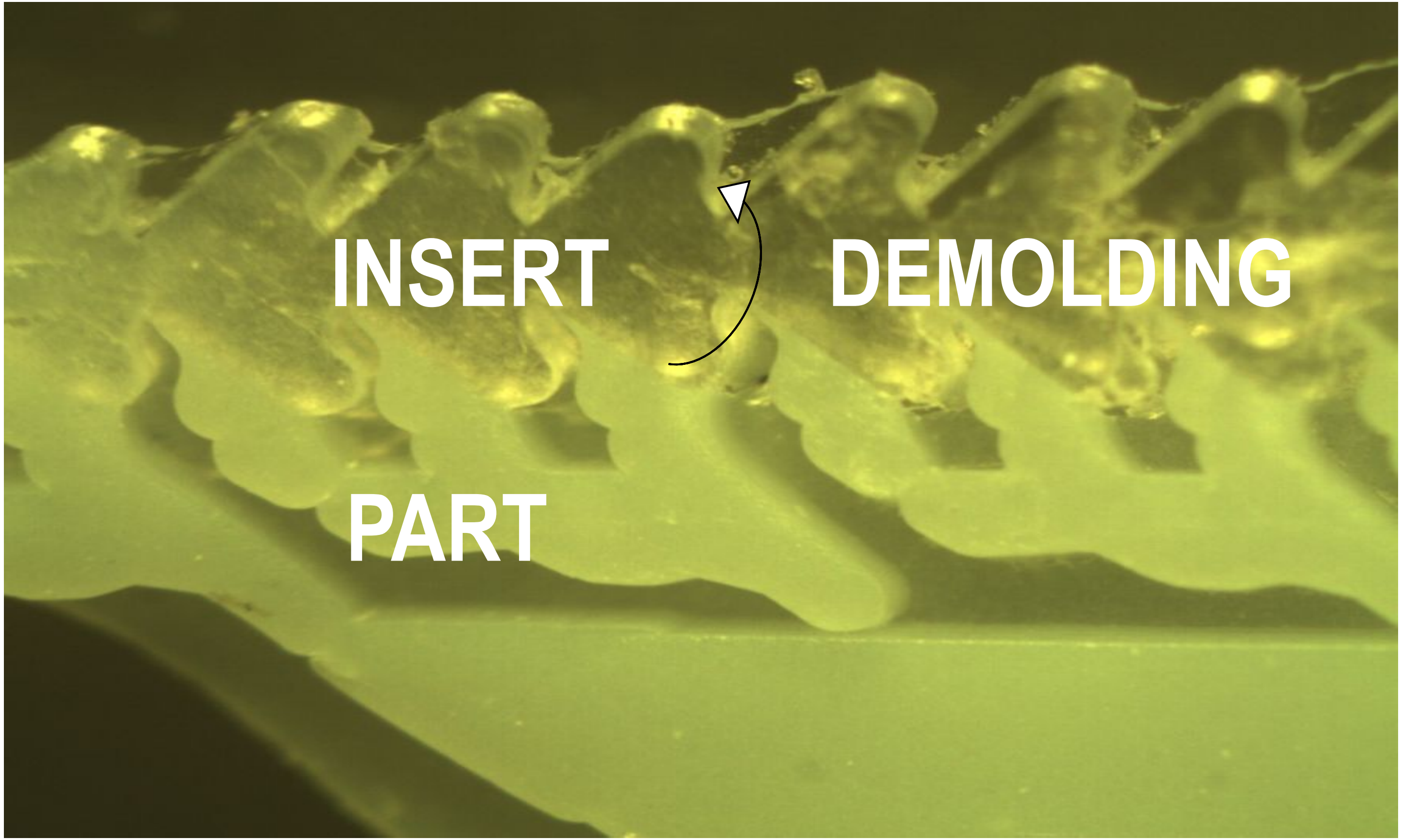
Tensile strength [MPa]: 54

Elongation [%]: 6

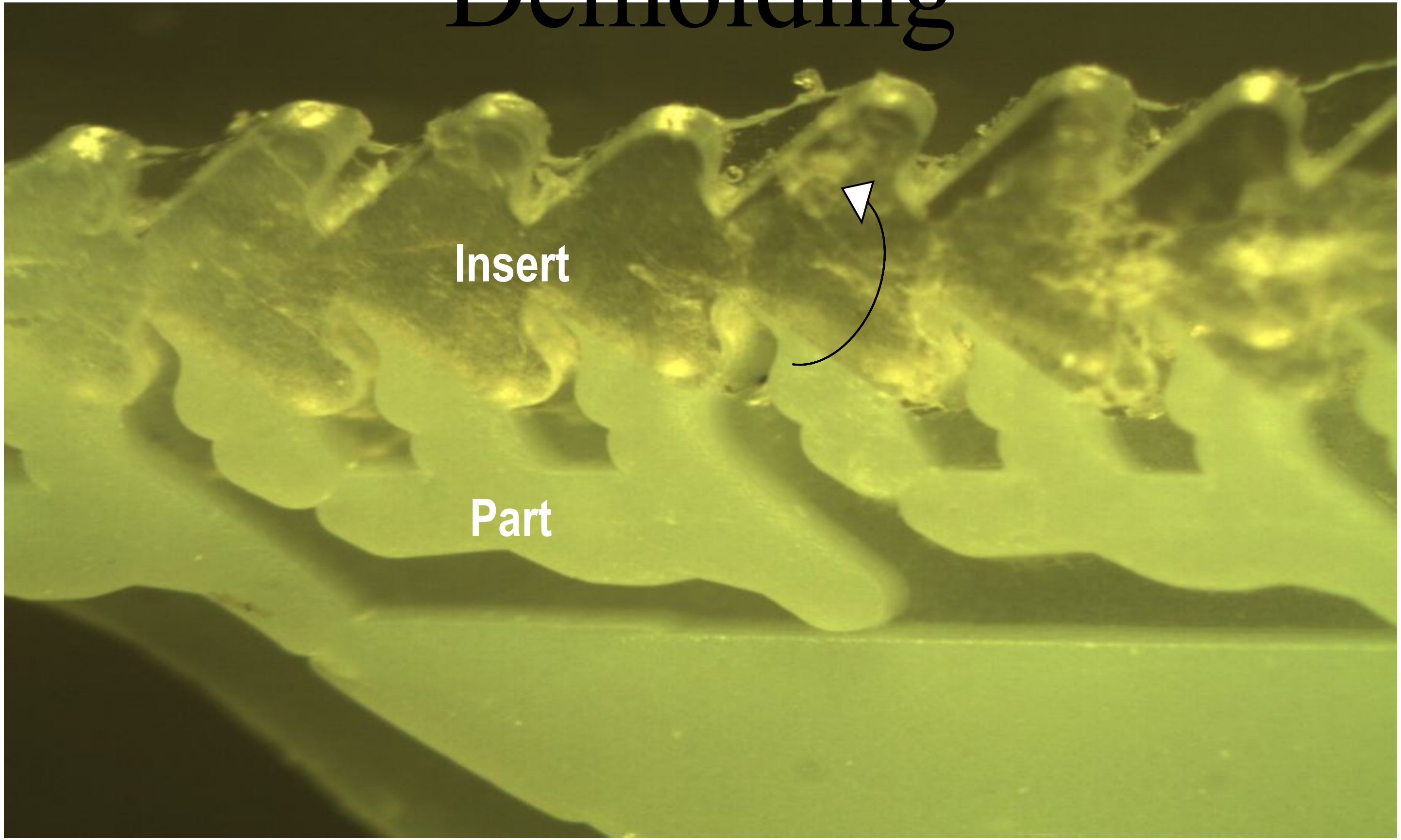
Degassing in vacuum @ 26” Hg

Layer thickness:

100 µm, 200 µm & 400 µm


INSERT
DEMOLDING
PART

Demolding



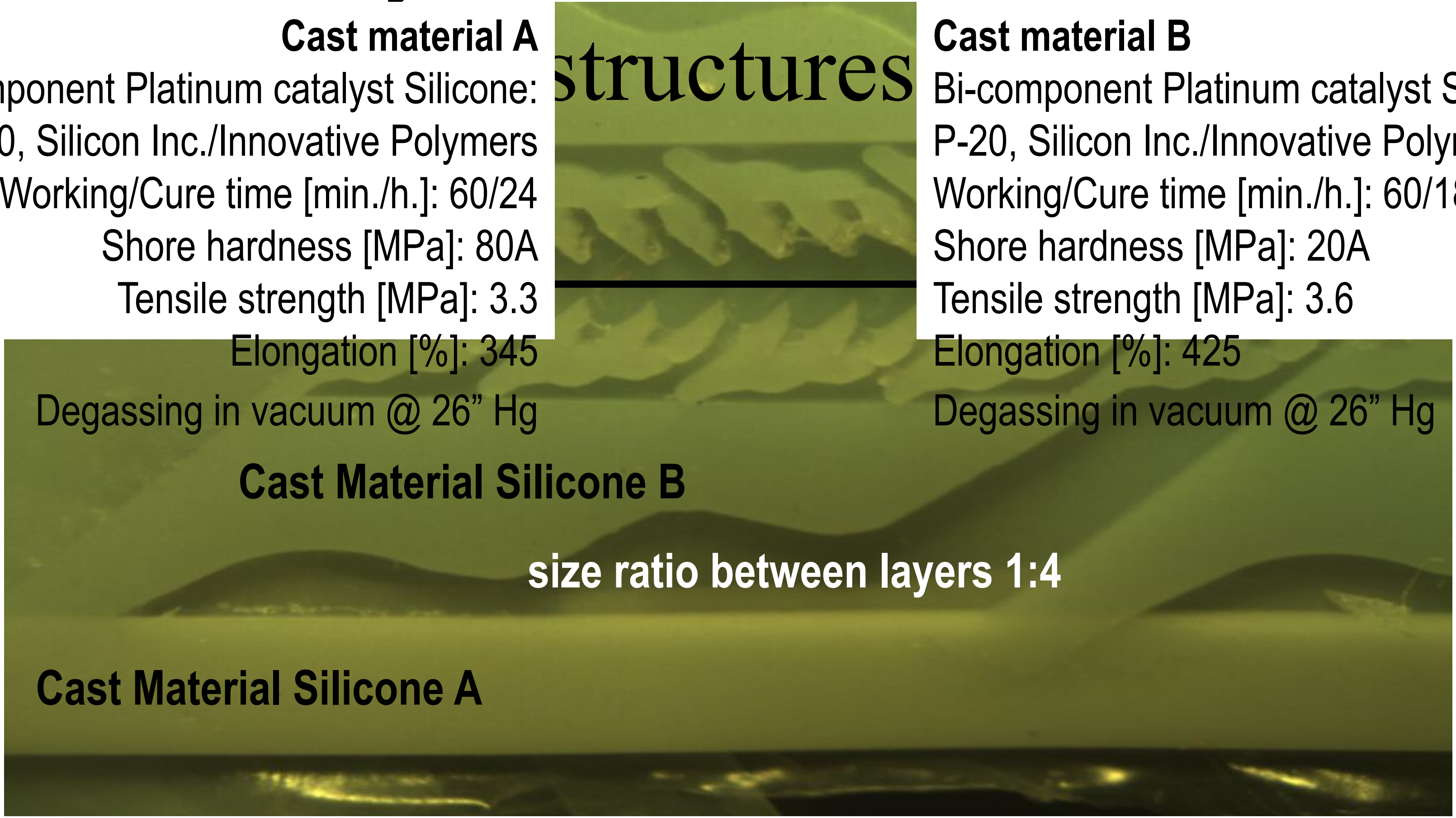
Two symmetrical hierarchical structures

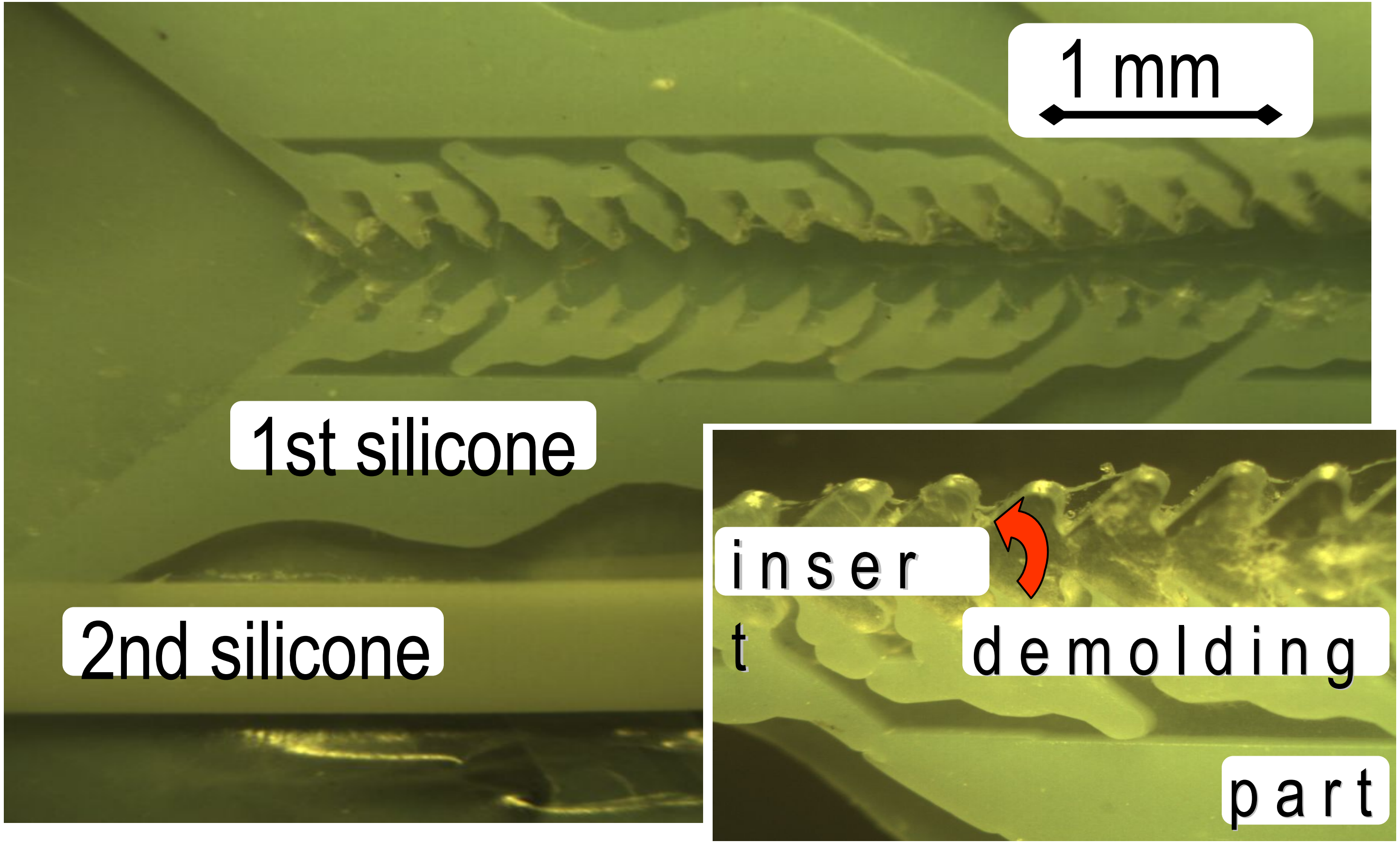
Cast material A

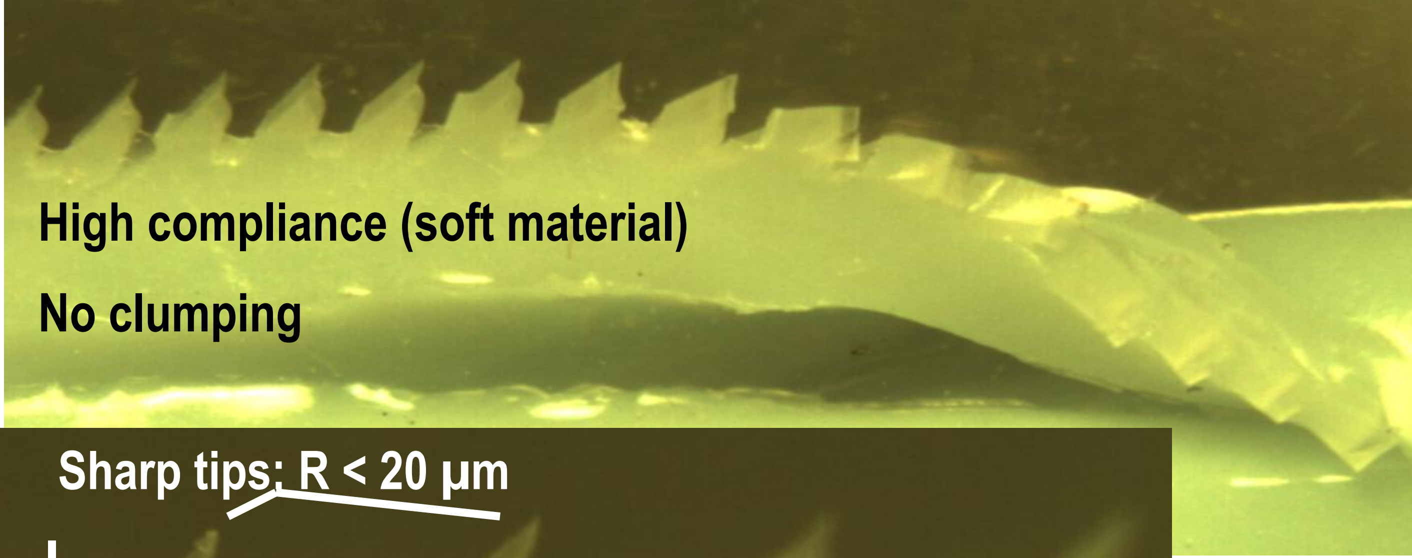
Bi-component Platinum catalyst Silicone:
P-100, Silicon Inc./Innovative Polymers
Working/Cure time [min./h.]: 60/24
Shore hardness [MPa]: 80A
Tensile strength [MPa]: 3.3
Elongation [%]: 345
Degassing in vacuum @ 26” Hg

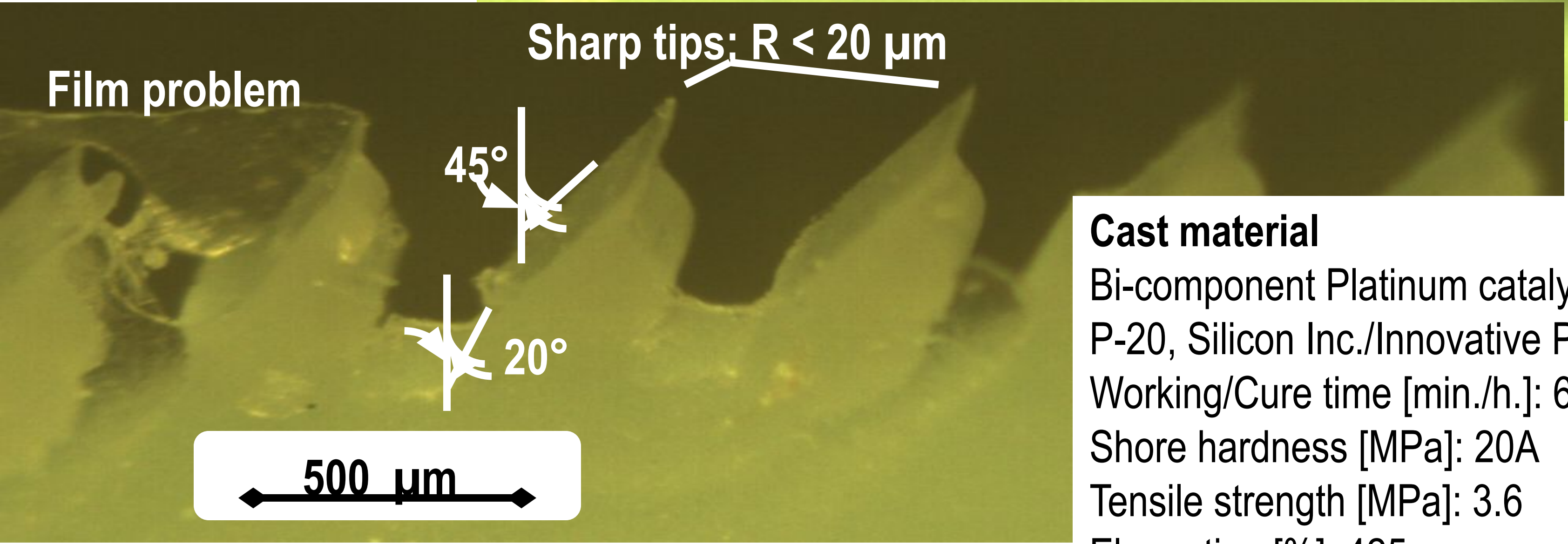
Cast material B

Bi-component Platinum catalyst Silicone:
P-20, Silicon Inc./Innovative Polymers
Working/Cure time [min./h.]: 60/18
Shore hardness [MPa]: 20A
Tensile strength [MPa]: 3.6
Elongation [%]: 425
Degassing in vacuum @ 26” Hg




1 mm
1st silicone
2nd silicone
inser
t
demolding
part



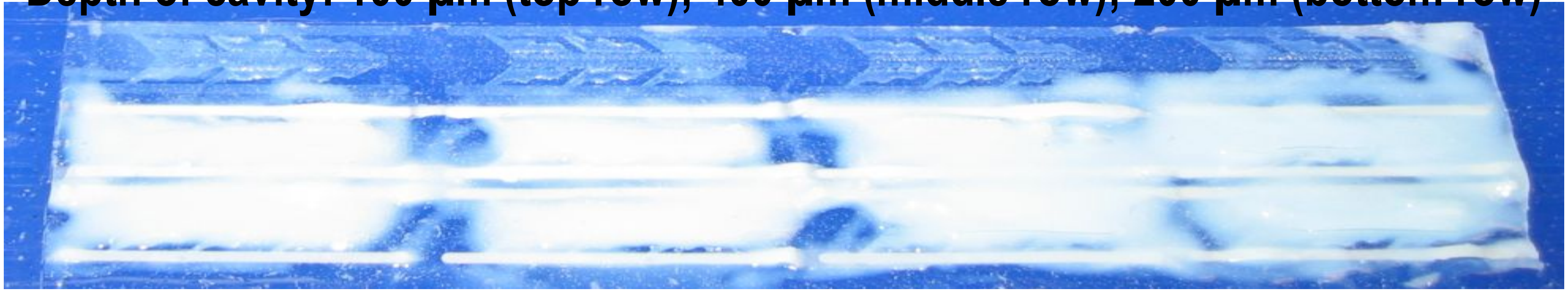


Cast material
Bi-component Platinum catalyst Silicone:
P-20, Silicon Inc./Innovative Polymers
Working/Cure time [min./h.]: 60/18
Shore hardness [MPa]: 20A
Tensile strength [MPa]: 3.6
Elongation [%]: 425
Degassing in vacuum @ 26” Hg

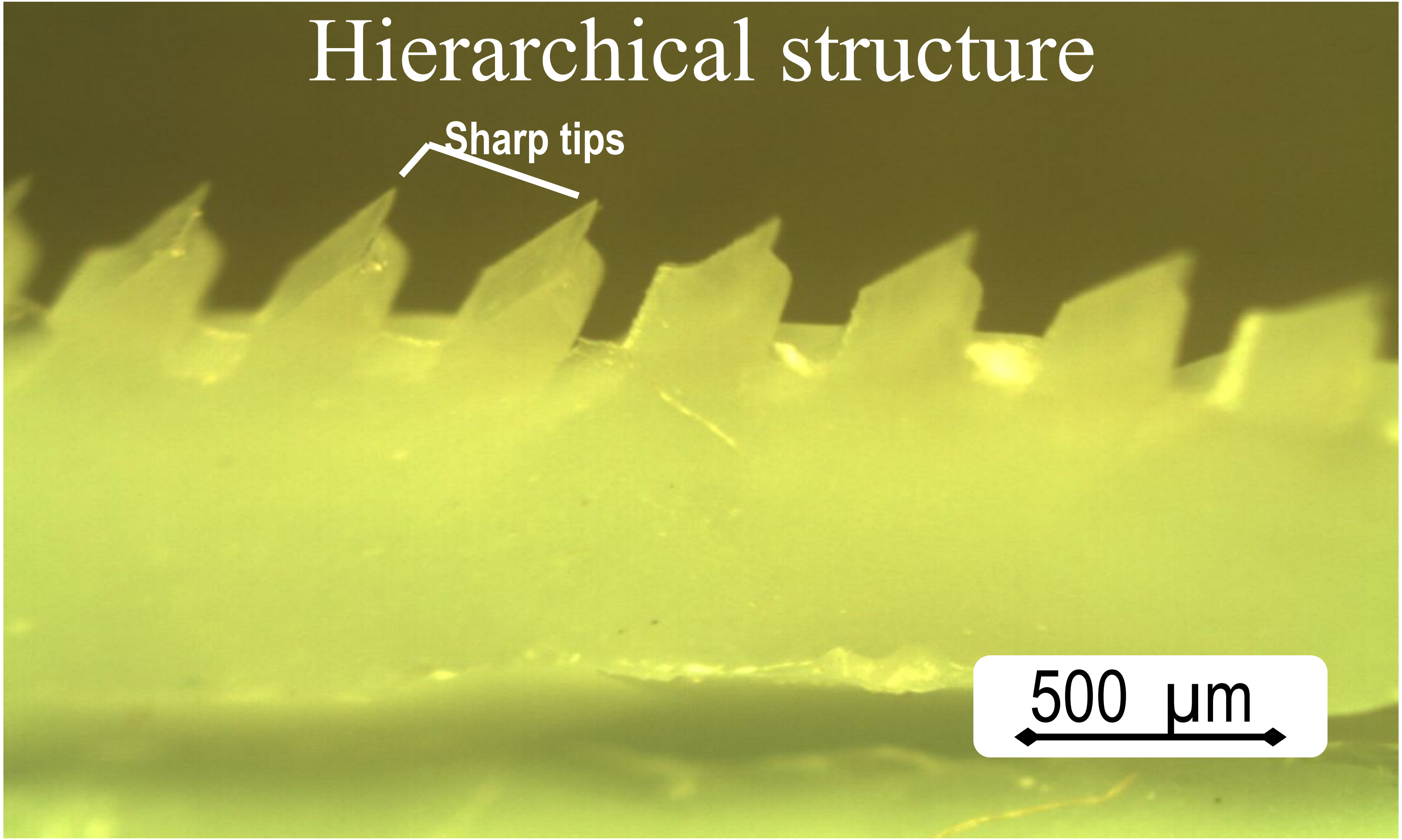
Casting problem

Batch of 42 parts

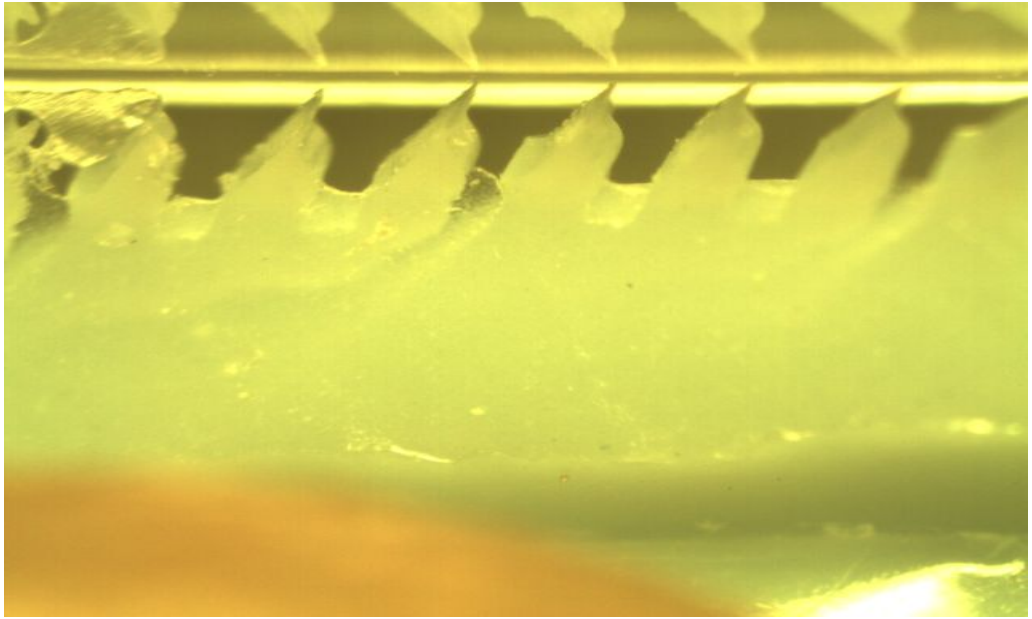
Depth of cavity: 100 µm (top row); 400 µm (middle row); 200 µm (bottom row)



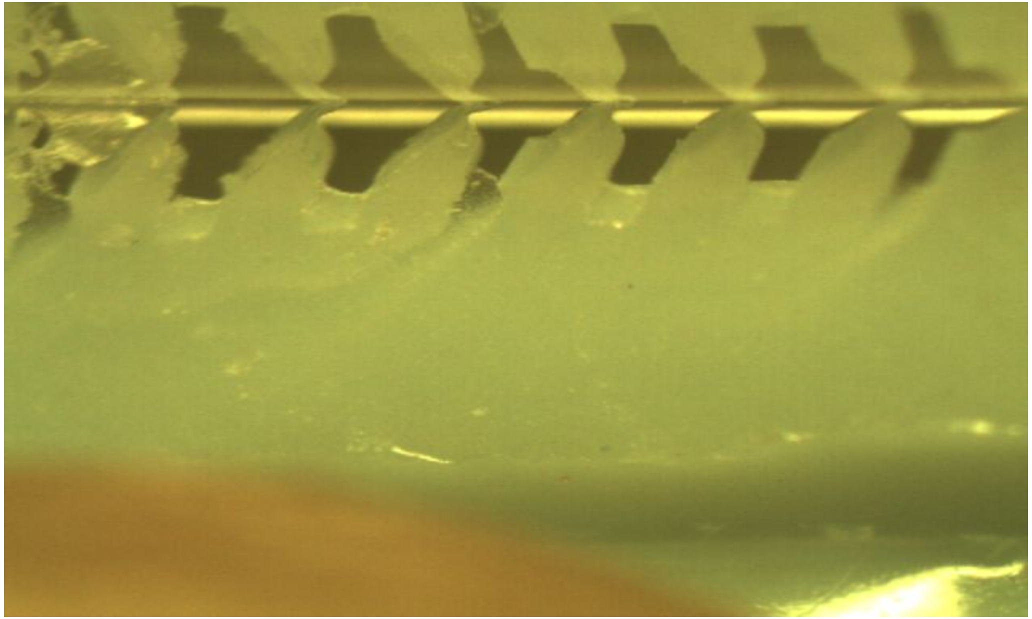
- Excess of cast material
  - – it is too thick to spread uniformly
  - – is too soft to plane after curing


Hierarchical structure
Sharp tips
500 μm

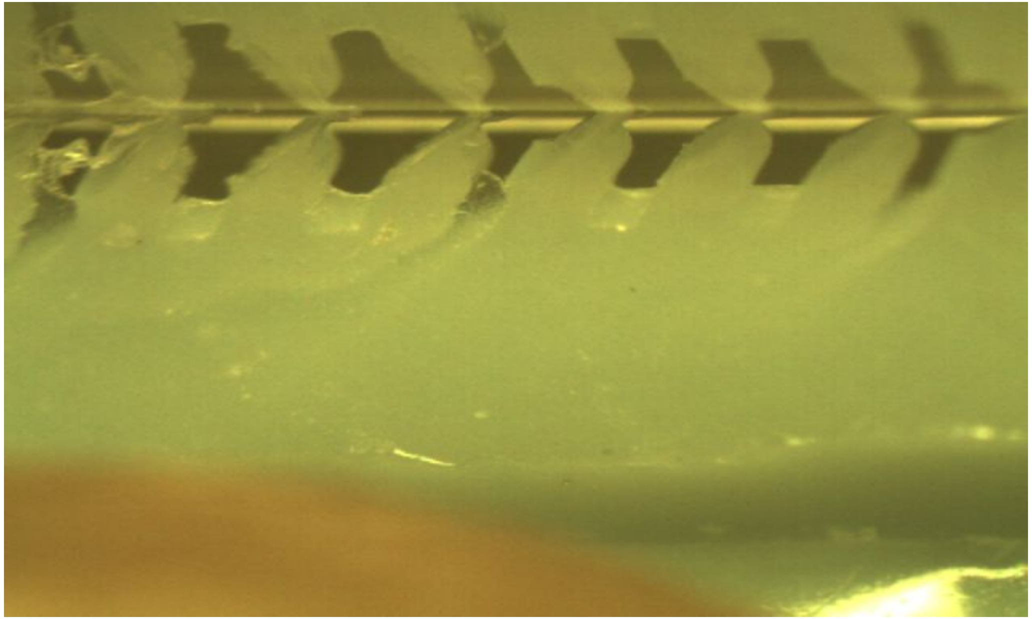
Adhesion activation



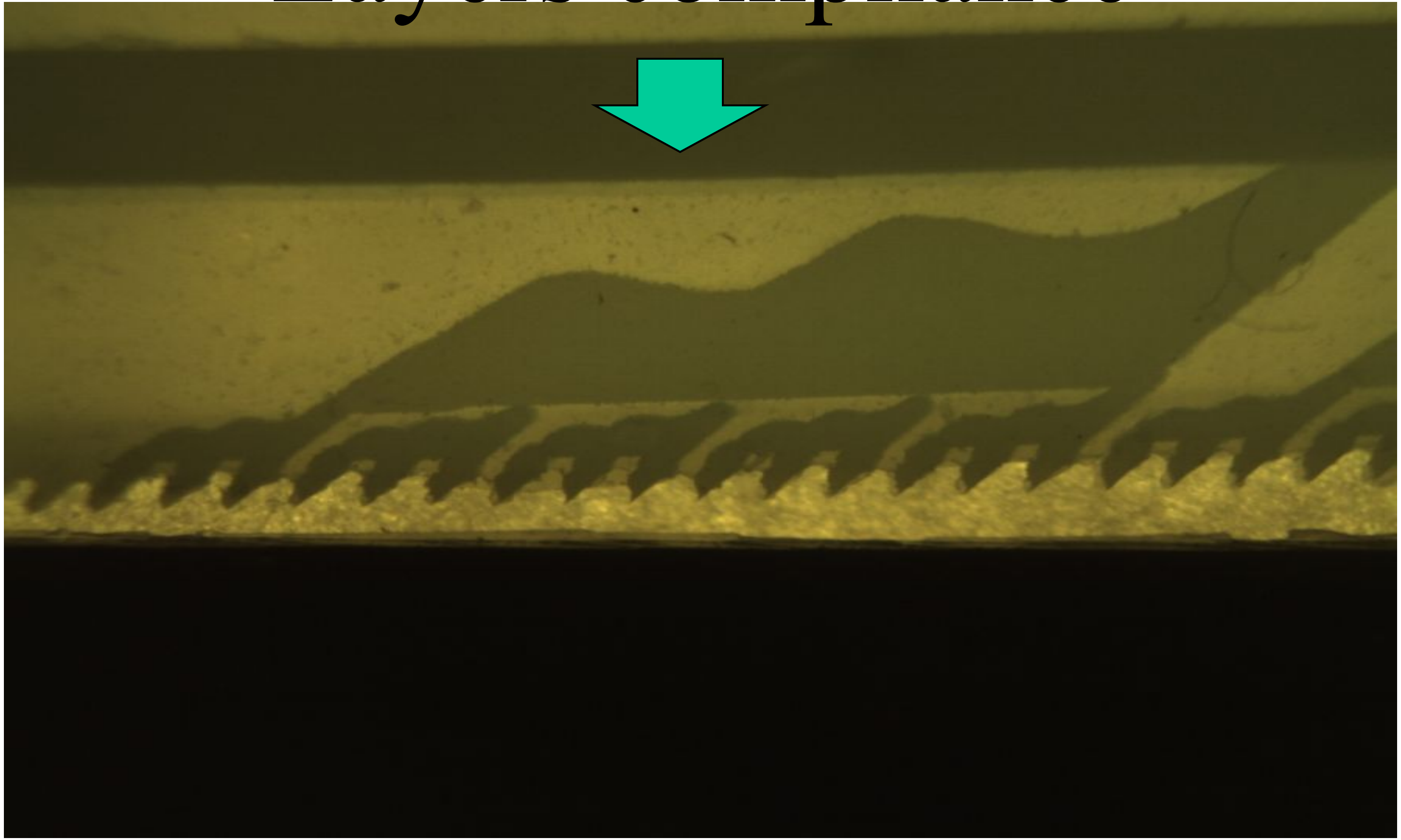
Adhesion activation



Adhesion activation

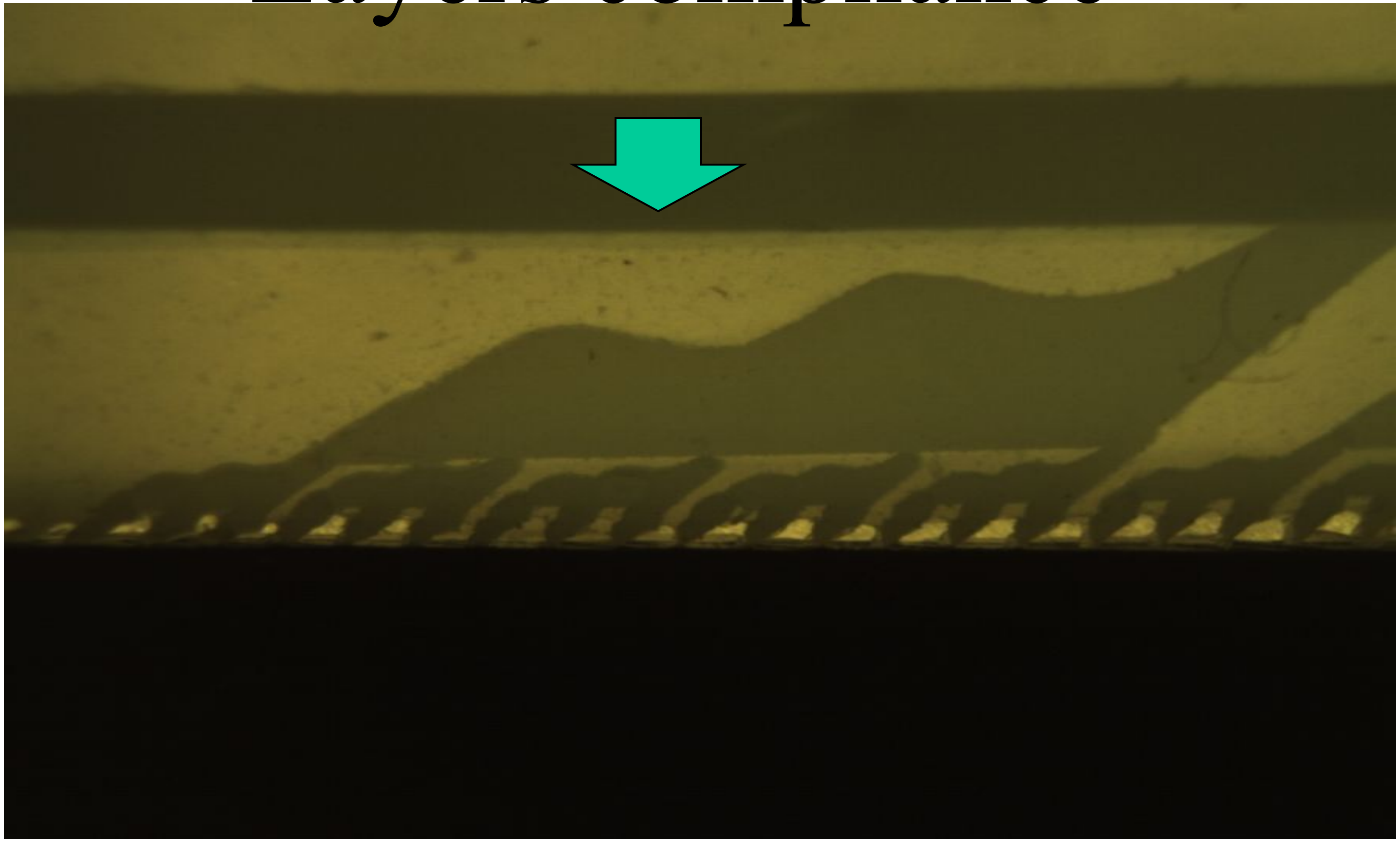


Layers compliance



Layers compliance

Layers compliance

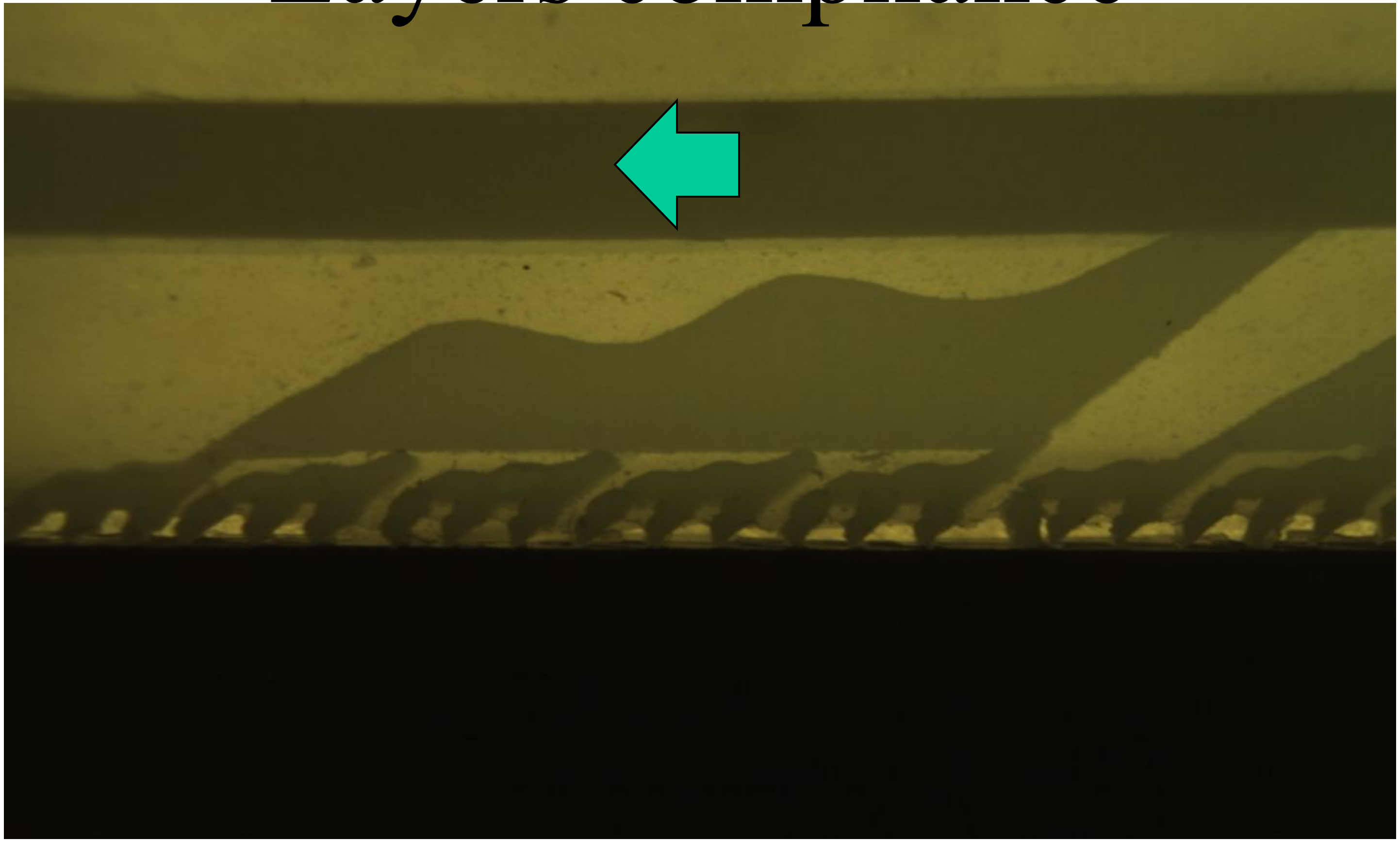


Layers compliance

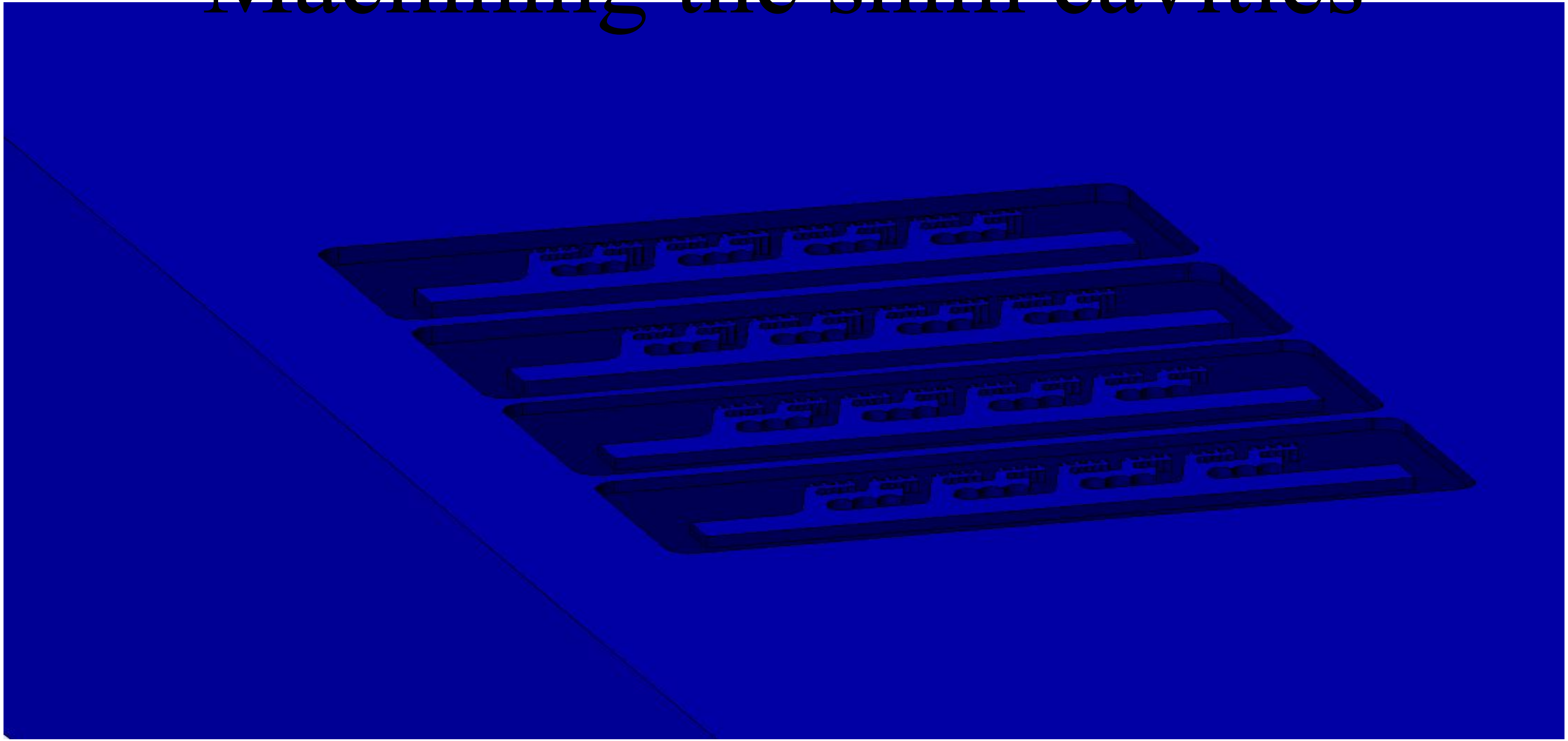
Layers compliance

Layers compliance

Layers compliance

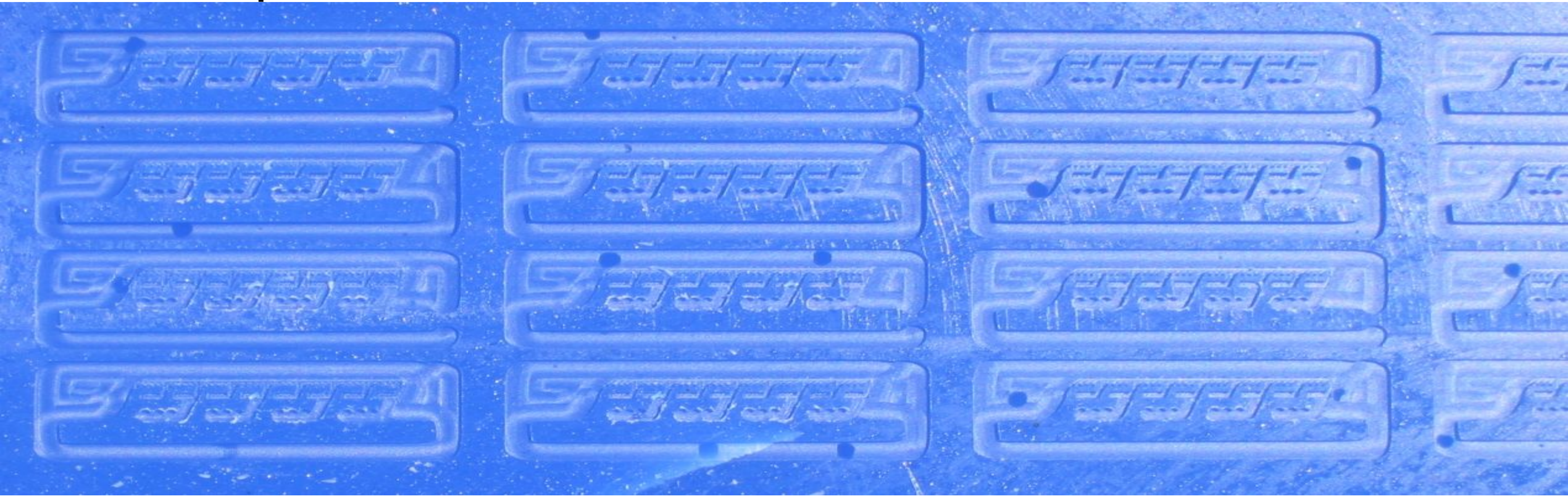


Machining the shim cavities



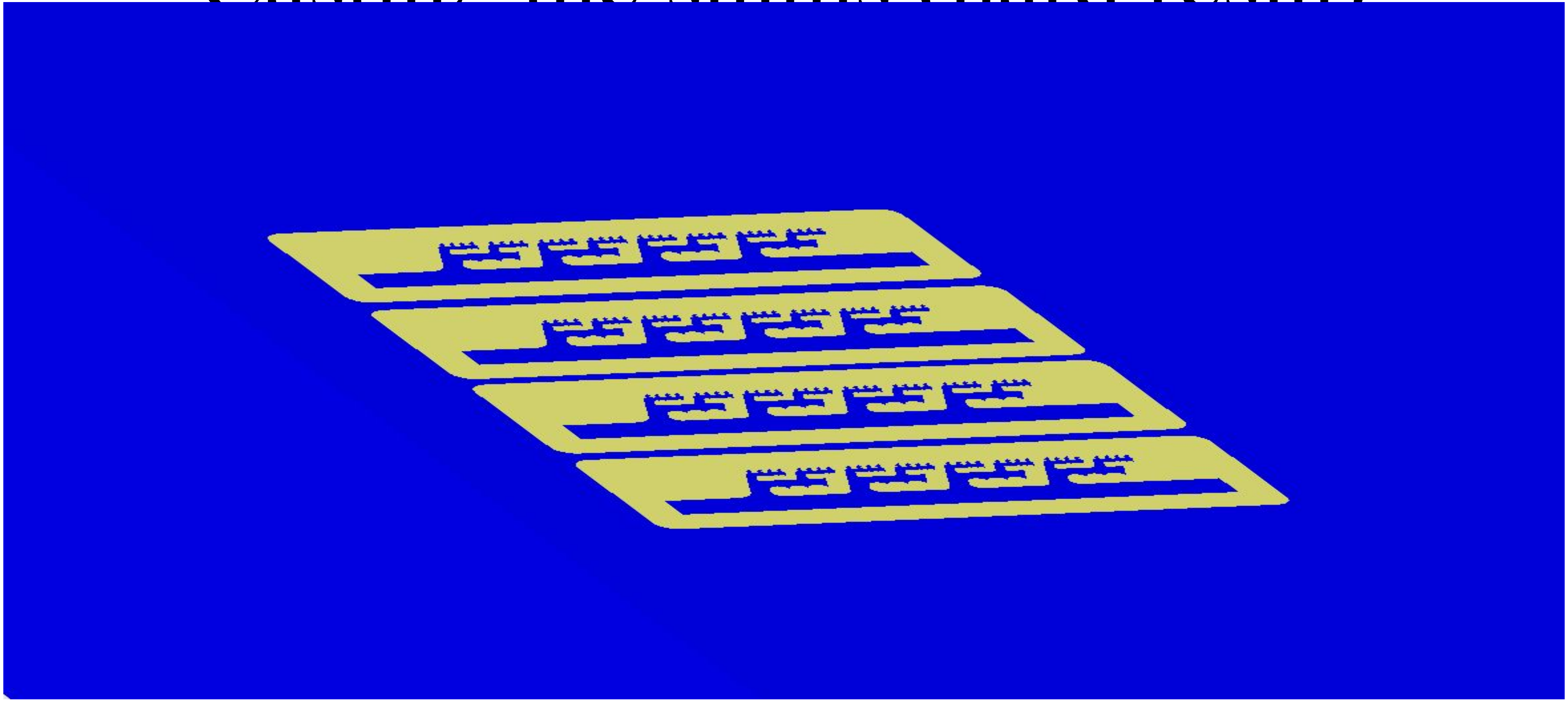
Machining the shim cavities

Batch of 40 parts

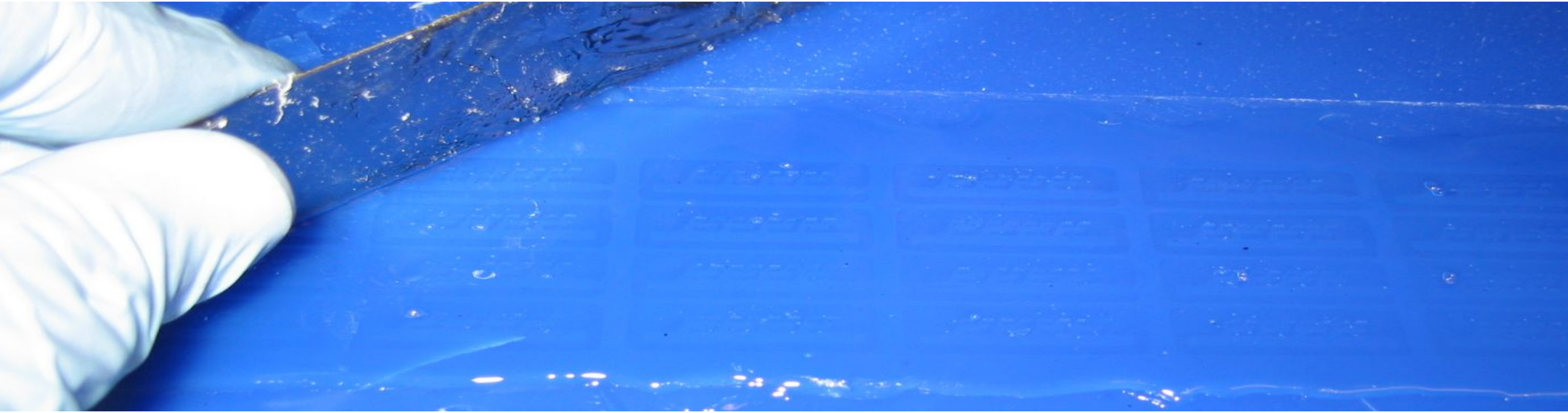


Depth of cavity: 750 µm (top two rows); 500 µm (bottom two rows)

Casting the shims (hard resin)



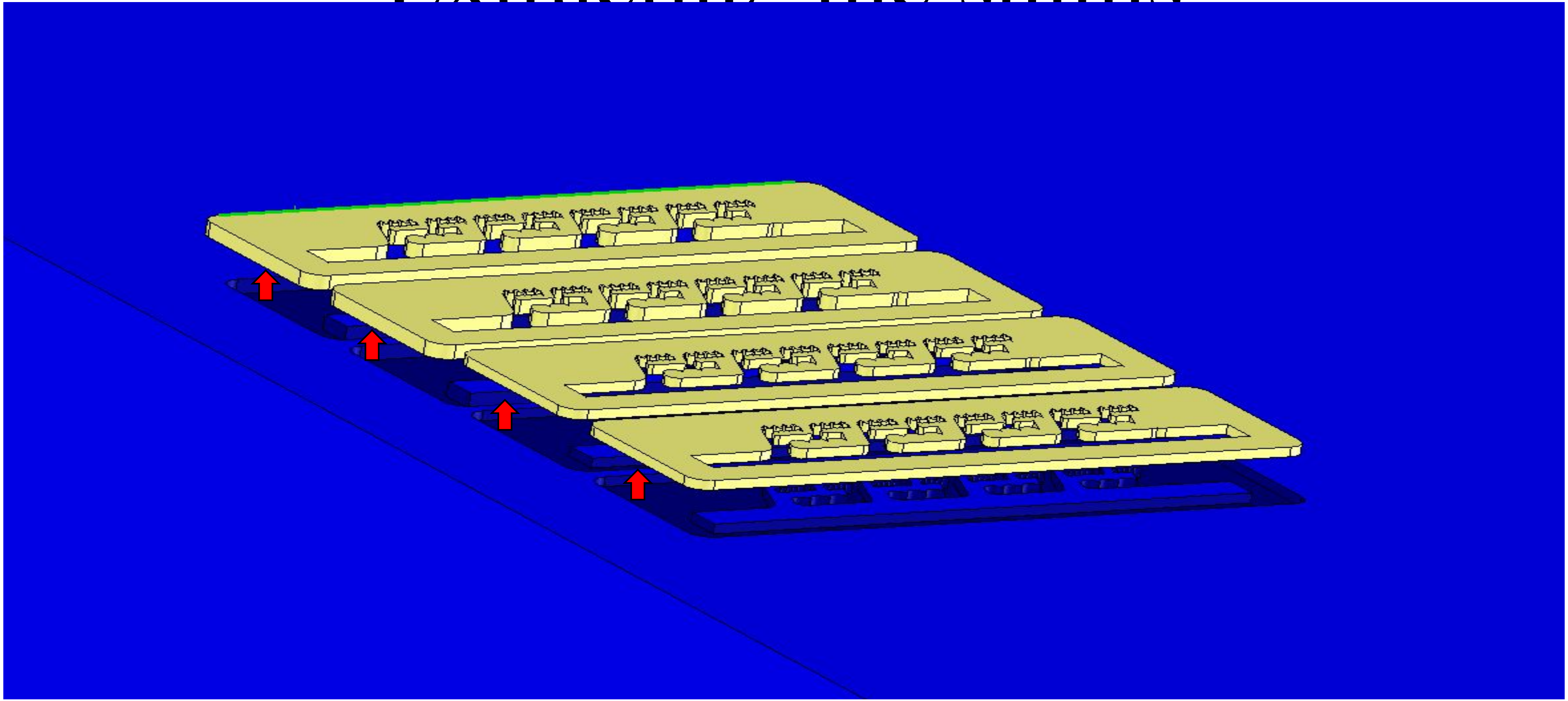
Spreading the resin



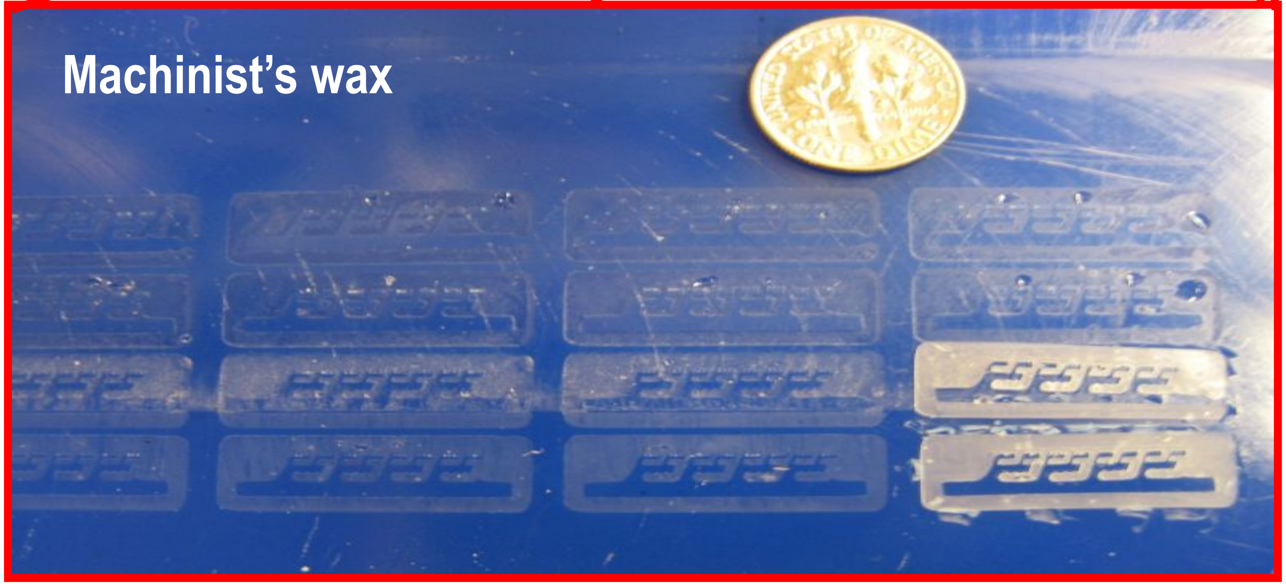
Cast material: Bi-component Urethane from SmoothOn Task 9

Degassing in vacuum @ 26” Hg for 5 minutes (working time)

Extracting the shims



Extracting the shims



Batch of 40 parts

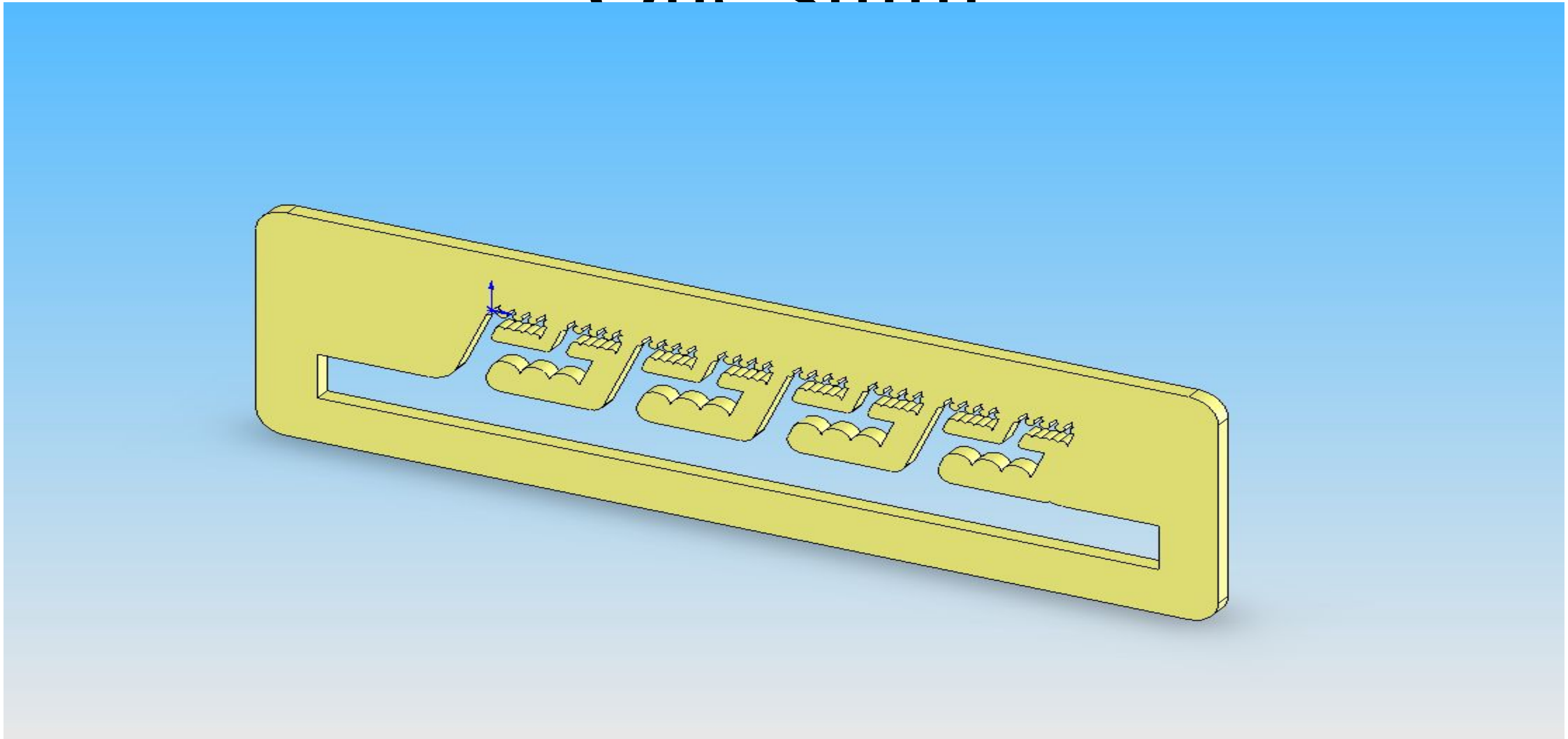
CNC machining

end mill ⌀ 250 µm

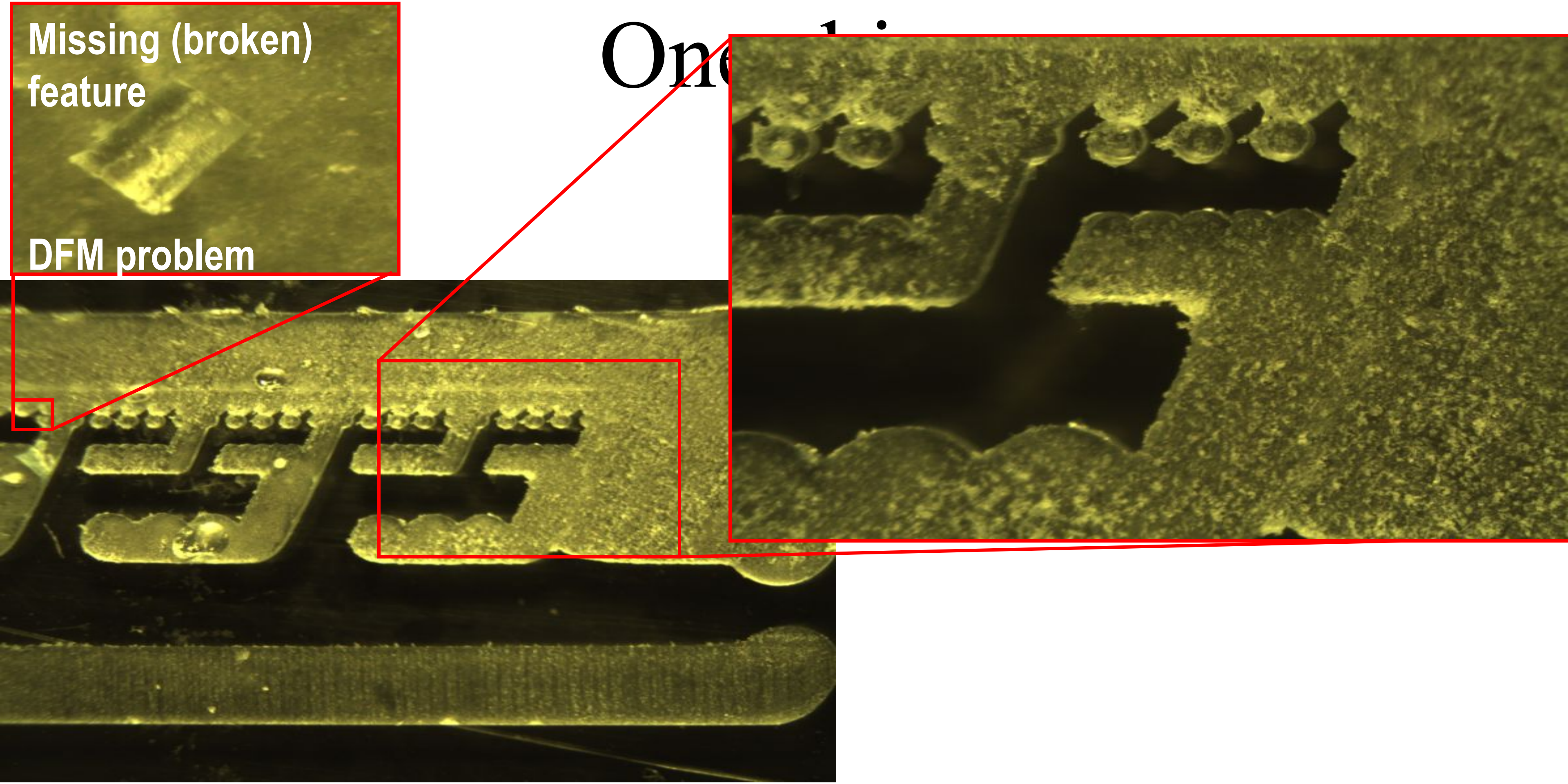
Depth of cavity:

- **750 µm (top two rows)**
- **500 µm (bottom two**

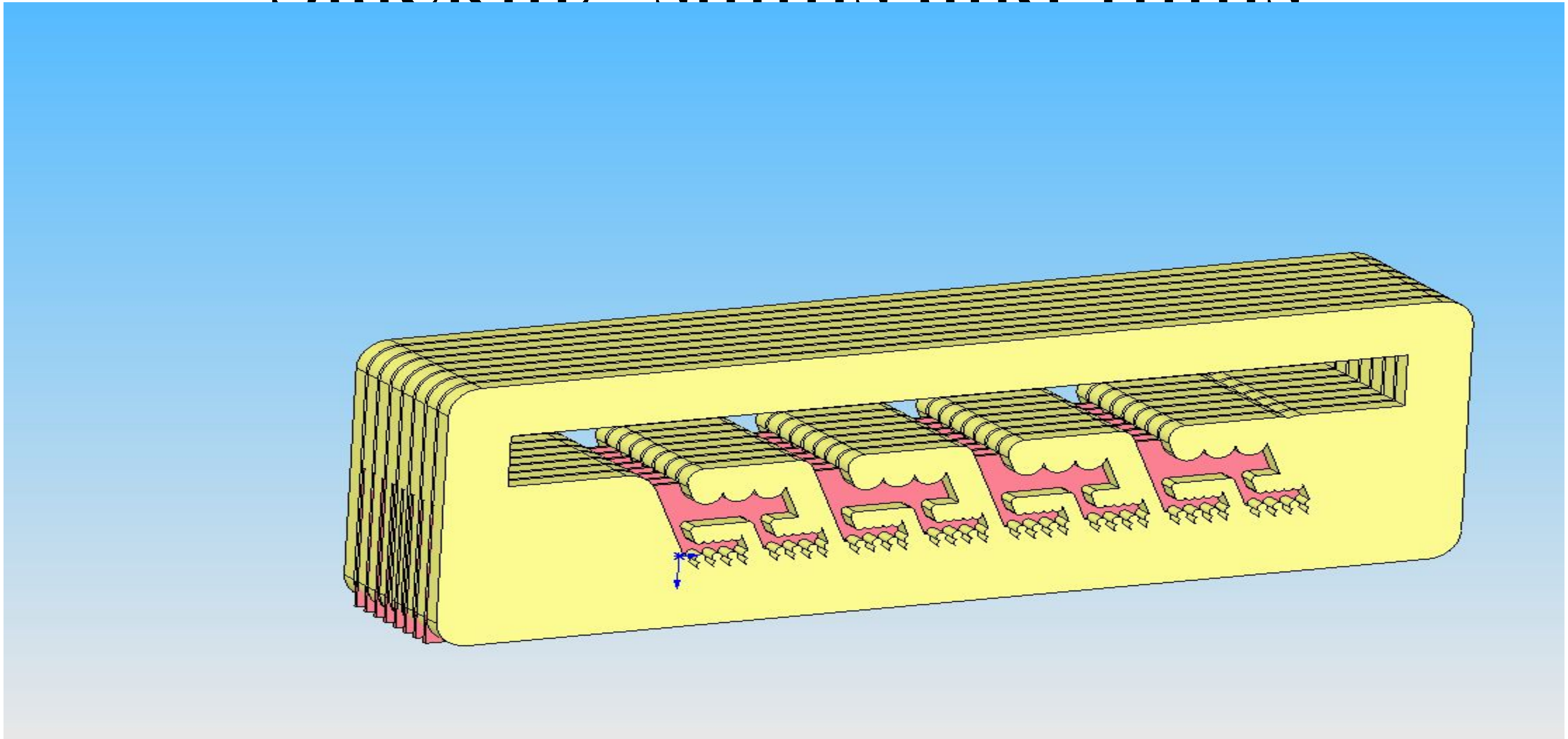
One shim



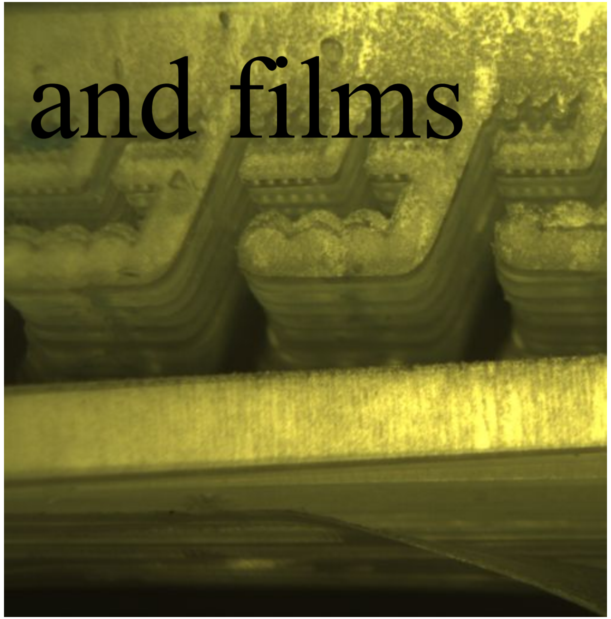
One

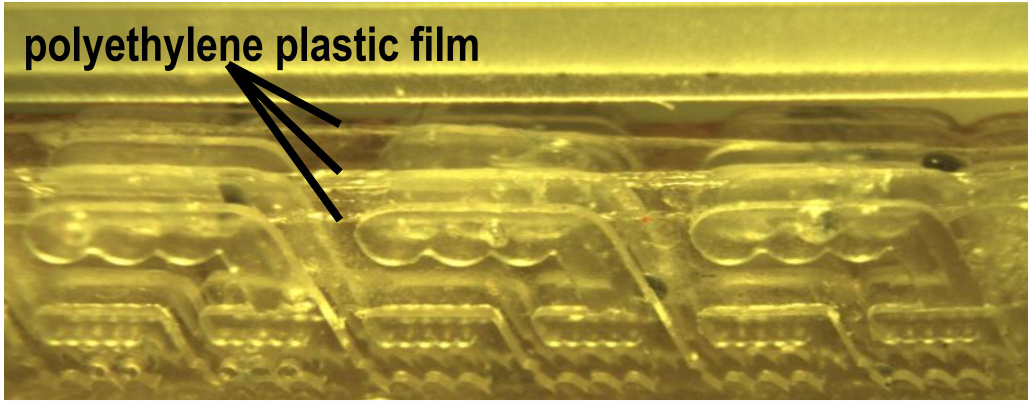


Stacking shims and films



Stacking shims and films





Shim material

Bi-component Urethane:

Task 9, Smooth-On Polymers, Inc.

Working/Cure time [min./h.]: 7/14

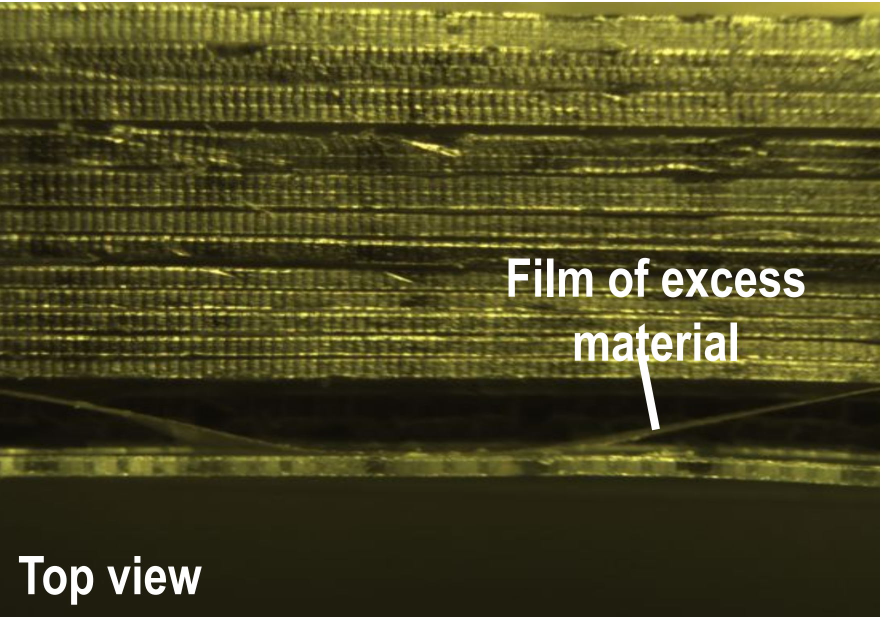
Shore hardness [MPa]: 85D

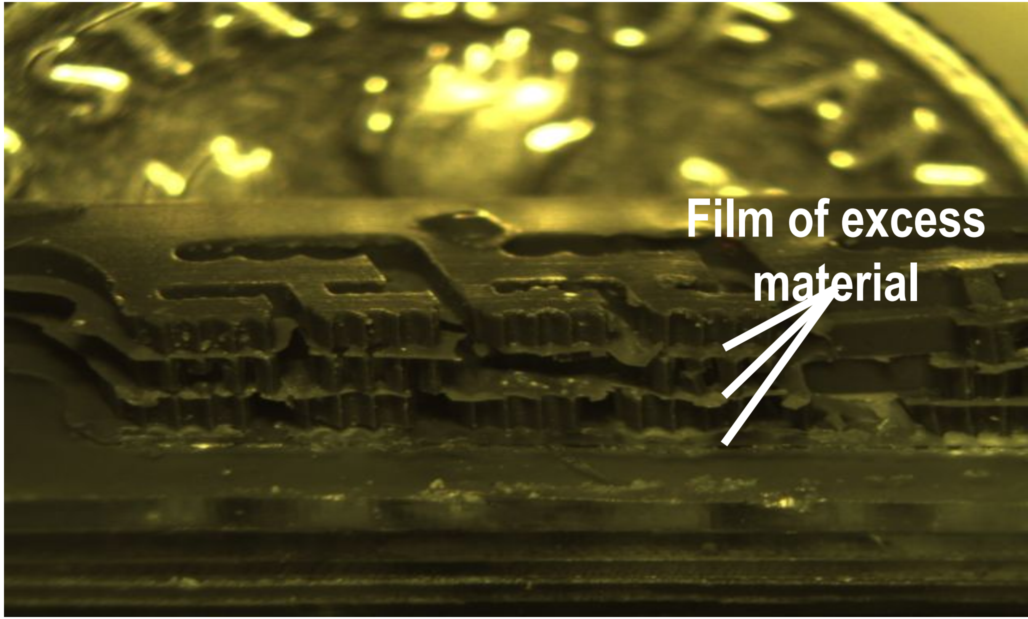
Tensile strength [MPa]: 54

Elongation [%]: 6

Degassing in vacuum @ 26” Hg

Mold without tape: connected stacks





Cast material: Bi-component Platinum catalyst Silicone from Dow Corning Sylgard 170

Degassing in vacuum @ 26” Hg for 30 minutes (working time)

Casting material (clear silicone)

Cast material

Bi-component Platinum catalyst Silicone:

P-20, Silicon Inc./Innovative Polymers

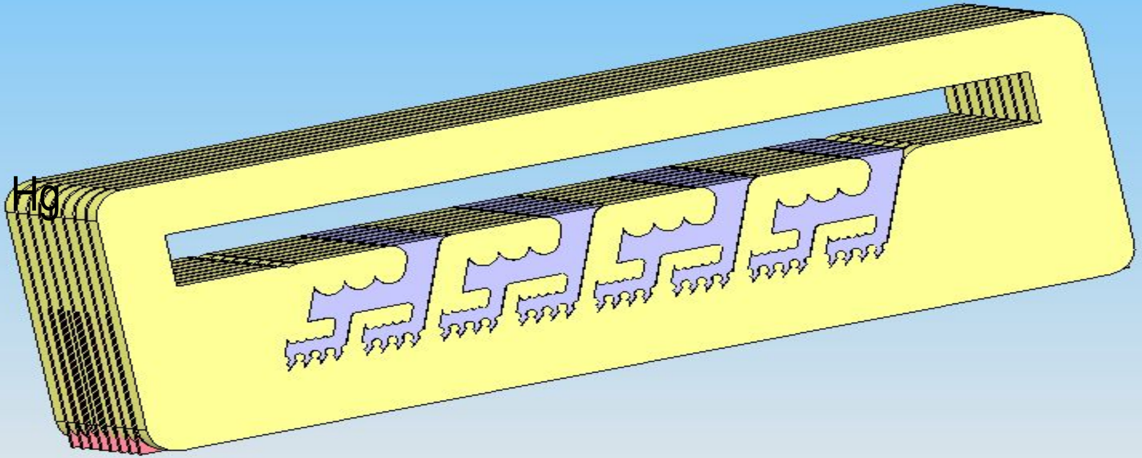
Working/Cure time [min./h.]: 60/18

Shore hardness [MPa]: 20A

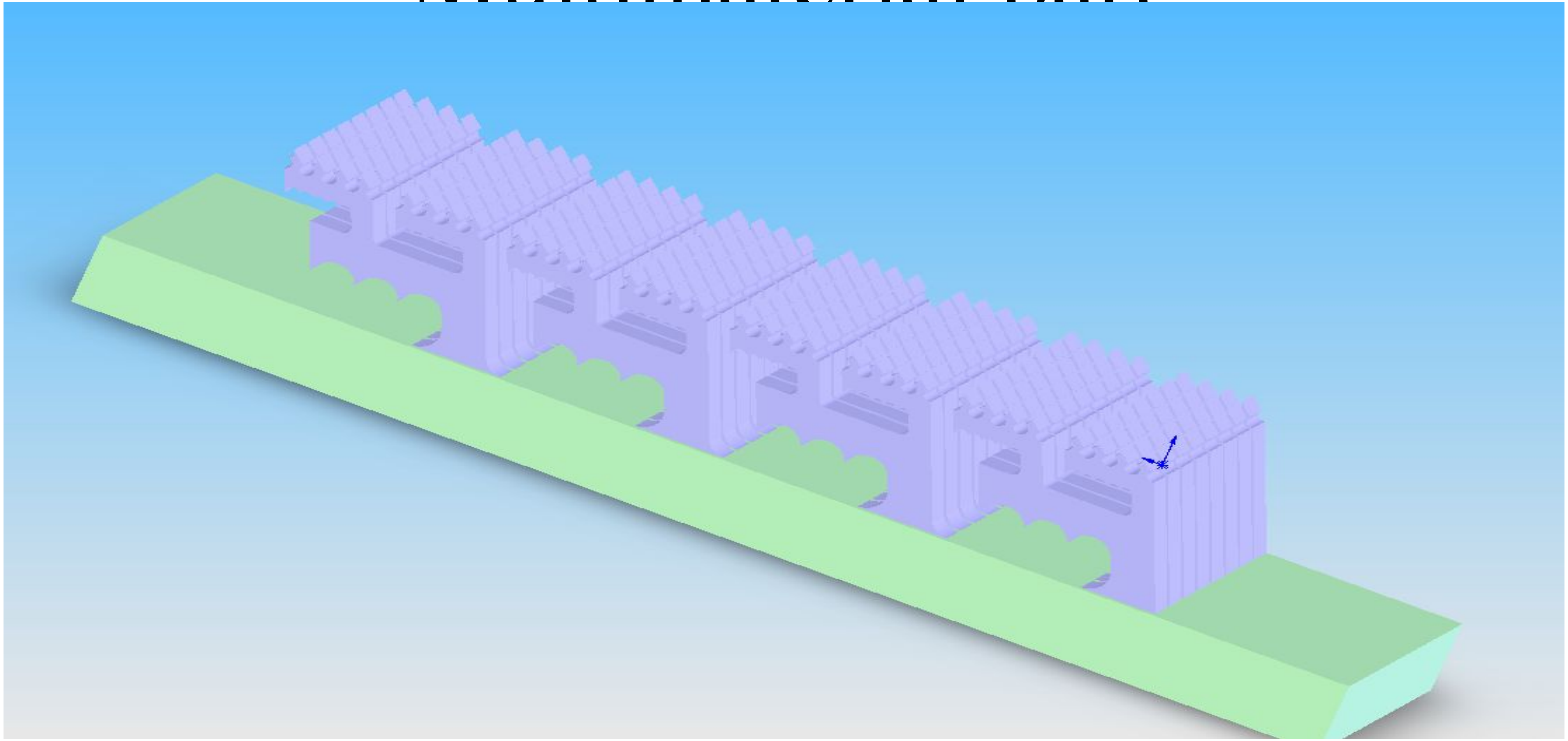
Tensile strength [MPa]: 3.6

Elongation [%]: 425

Degassing in vacuum @ 26” Hg



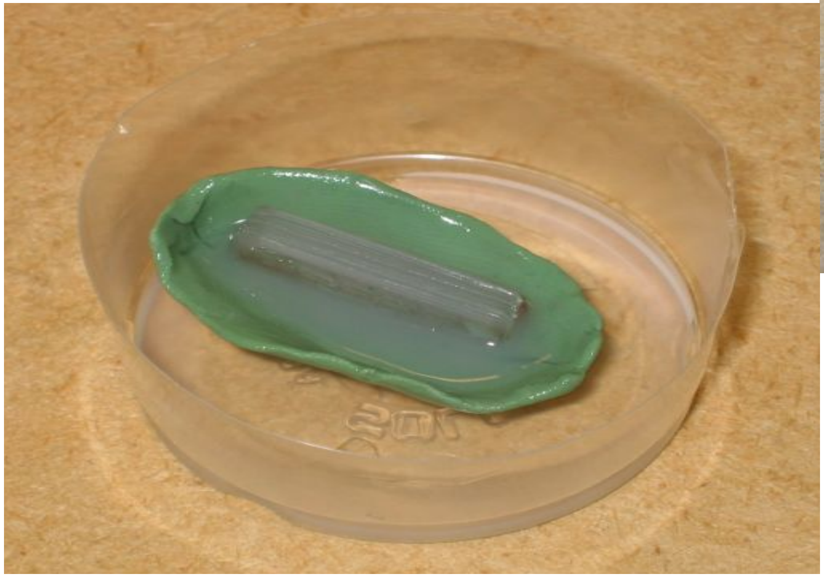
Multimaterial part



Casting material A (clear sili

In fact, it filled completely the mold (very good wetting/filling property)

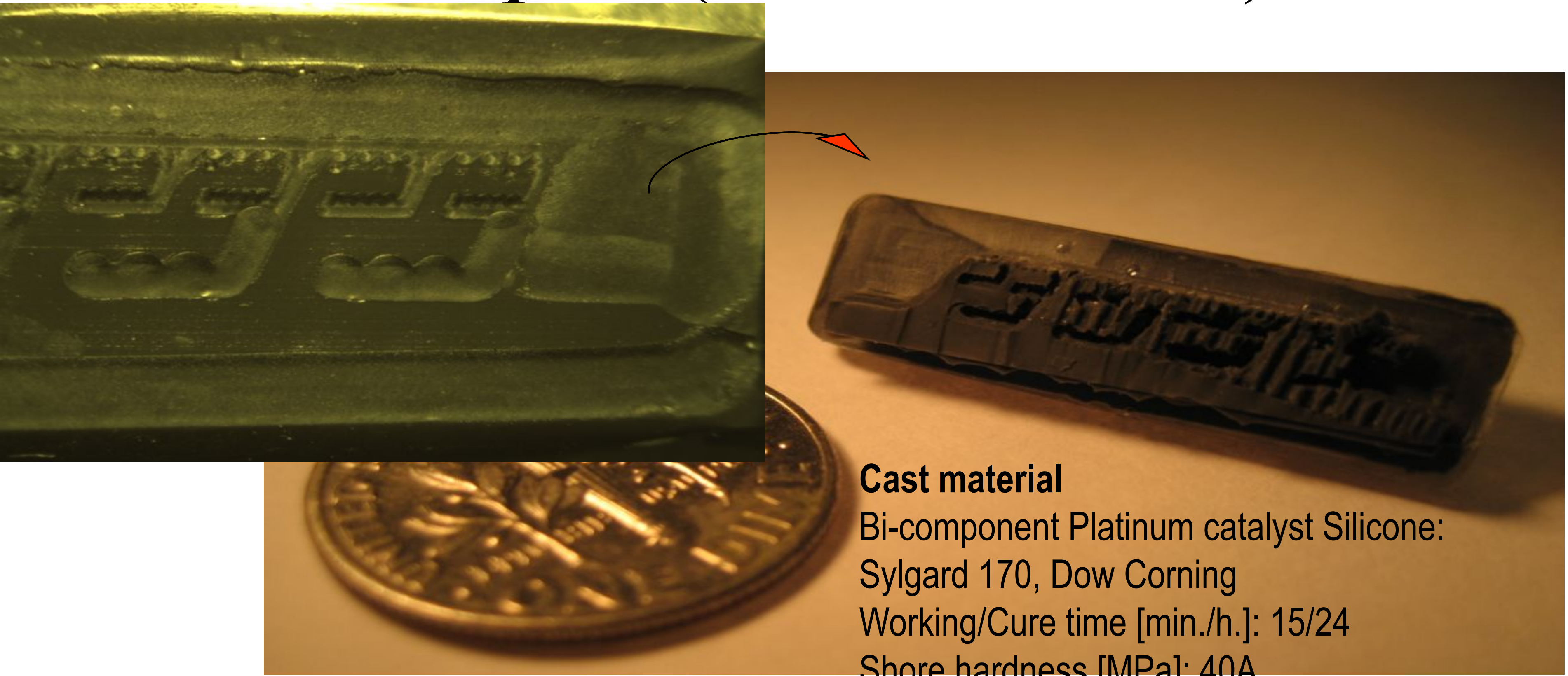
Too low clearance above film



Cast material: Bi-component Platinum catalyst Silicone from Silicon Inc./Innovative Polymers P-20

Degassing in vacuum @ 26” Hg for 30 minutes (working time)

Cast part (black silicone)



Cast material

Bi-component Platinum catalyst Silicone:

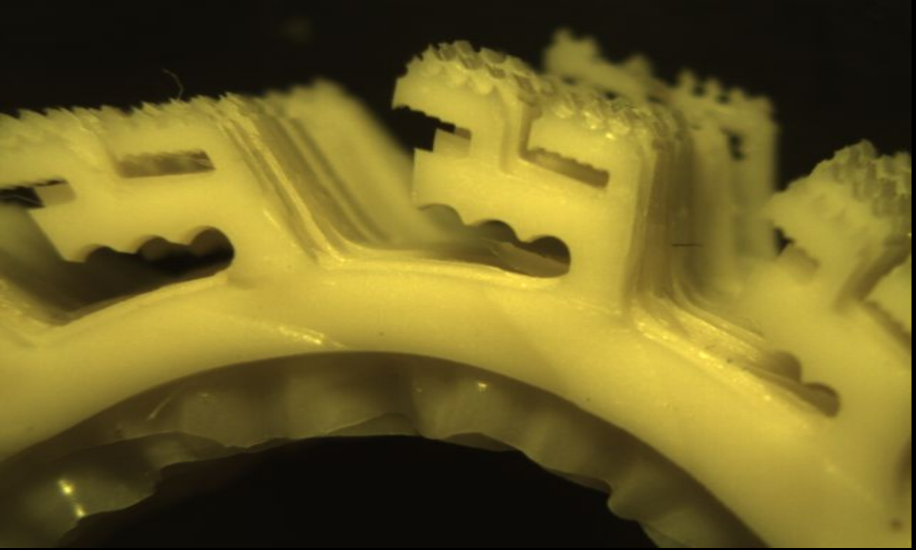
Sylgard 170, Dow Corning

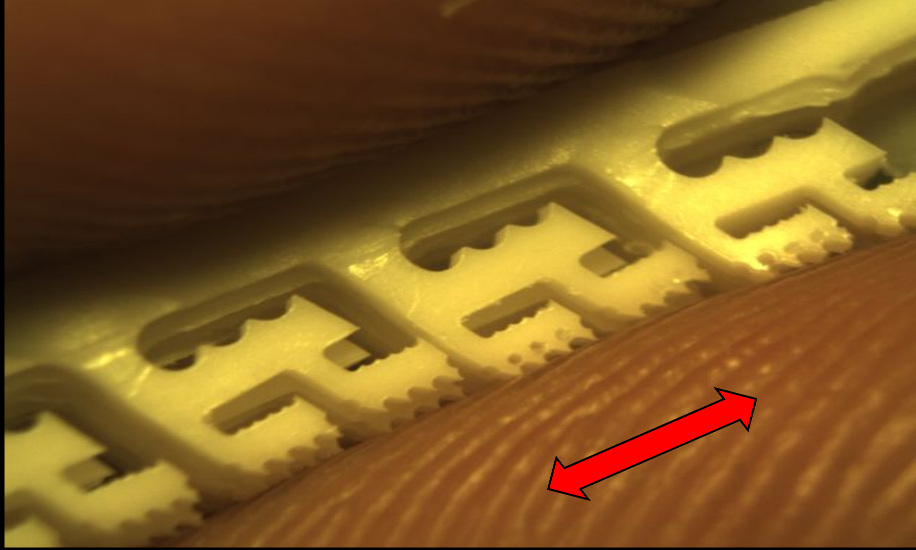
Working/Cure time [min./h.]: 15/24

Shore hardness [MPa]: 40A

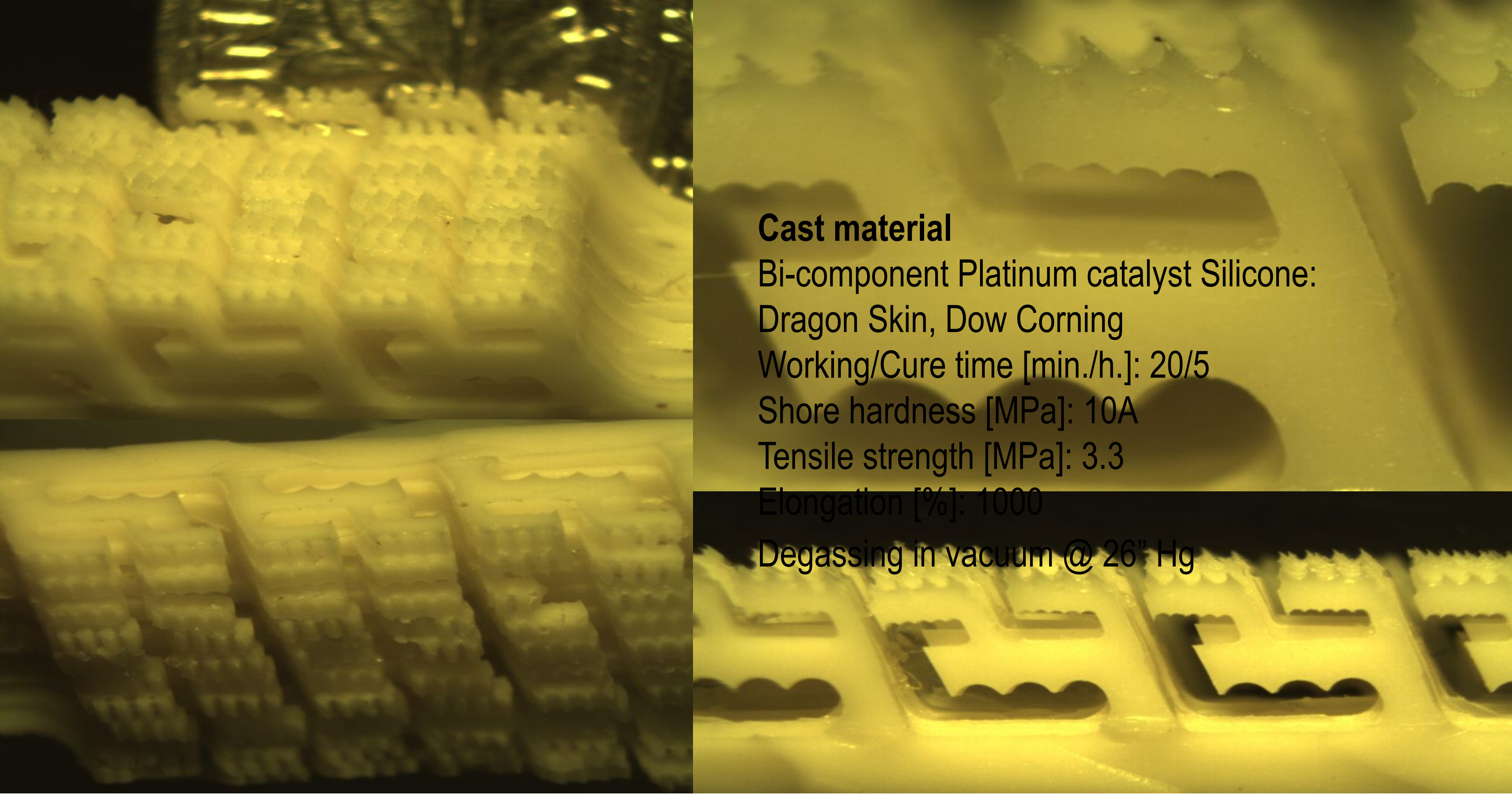
Degassing in vacuum @ 26” Hg

Demolding problems

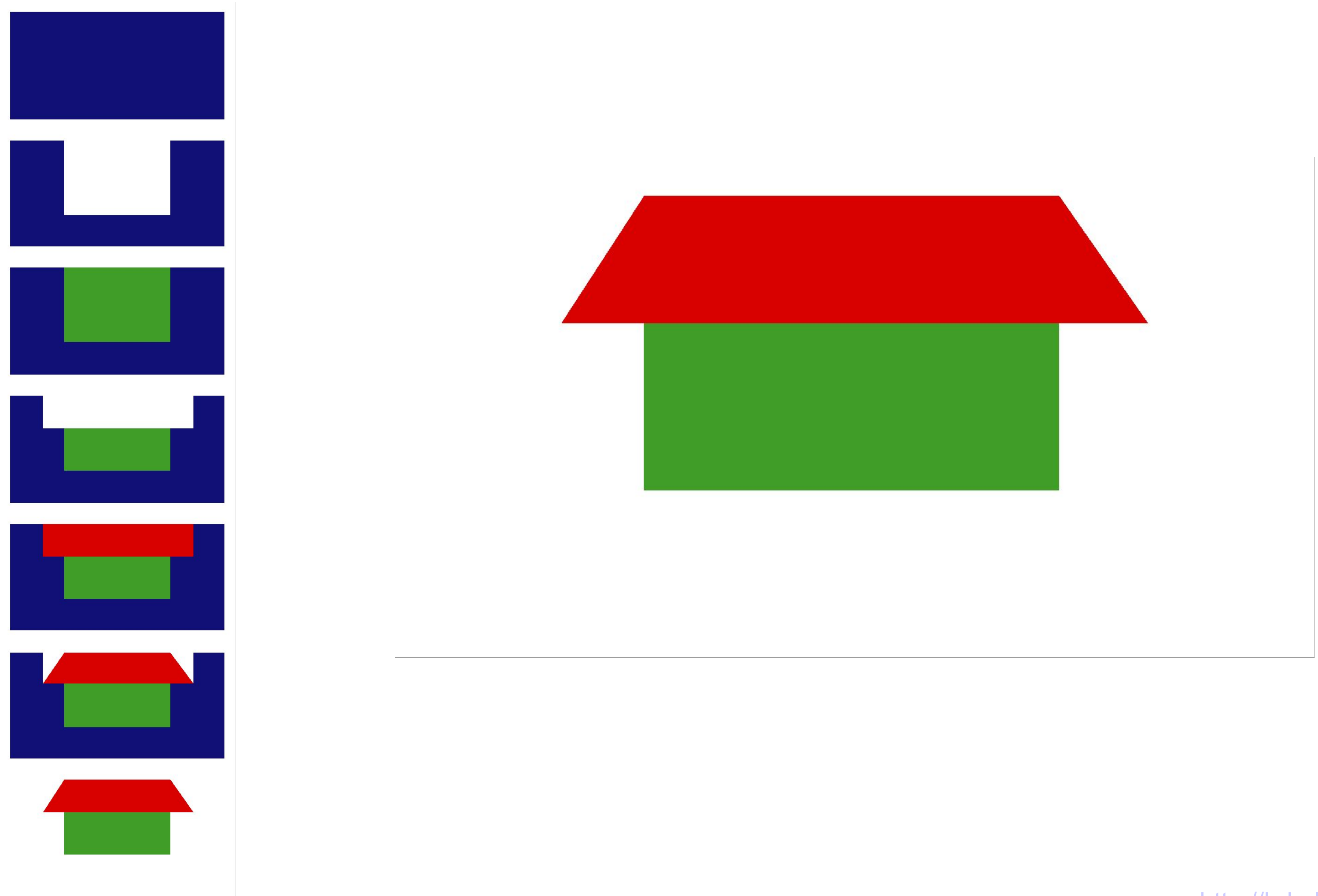




MOLD
SDM


Cast material
Bi-component Platinum catalyst Silicone:
Dragon Skin, Dow Corning
Working/Cure time [min./h.]: 20/5
Shore hardness [MPa]: 10A
Tensile strength [MPa]: 3.3
Elongation [%]: 1000
Degassing in vacuum @ 26” Hg

dia sul nostro processo CIRP con metallo



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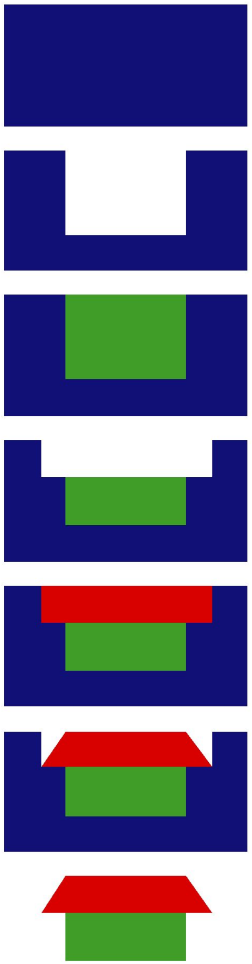

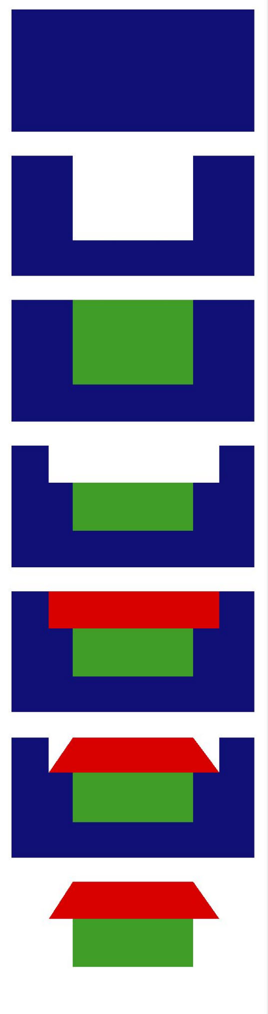

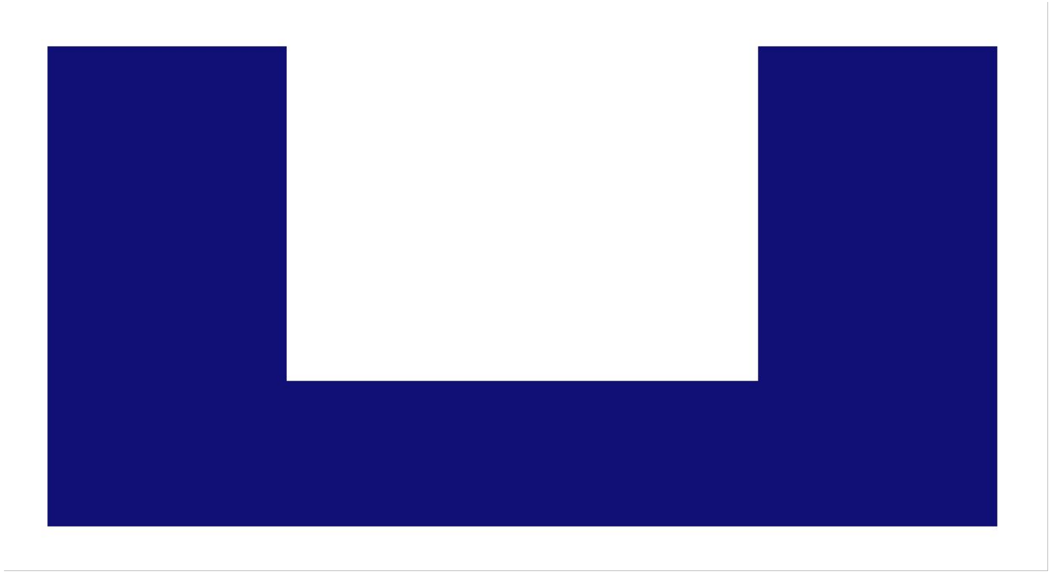

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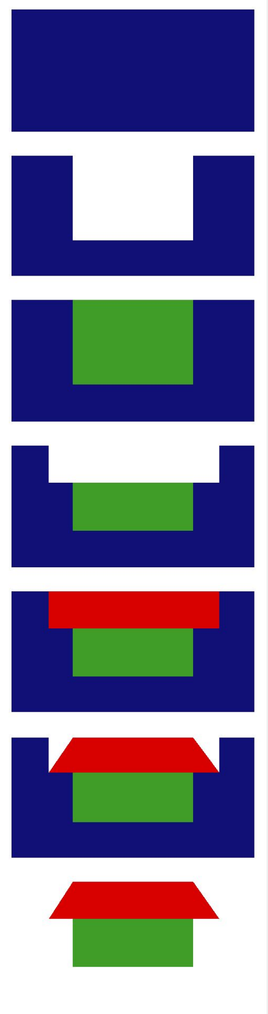

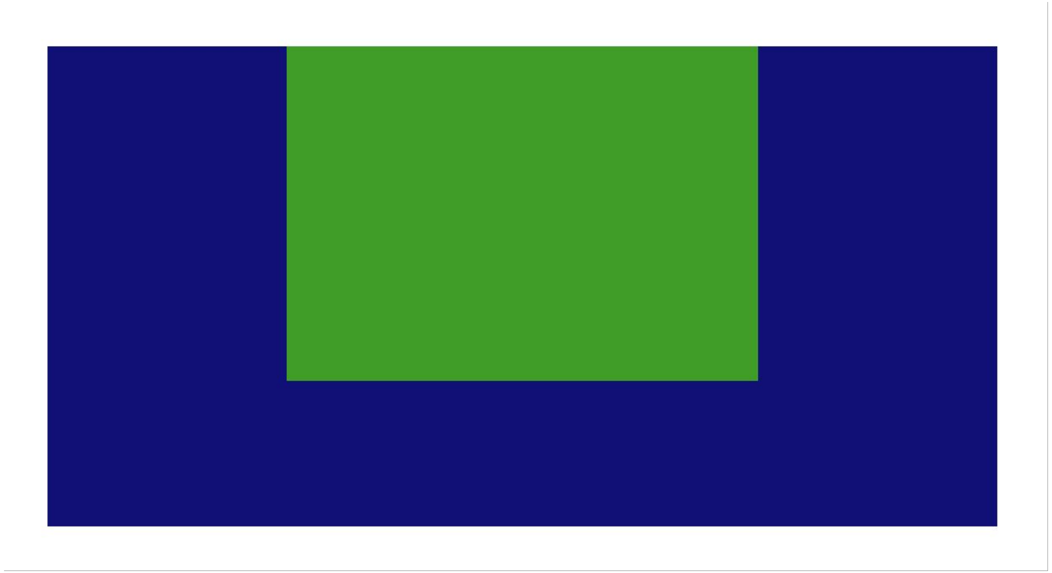

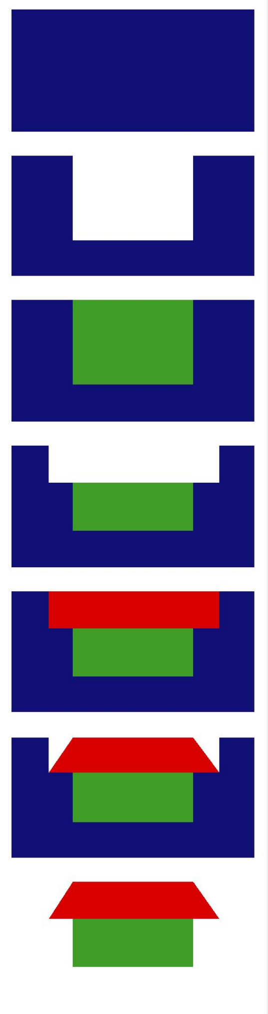

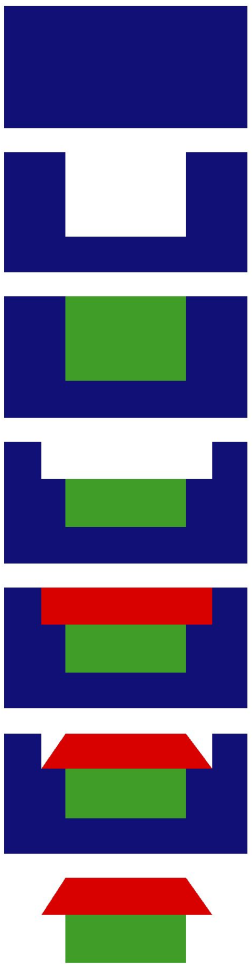

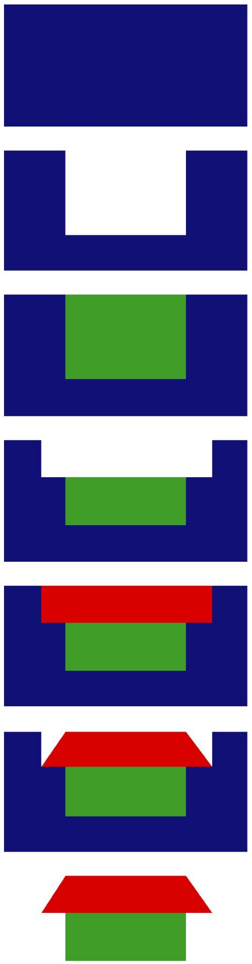

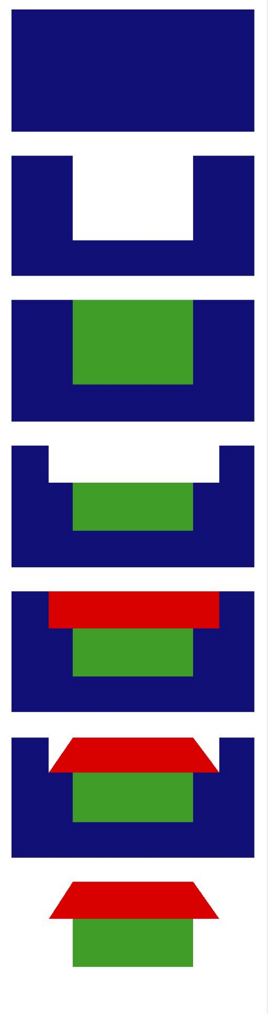

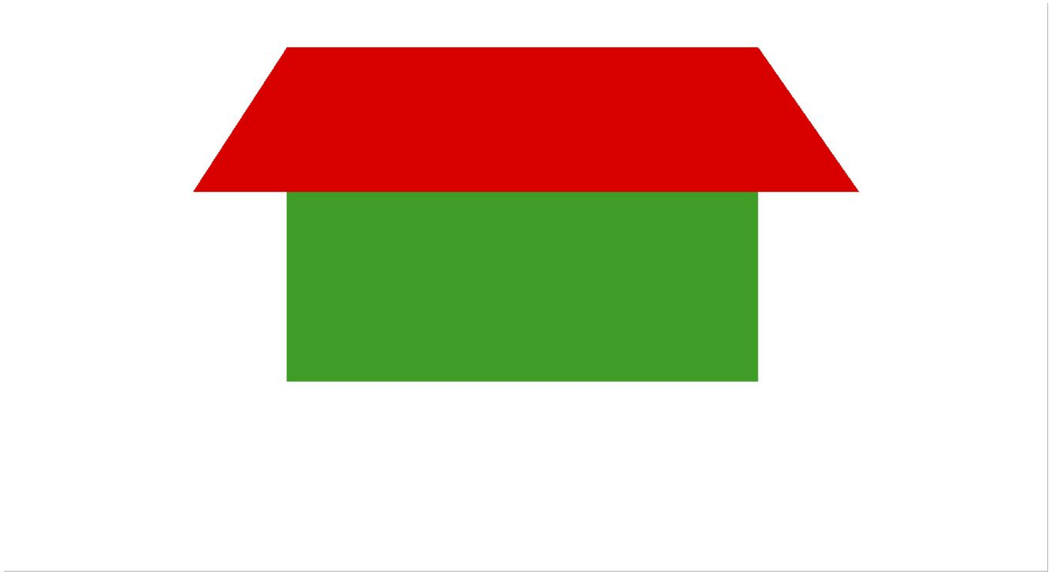

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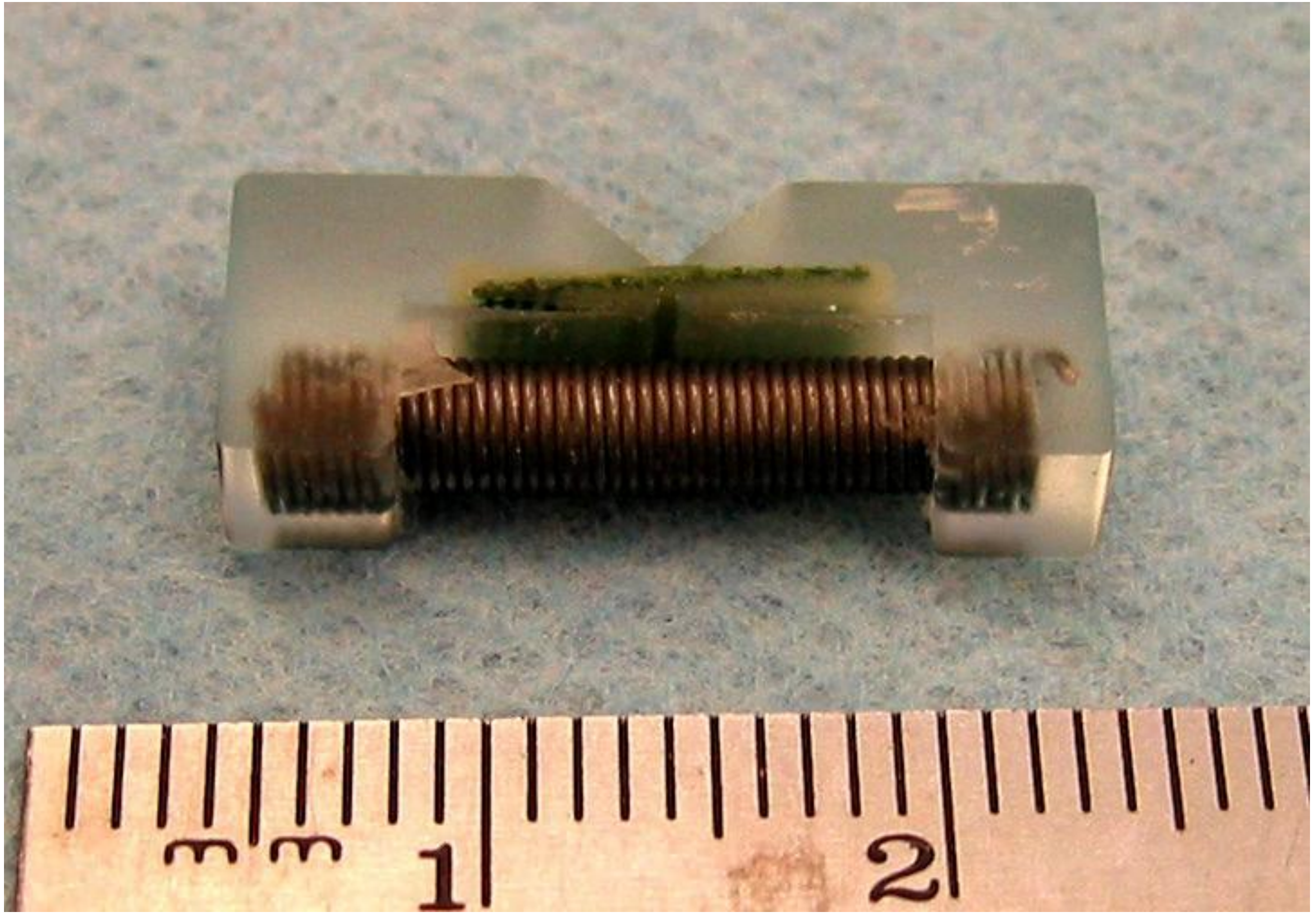

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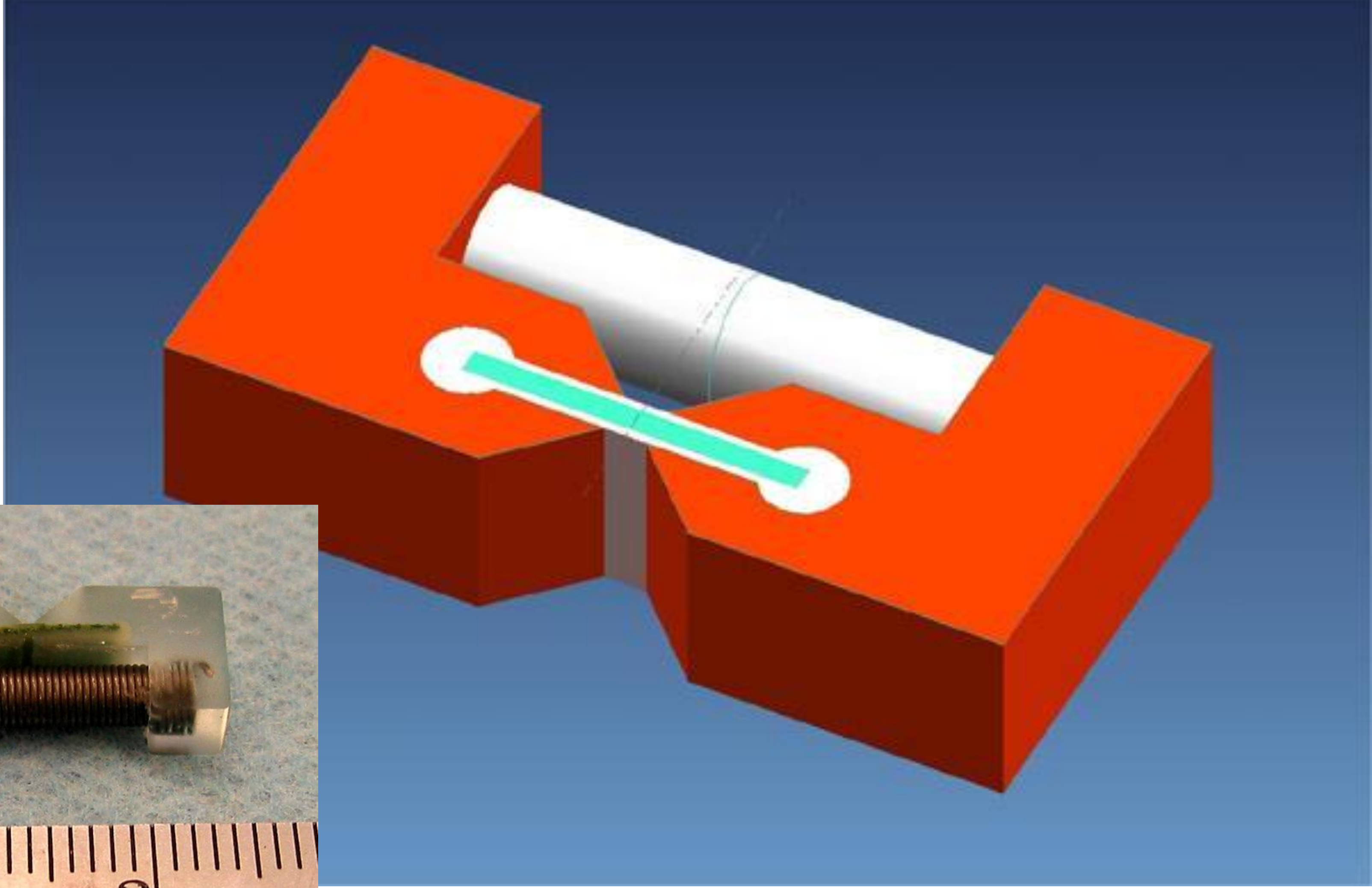

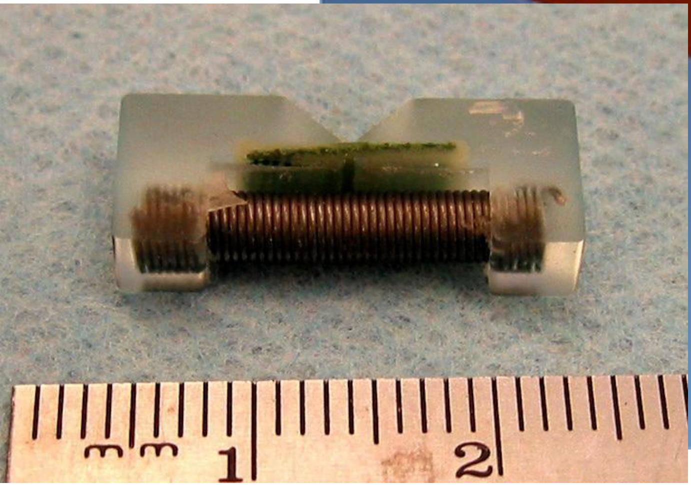

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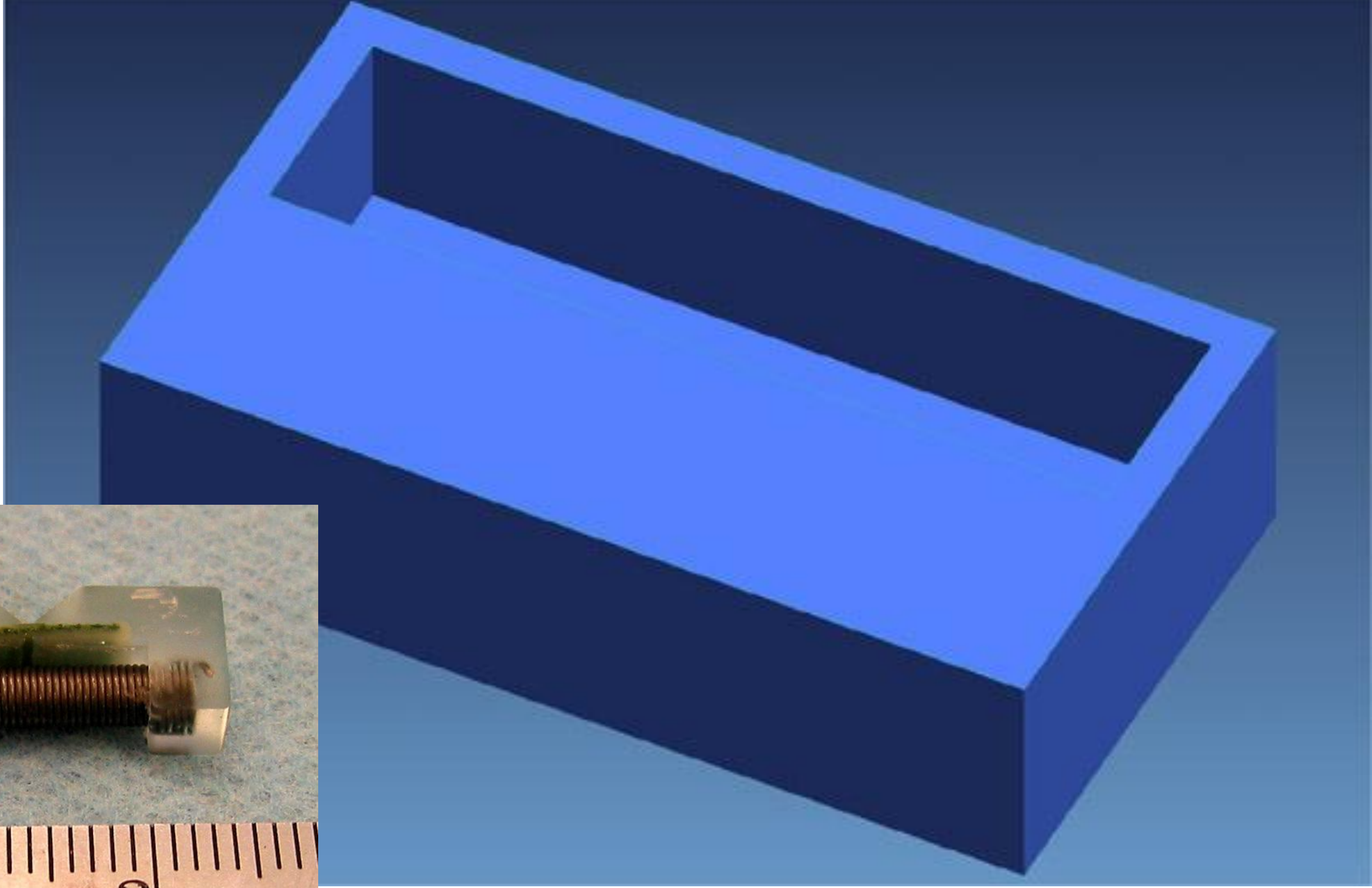

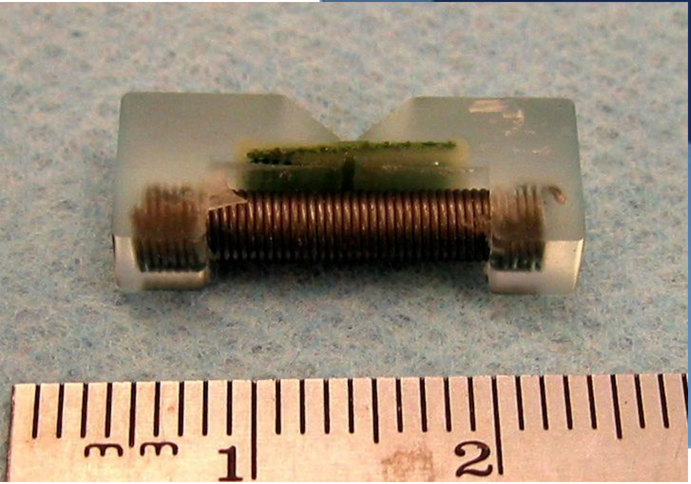

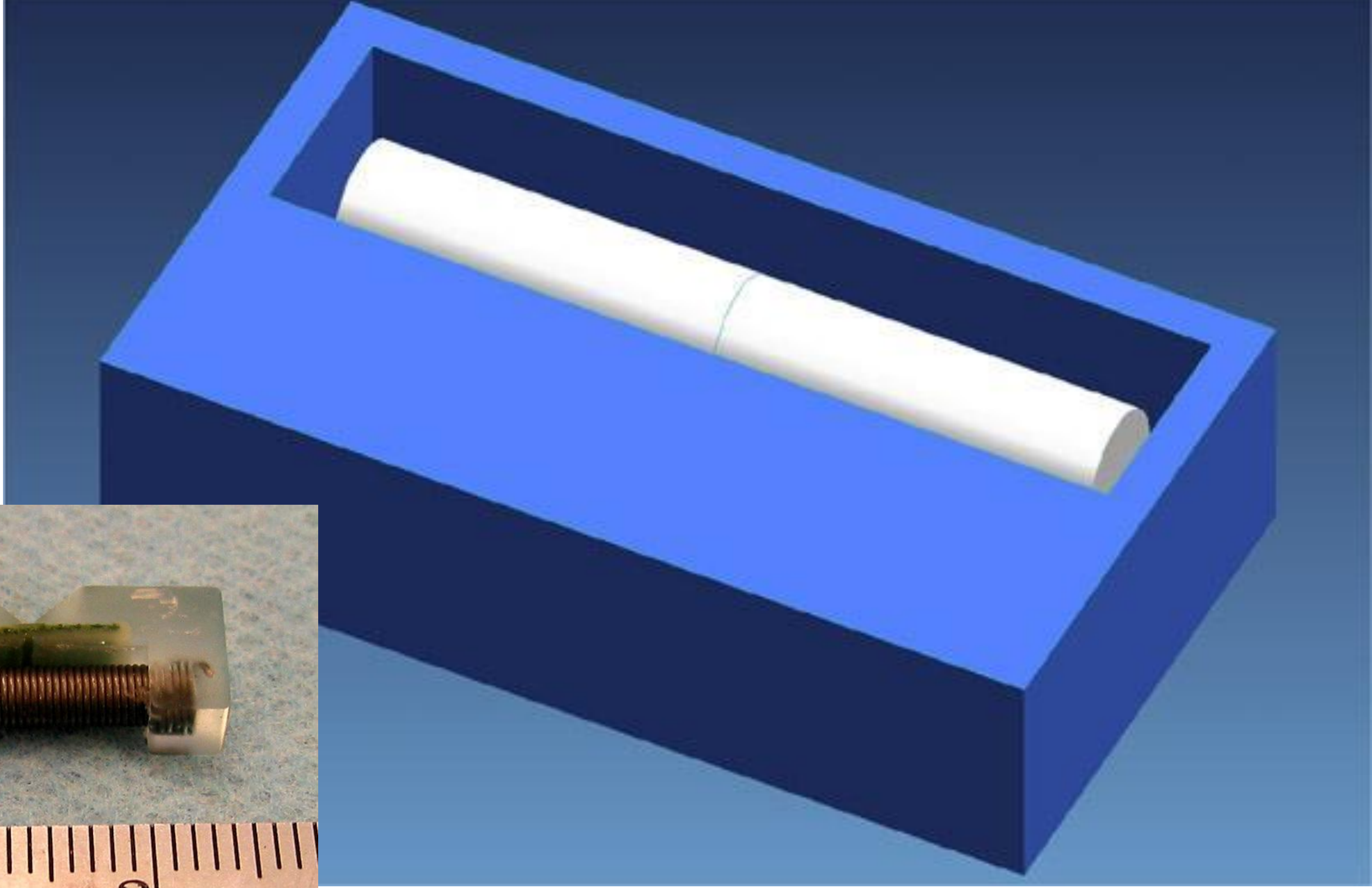

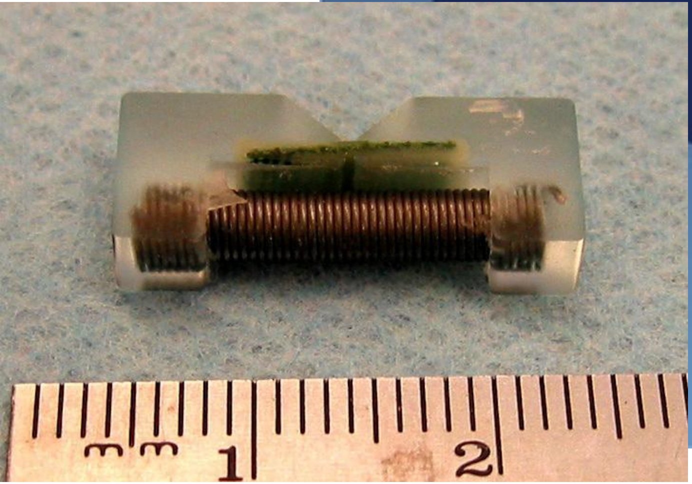

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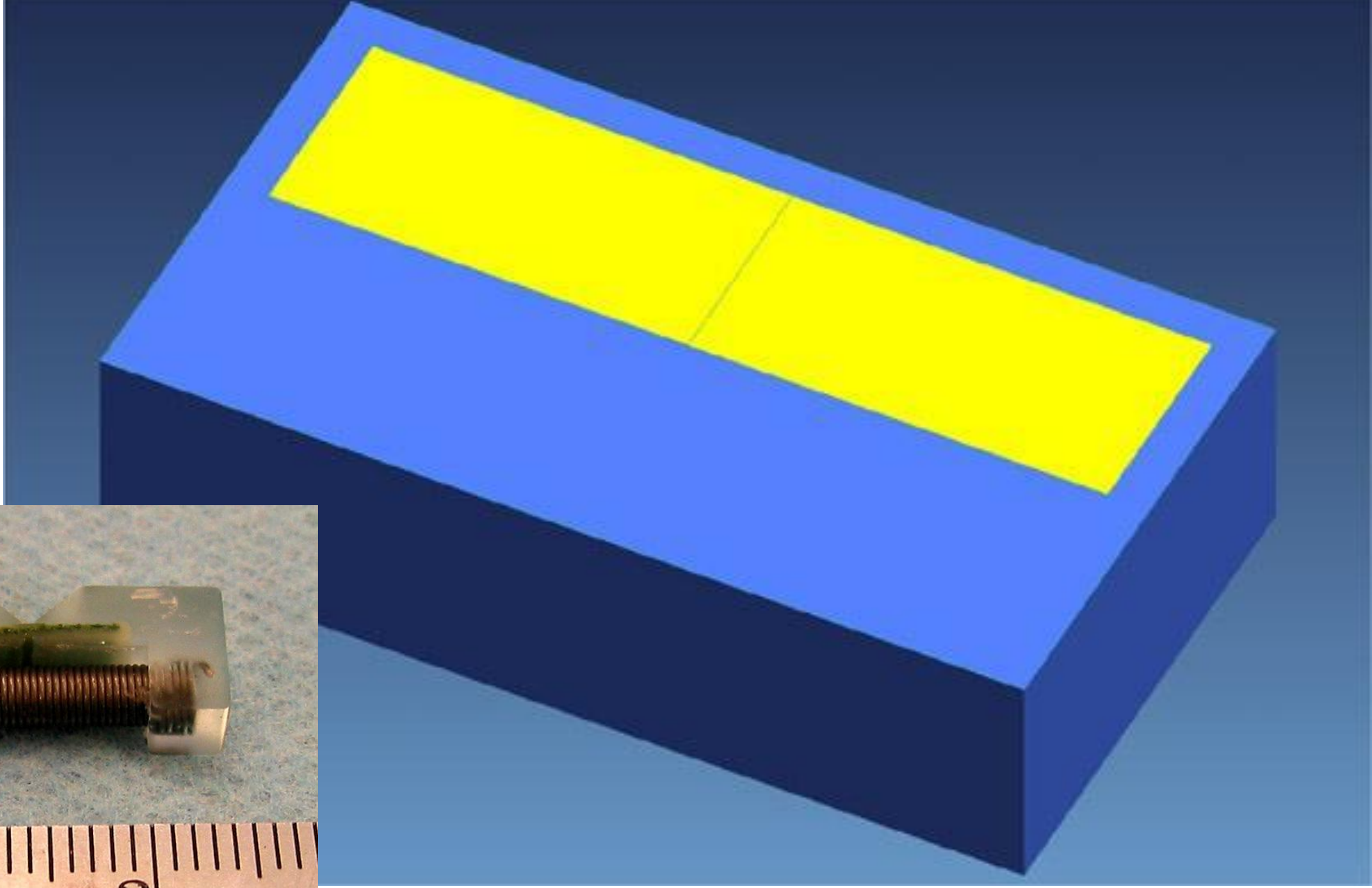

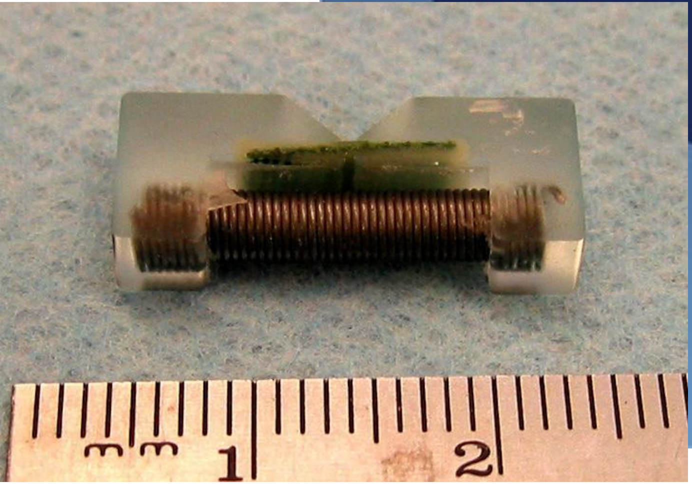

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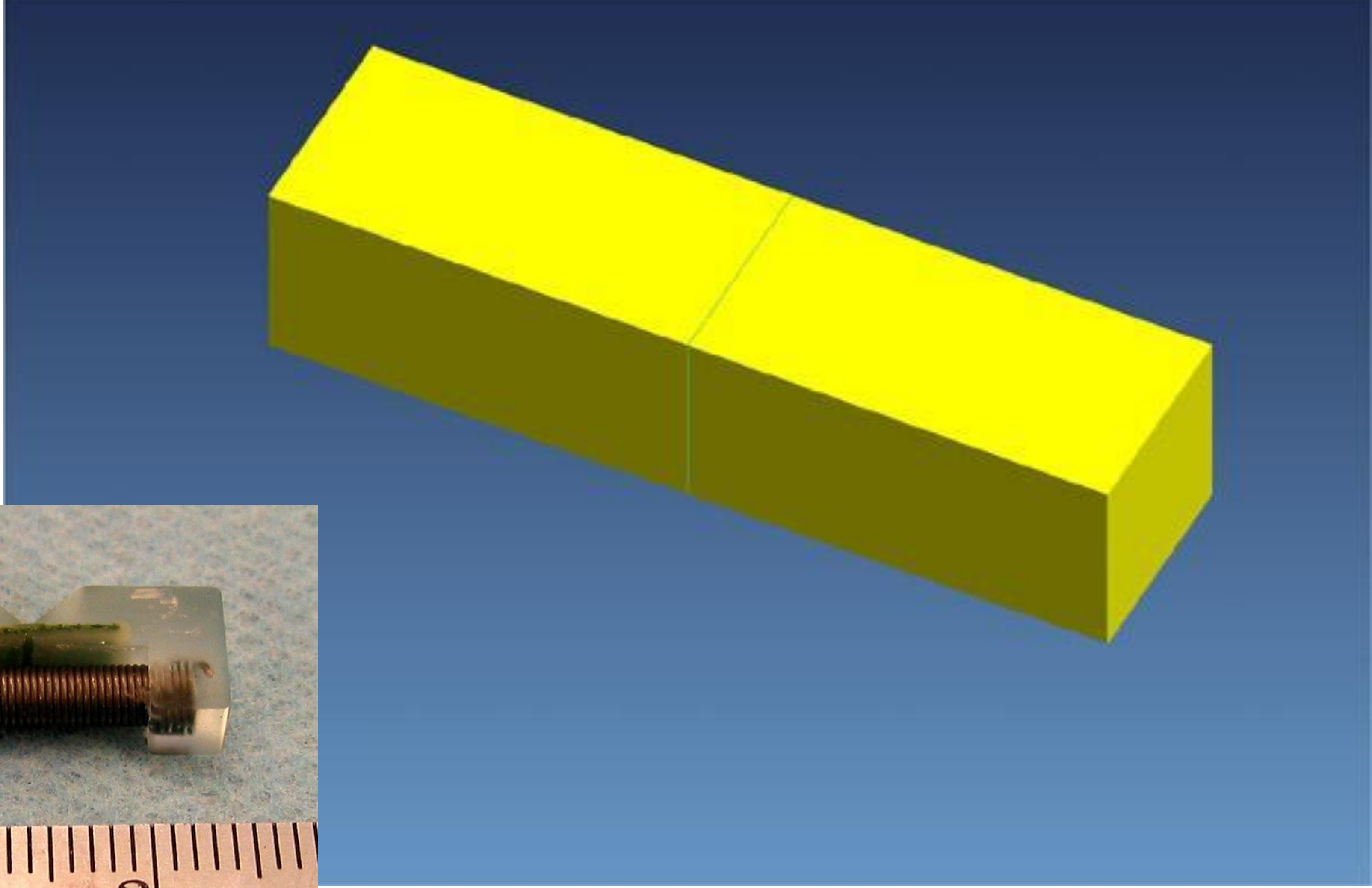

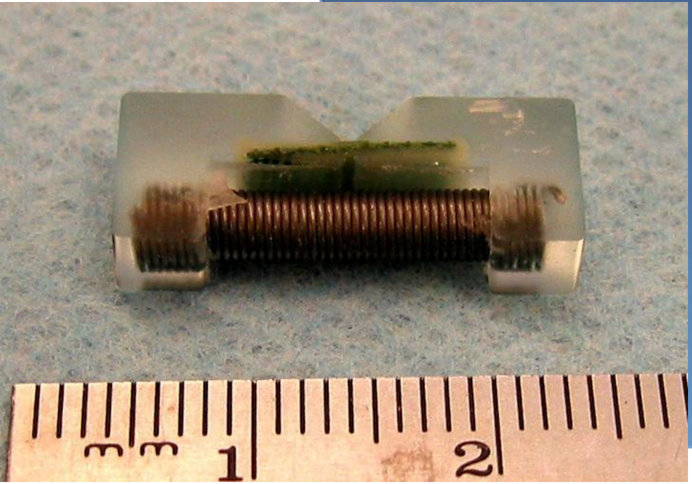

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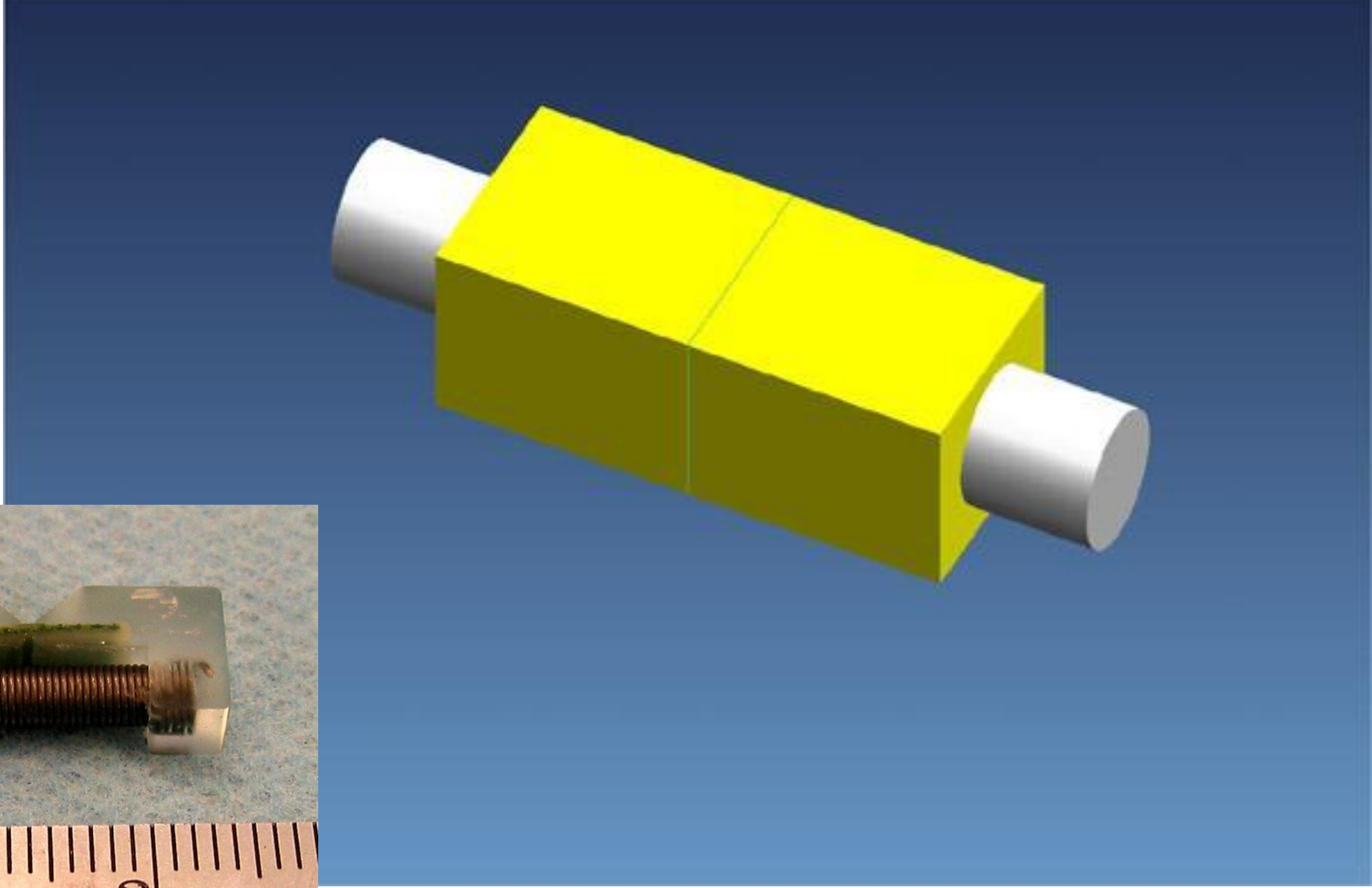

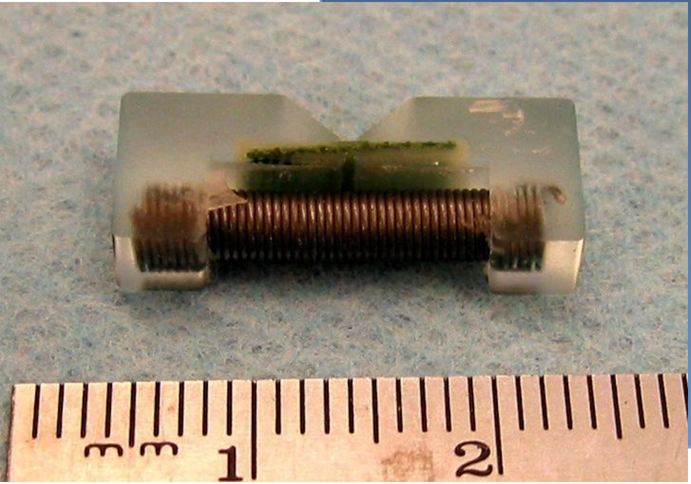

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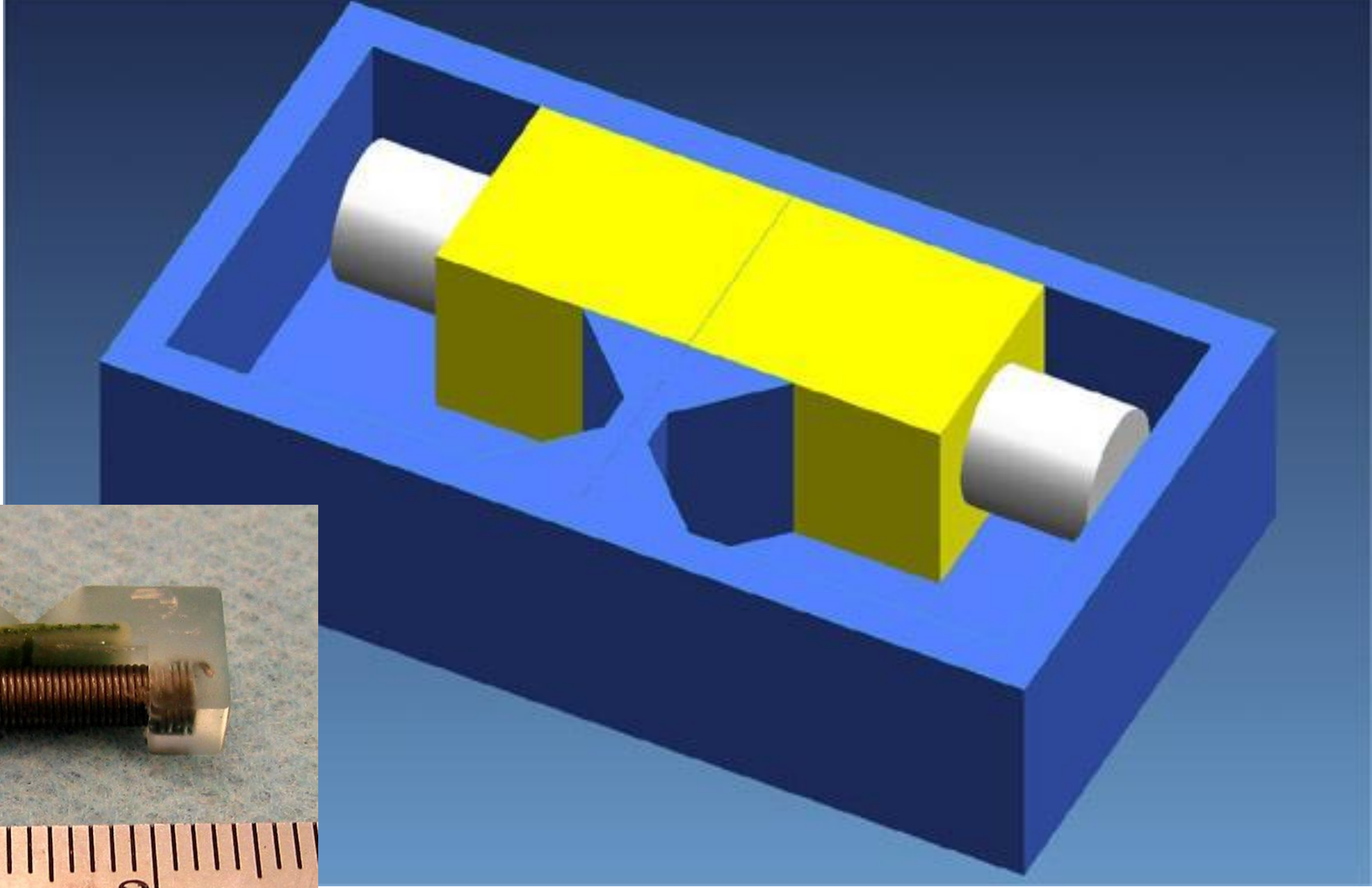

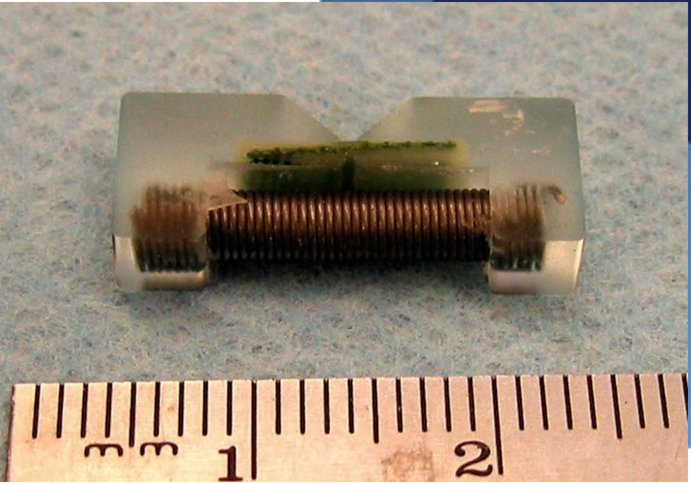

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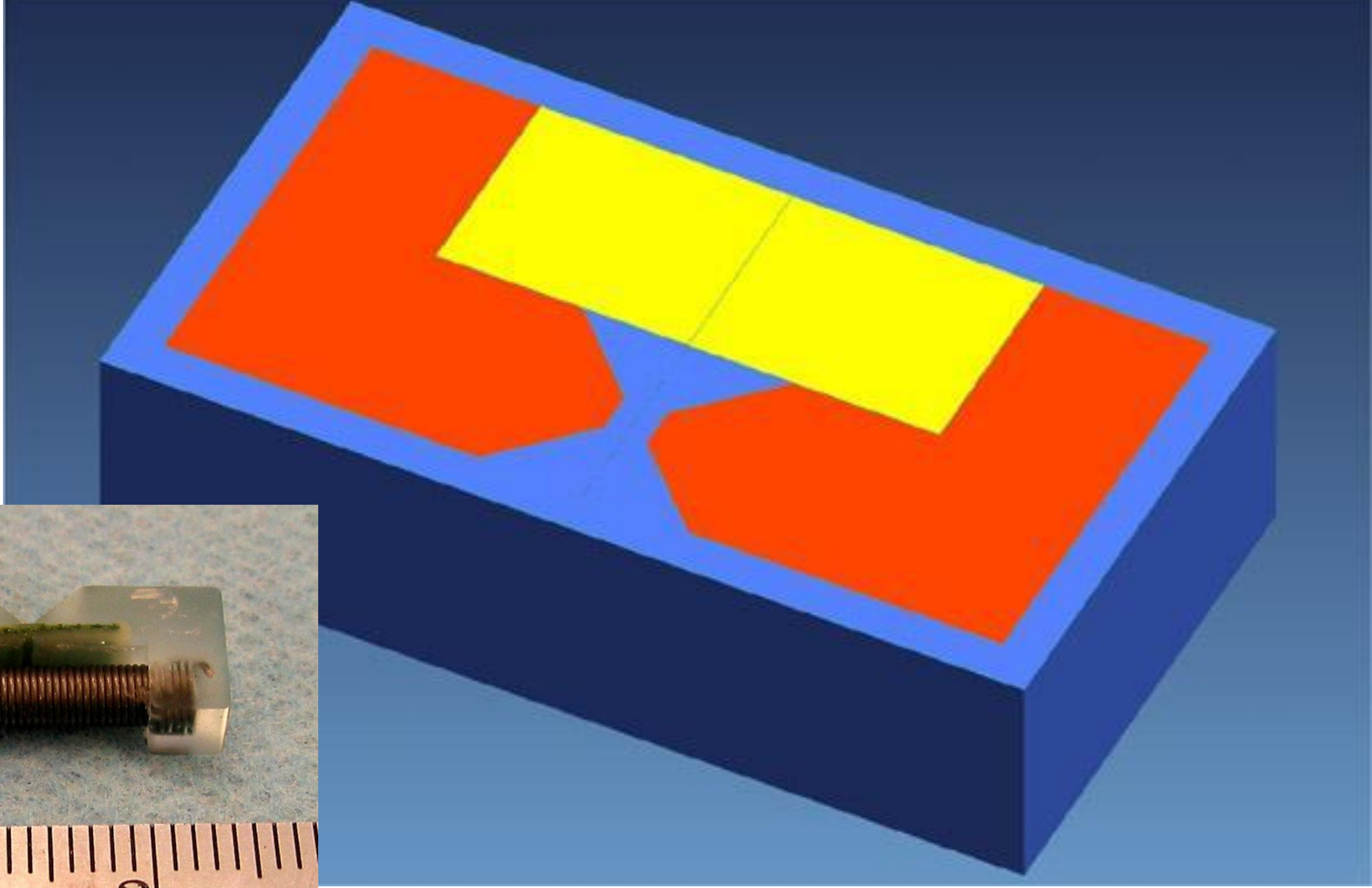

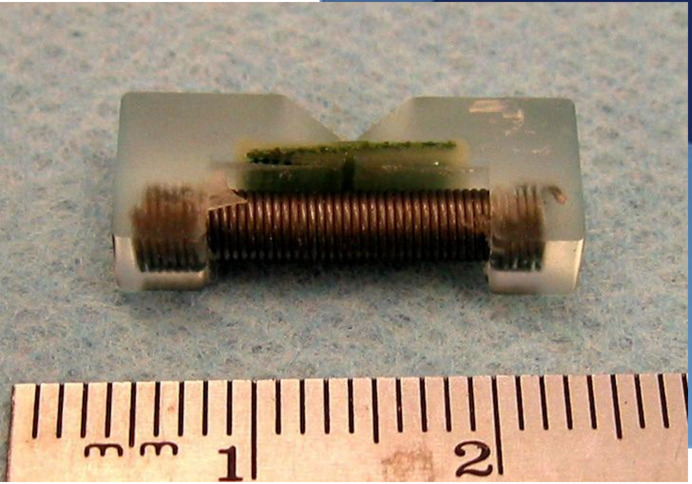

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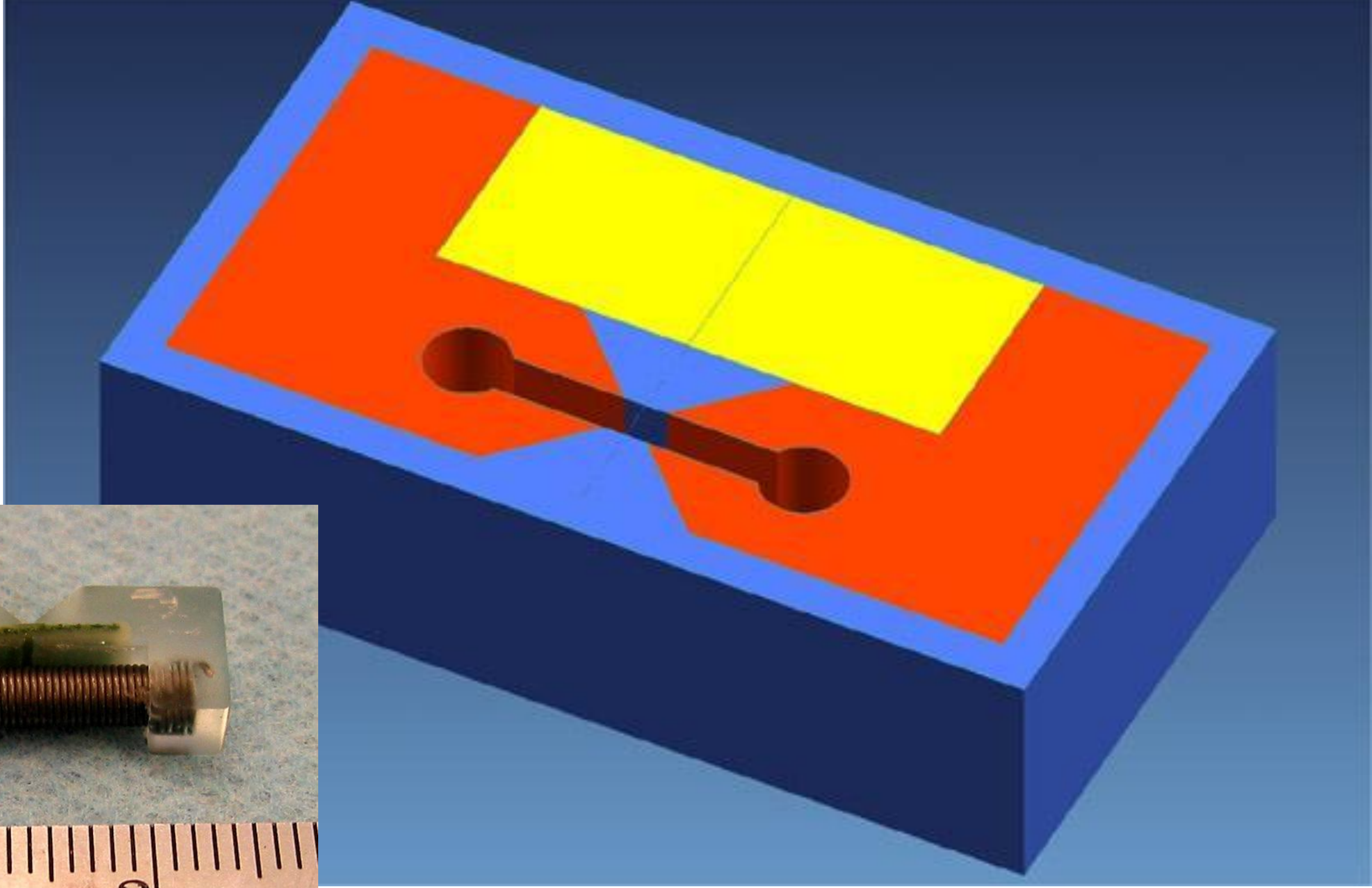

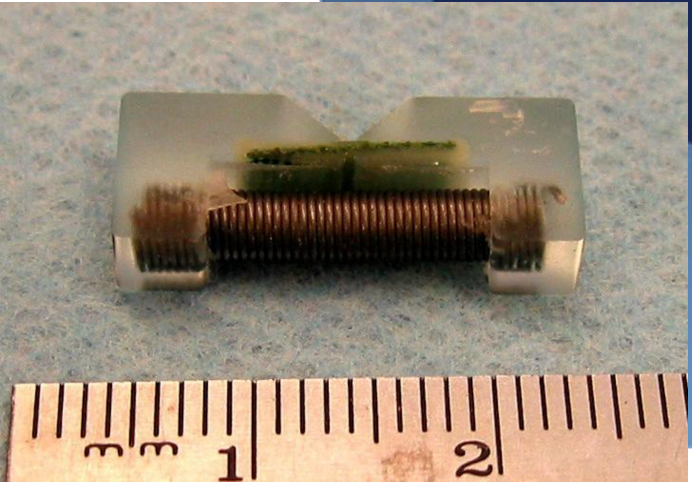

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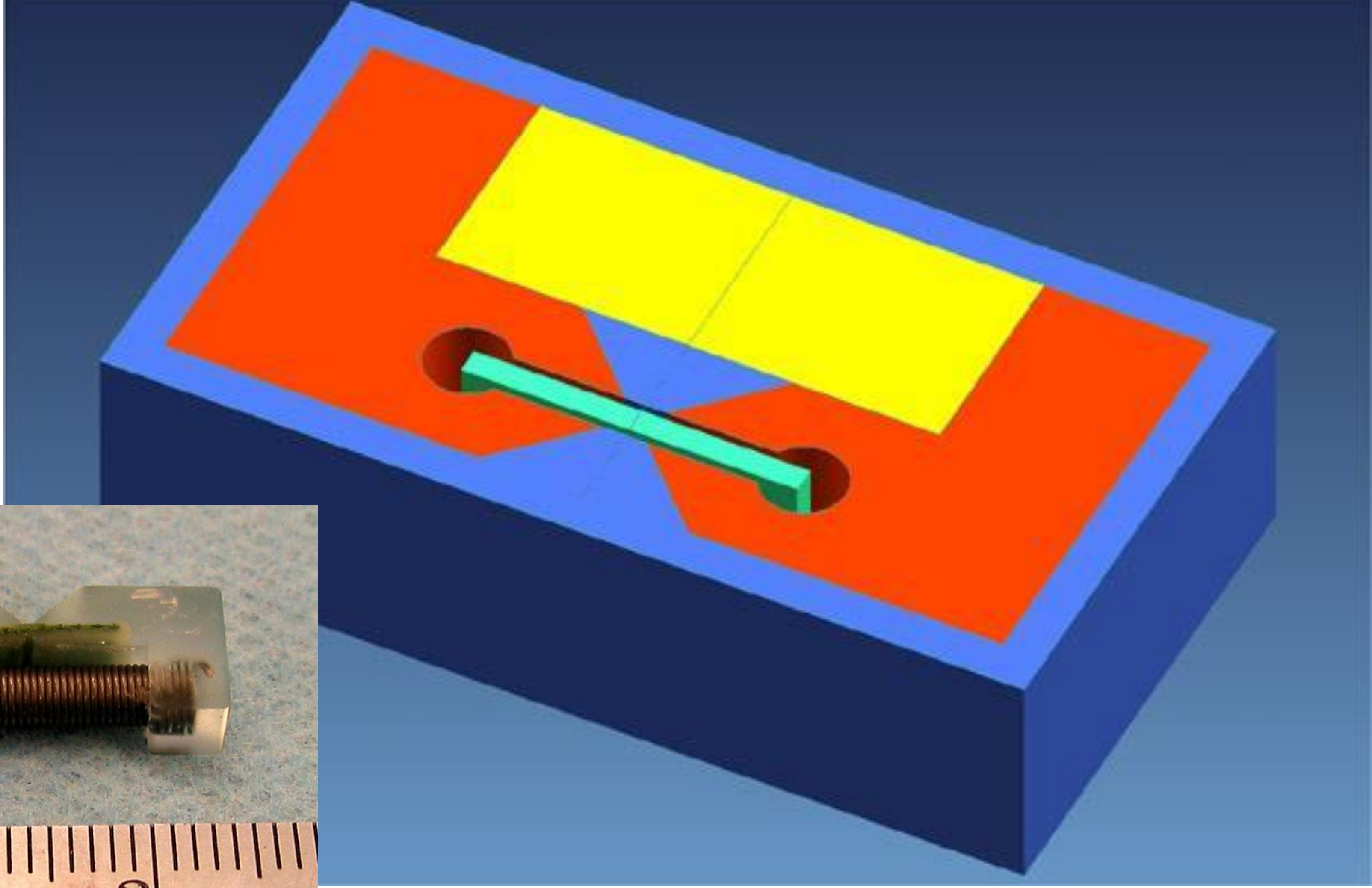

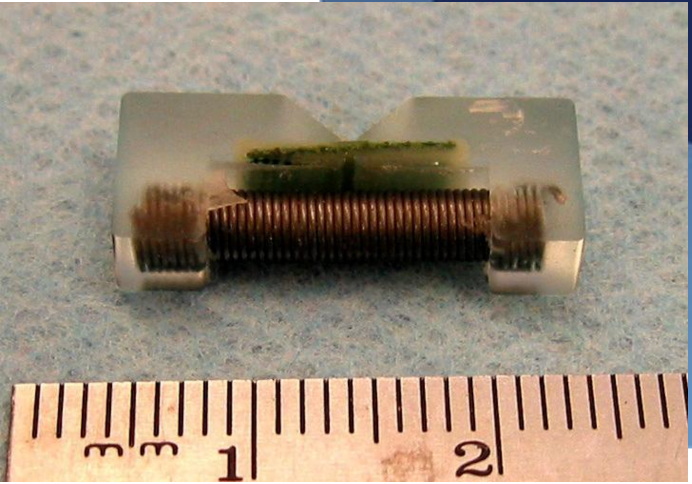

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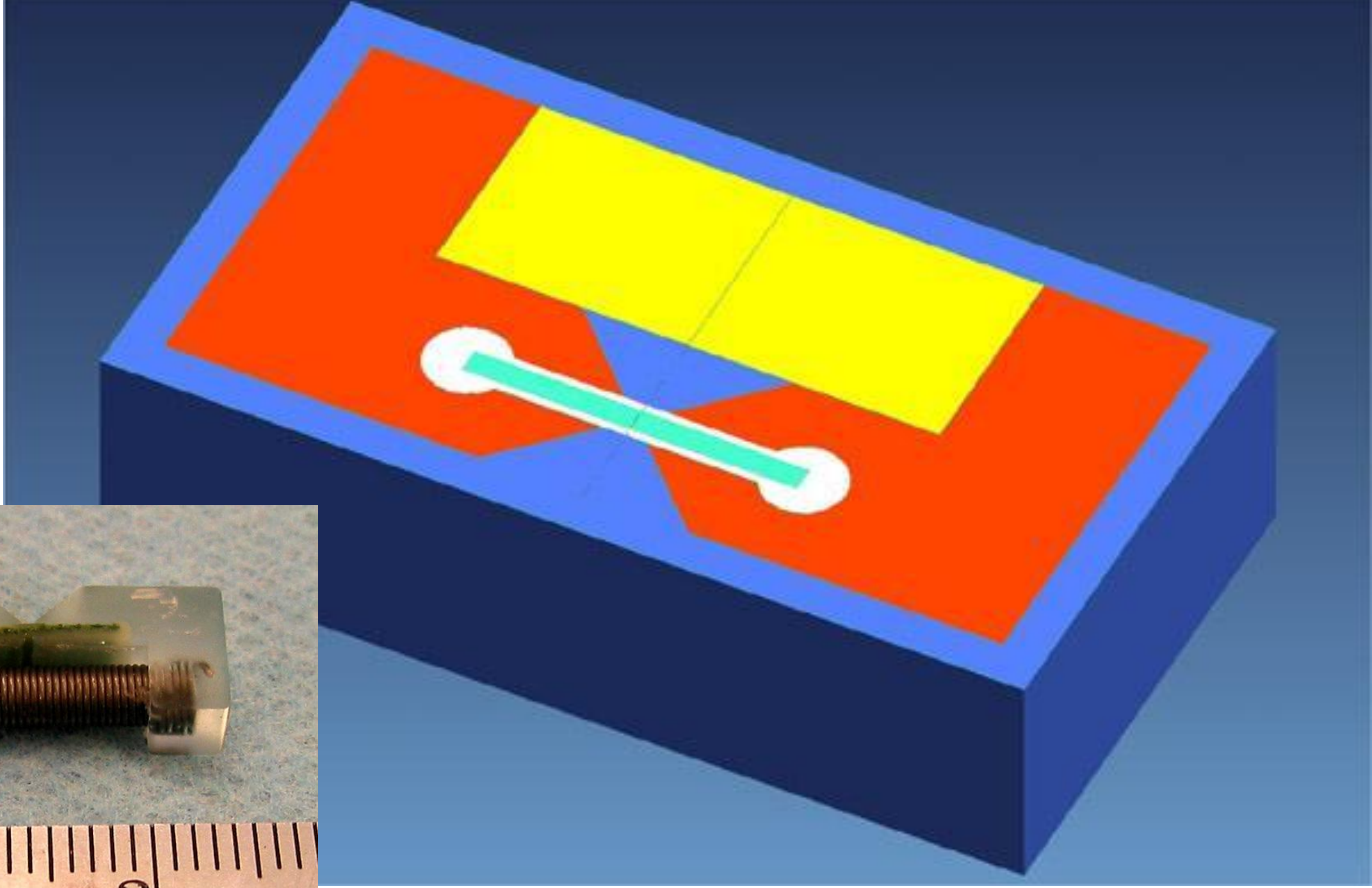

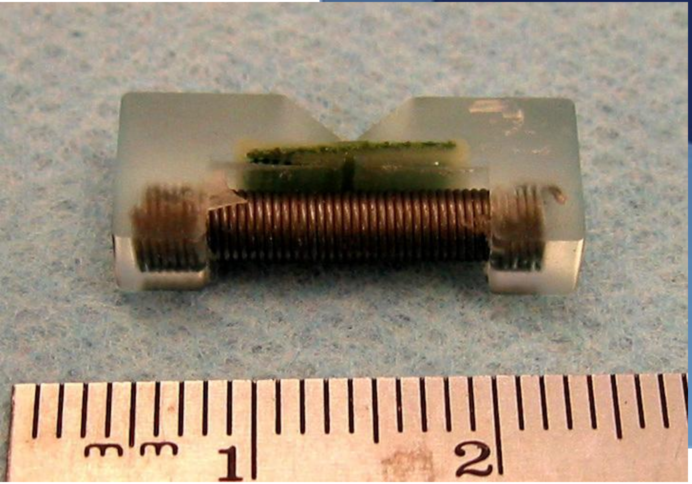

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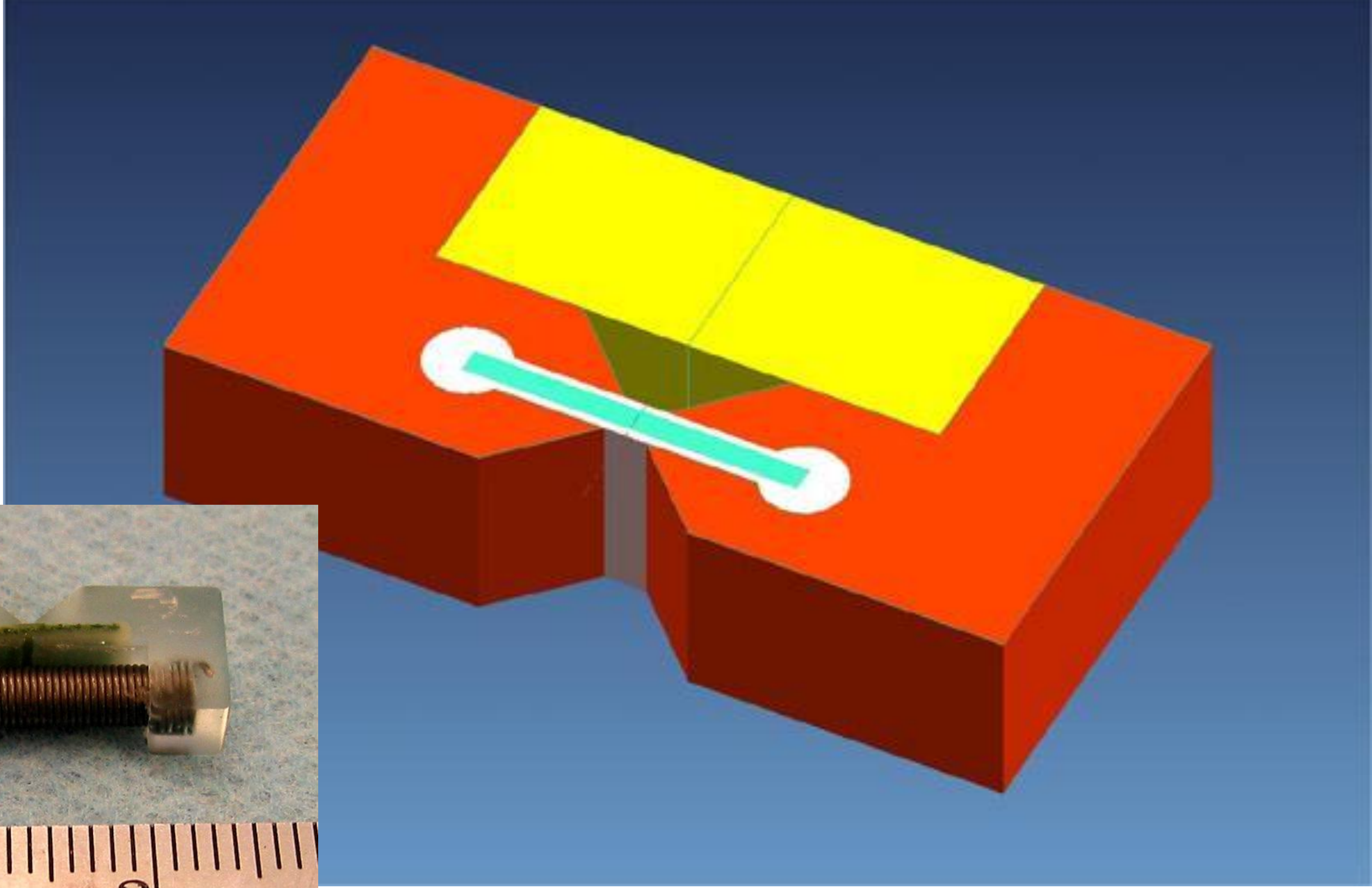

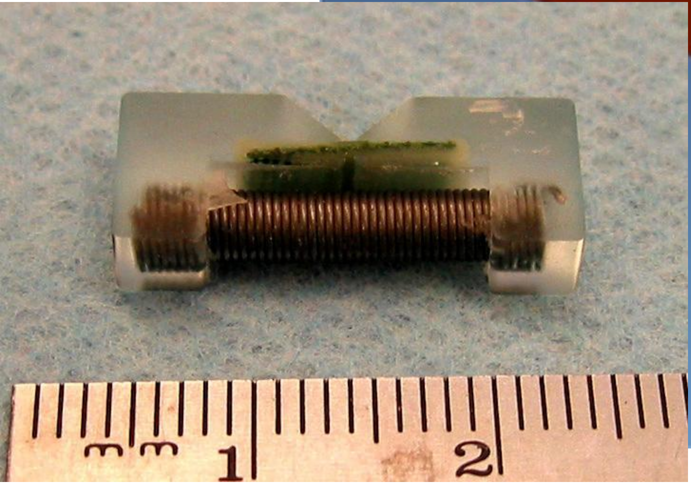

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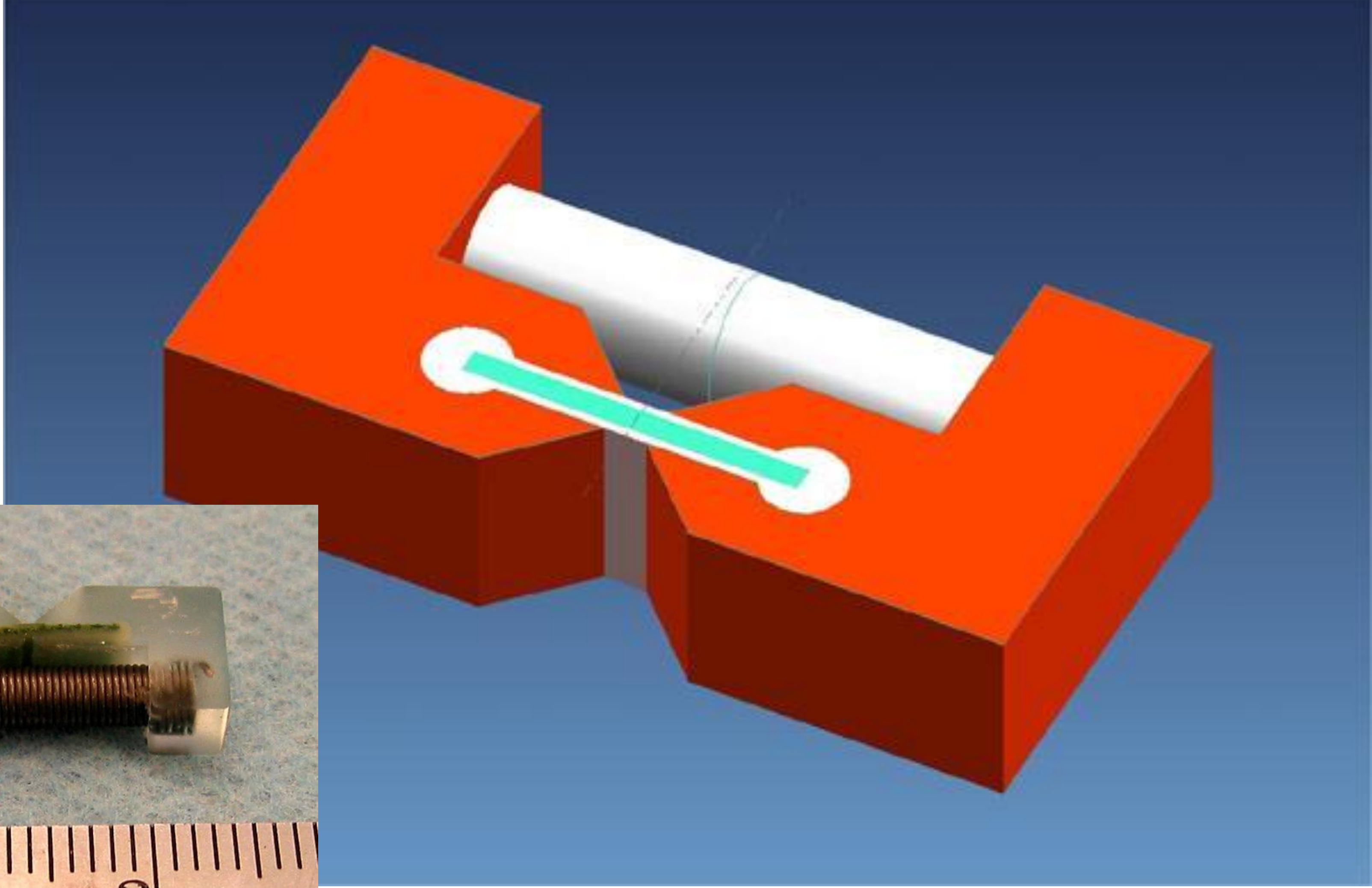

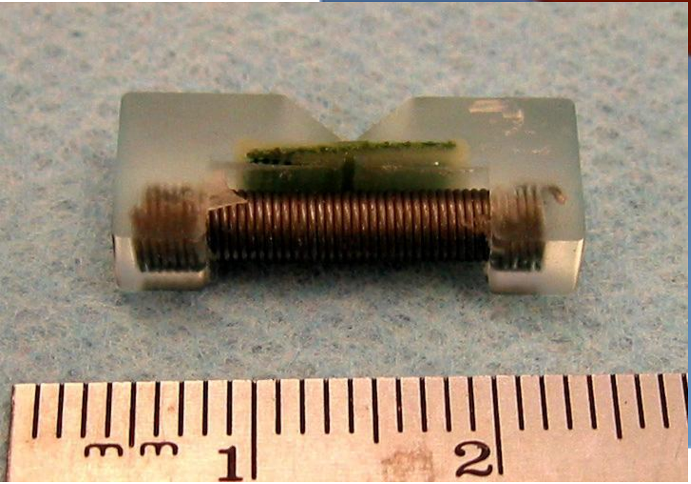

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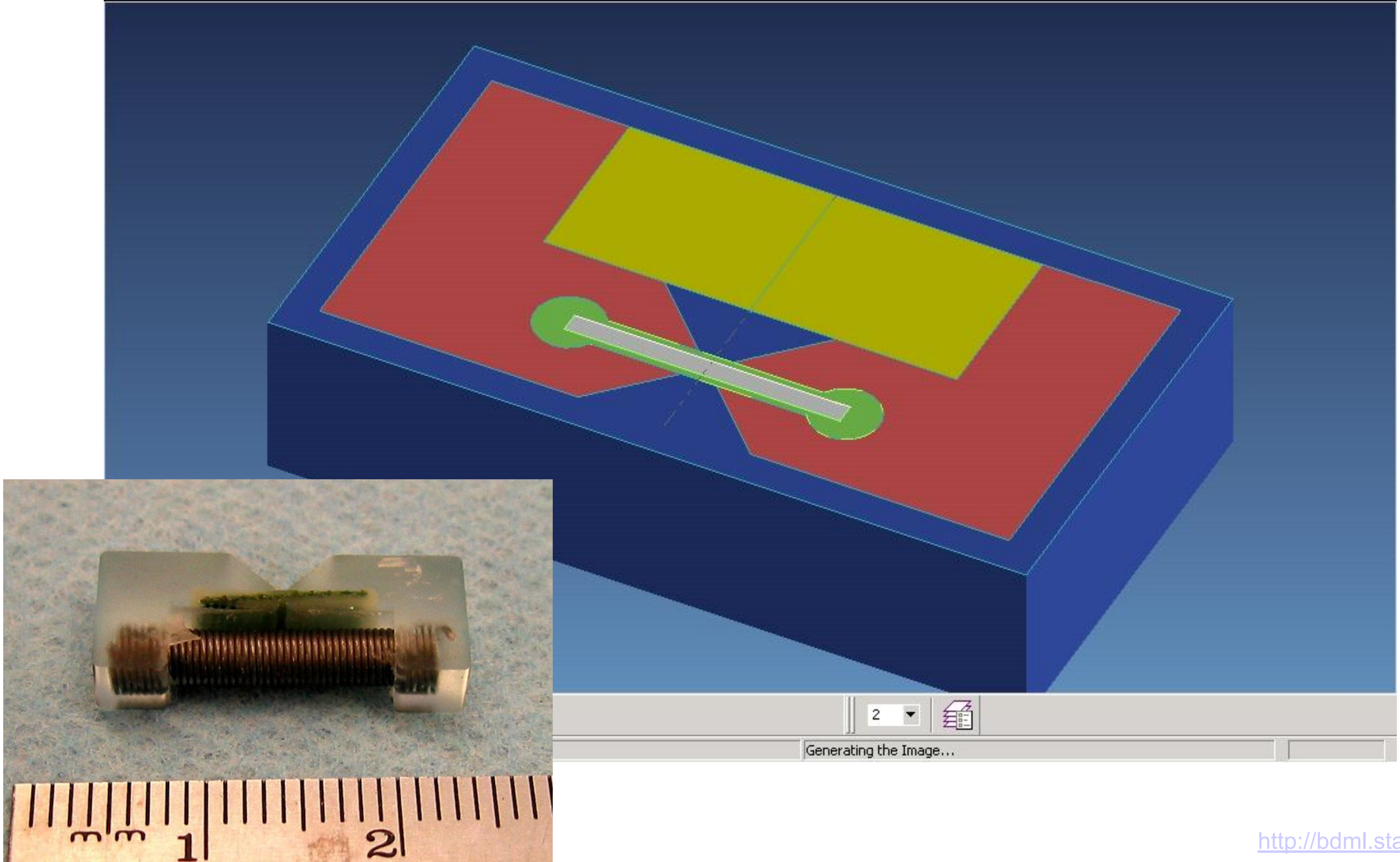

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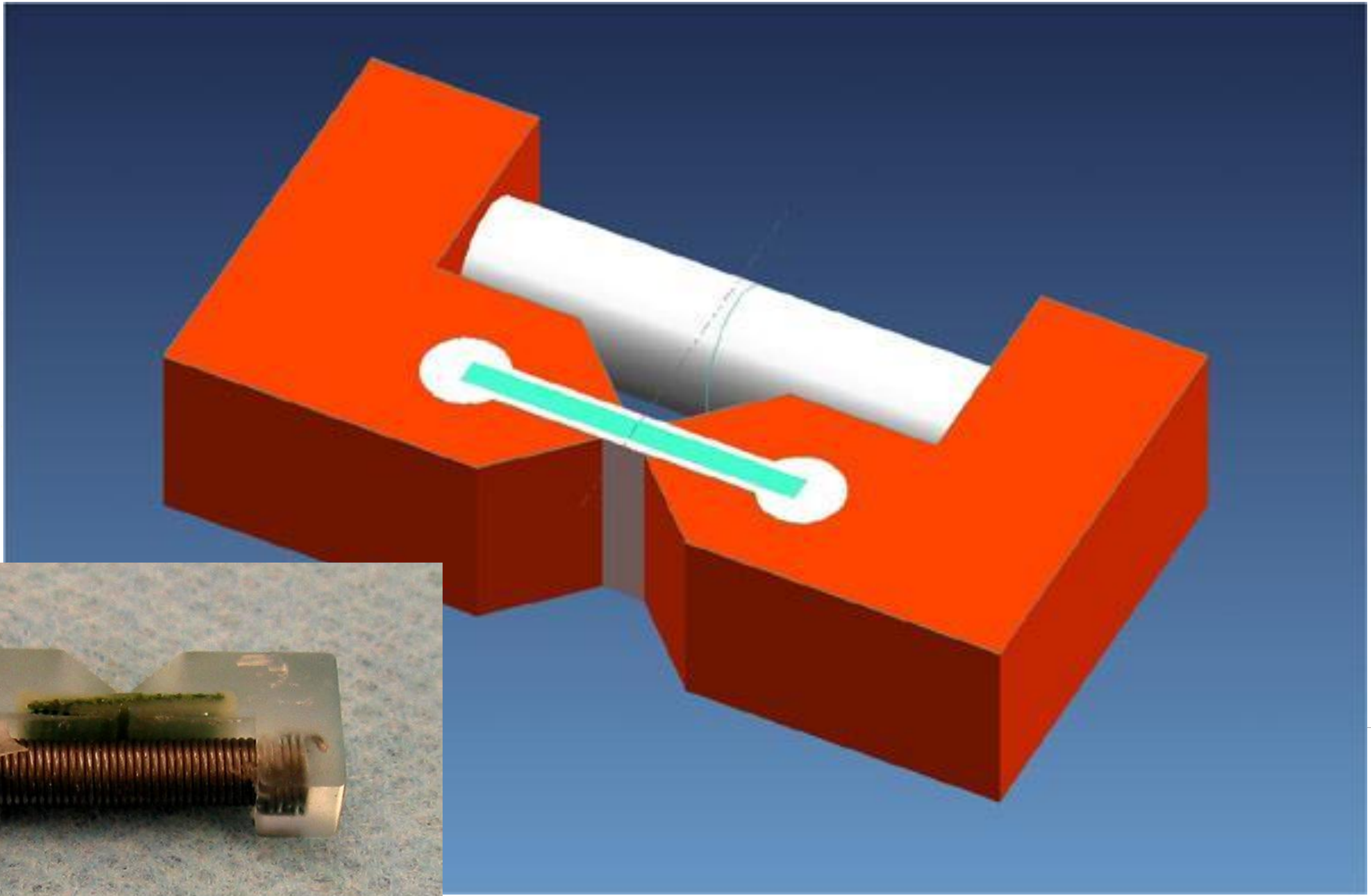

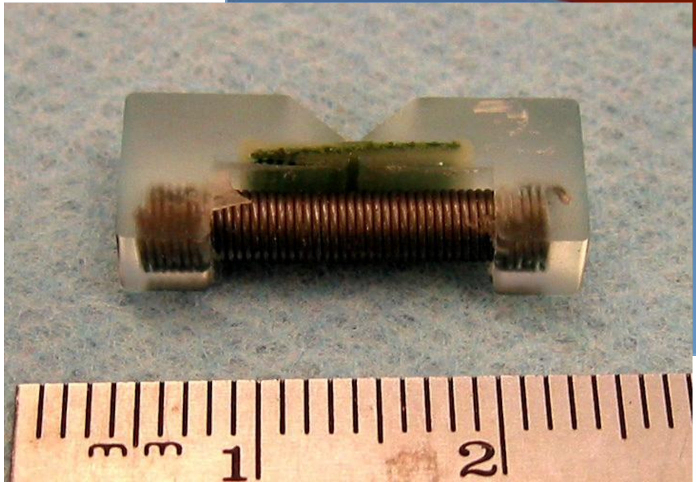

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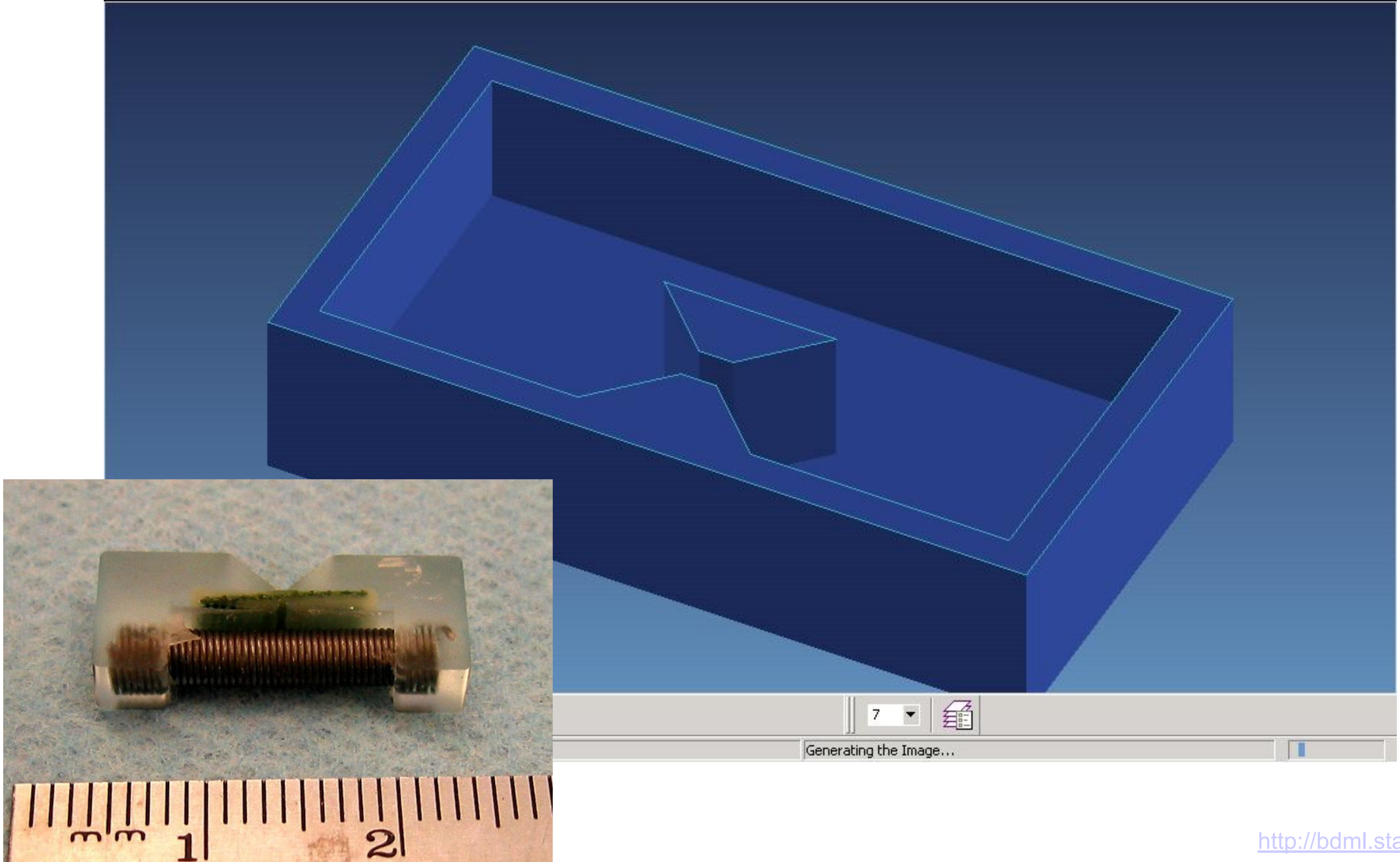

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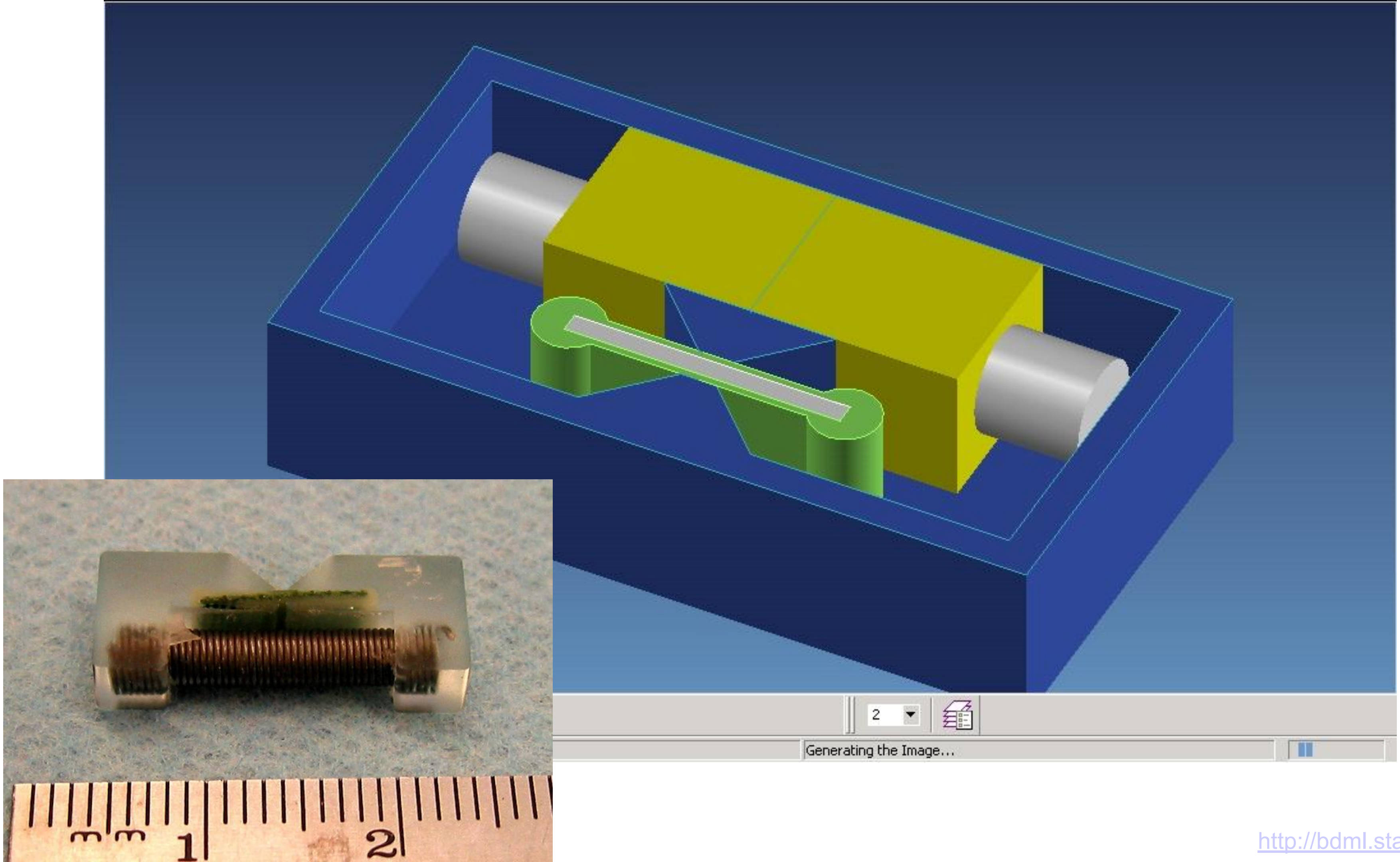

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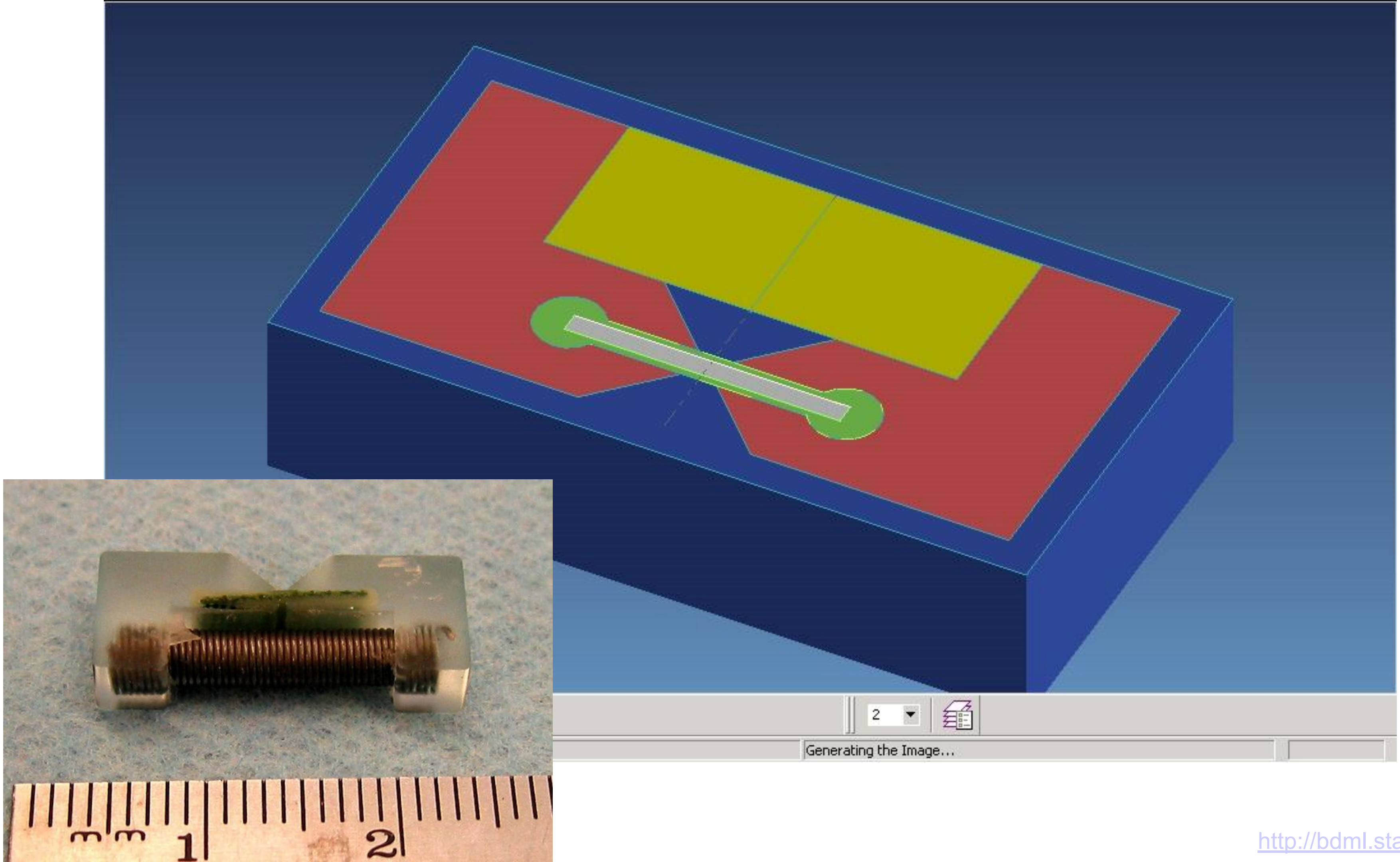

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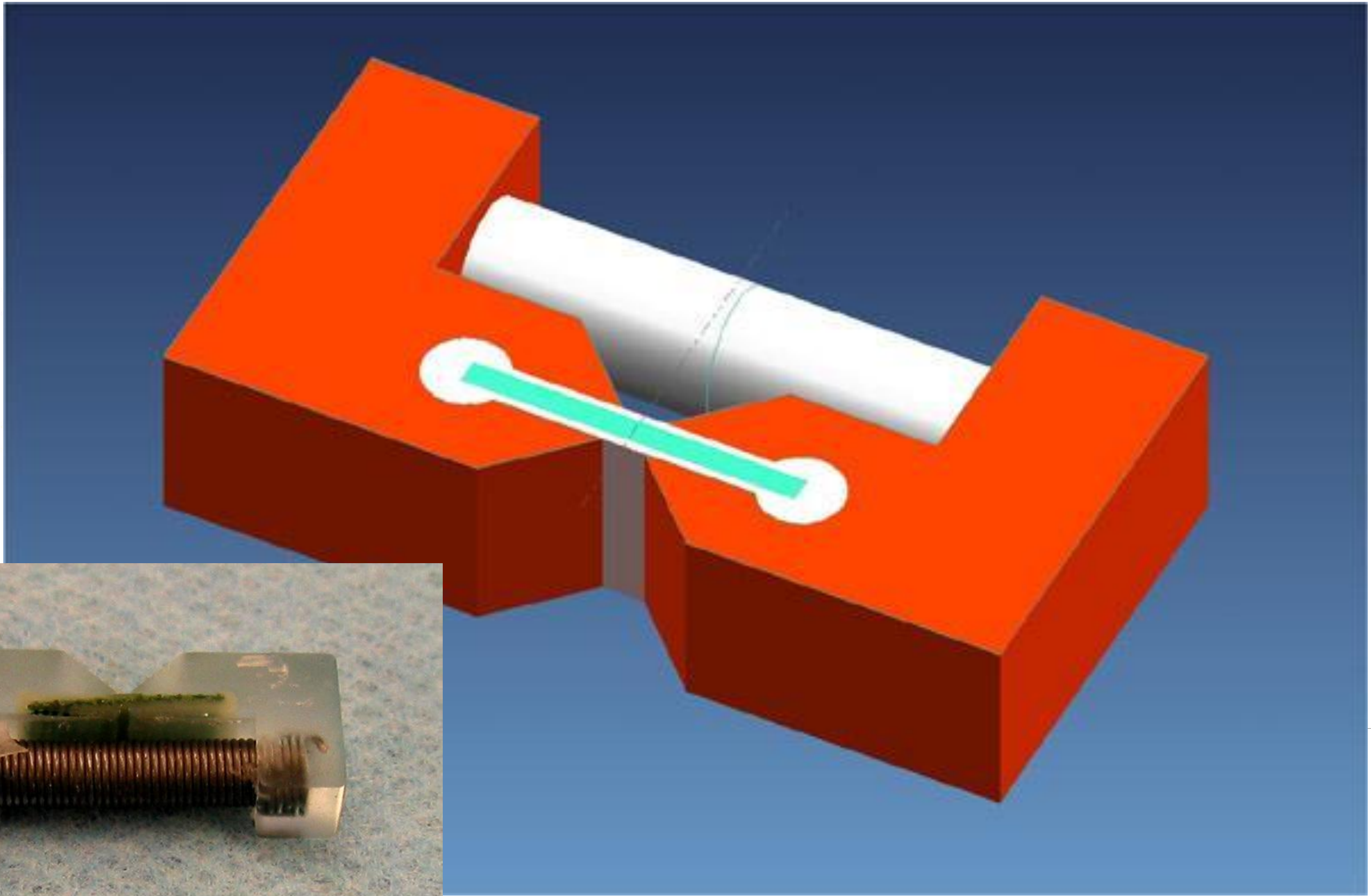

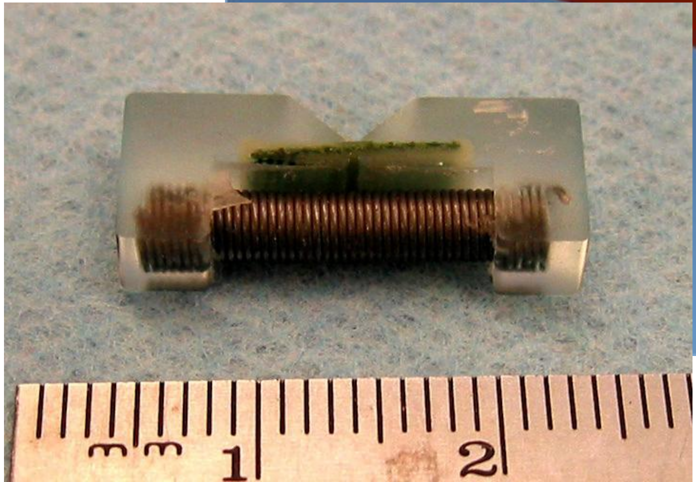

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DMG MORI


Additive manufacturing
Industry 4.0
Rapid prototyping
Rapid tooling
Sustainable development
Incremental sheet forming
Molecular dynamics
Diamond coating
Distortion correction
Eco-design methodology
In-process measurement
Residual stress
Linear motor
Statistical process control
Sustainable machining
Measuring instrument
Production planning
Stereo lithography
Distributed control
Hot stamping
Cold forming
Hot deformation
Nickel alloy
Ultra precision
Super abrasive
End milling
Customisation
Distributed manufacturing
Fracture analysis
Scheduling
Flexible manufacturing system
Product development
Electrical discharge machining
Adaptive manufacturing
Finite element method
Deep hole drilling
Waterjet machining
Tool geometry
Standardization
Knowledge management
Electron beam machining
Surface modification
Compensation
Conceptual design
Chemical vapor deposition
Programming
Free forming
Cutting tool

AM networks

AITeM.org

Italian Academy of Production Engineering

www.additivemanufacturing.work

Interest Group
Additive Manufacturing

Coordinator: prof. Michele Lanzetta
University of Pisa
Department of Civil and Industrial Engineering

Università di Pisa
INGEGNERIA

DICI
DIPARTIMENTO DI INGEGNERIA
CIVILE E INDUSTRIALE

CIRAM
Centro Interuniversitario di Ricerca per l'Additive Manufacturing

www.ciram.net

Interuniversity research center for Additive Manufacturing

Co-Funder: prof. Michele Lanzetta
University of Pisa
Department of Civil and Industrial Engineering

Università di Pisa
INGEGNERIA

DICI
DIPARTIMENTO DI INGEGNERIA
CIVILE E INDUSTRIALE

Centro Interuniversitario di Ricerca per Manufacturing

Mission: to create a multidisciplinary **Additive Manufacturing** research platform with the aim of dealing with and overcoming the open challenges, in terms of **machines**, **materials** and **applications**, and of contributing, together with other industrial actors, in the development of new generation systems destined for final production from the Industry 4.0 viewpoint

Mission

The interest group **Additive Manufacturing Aitem** aims to *increase and spread the knowledge of additive technologies and their application to the design and production of goods and services to sustainably increase national competitiveness and well-being*

Members

The interest group Additive Manufacturing Aitem is funded from professors of the Technologies and Processing Systems sector of Italian universities

It is open to contributions from other academic sectors and from the industrial world

Enrollment and participation is free

Universities involved

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social e notizie

lunedì 30 dicembre 2013

Membri

Iscriviti qui

Ingrandisci l'elenco in una nuova finestra

calendario eventi

iscrizione (gratuita)

Agenda

Today ◀ ▶ **Friday, June 24** Print

Monday, June 27
5:30pm Skype Meeting di Giugno
Tuesday, June 28
9:00am Seminario tecnico Aitem Met

additivemanufacturing.work

POLITECNICO MILANO

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AITEM

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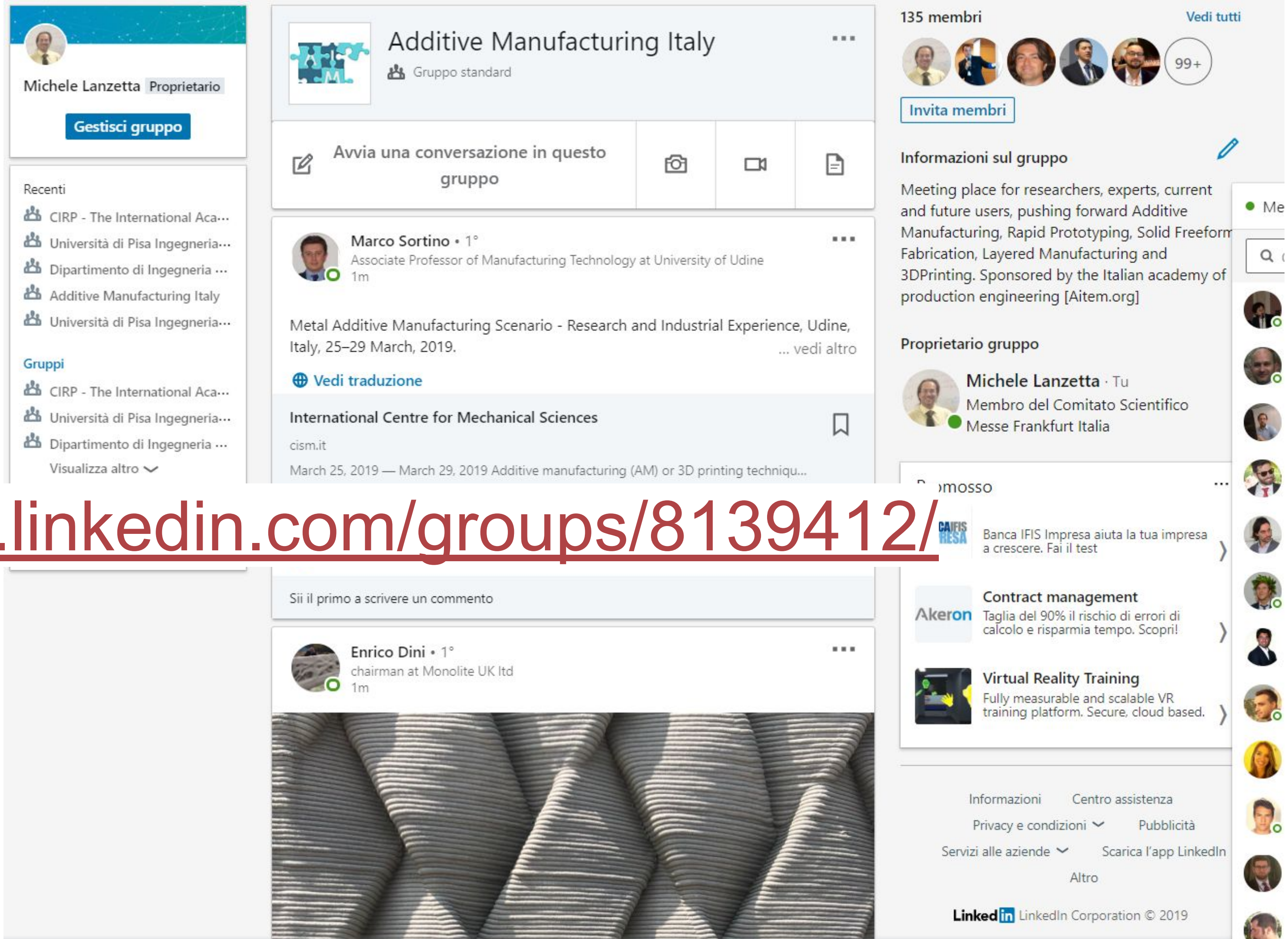

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Design for Additive Manufacturing: Trends, opportunities, considerations, and constraints

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Abstract

The past few decades have seen substantial growth in Additive Manufacturing (AM) technologies. However, this growth has mainly been process-driven. The evolution of engineering design to take advantage of the possibilities afforded by AM and to manage the constraints associated with the technology has lagged behind. This paper presents the major opportunities, constraints, and economic considerations for Design for Additive Manufacturing. It explores issues related to design and redesign for direct and indirect AM production. It also highlights key industrial applications, outlines future challenges, and identifies promising directions for

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Additive manufacturing, 3D printing, prototyping

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