

M2794.006900 DESIGN FOR MANUFACTURING

Week 10, November 09

Manufacturing Processes

2. Additive Processes

Fall 2017

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Outline

- 3D printing
- Cold spray
- Nano particle deposition system (NPDS)
- Injection molding
- Conclusions




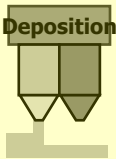
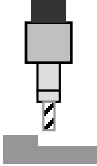


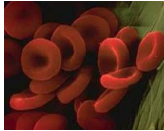
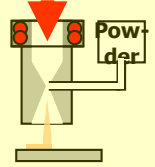
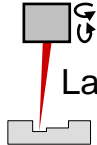
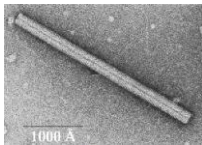

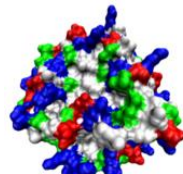

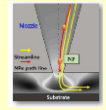
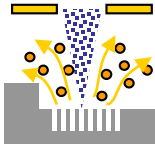




Multi-scale fabrication

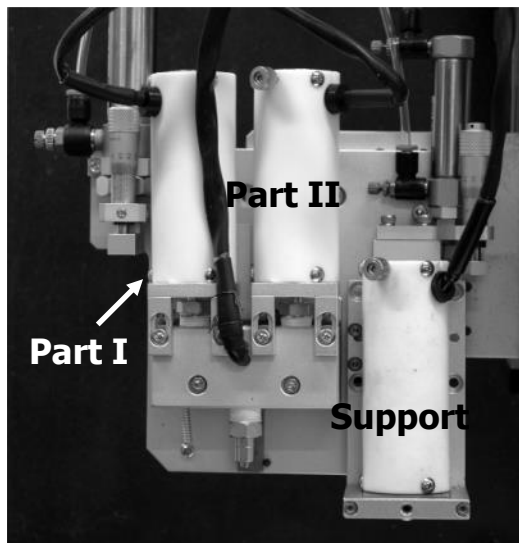
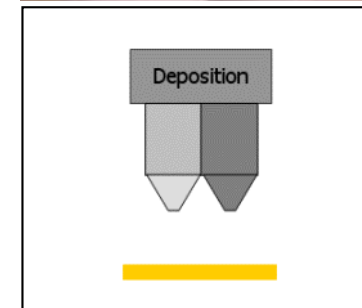
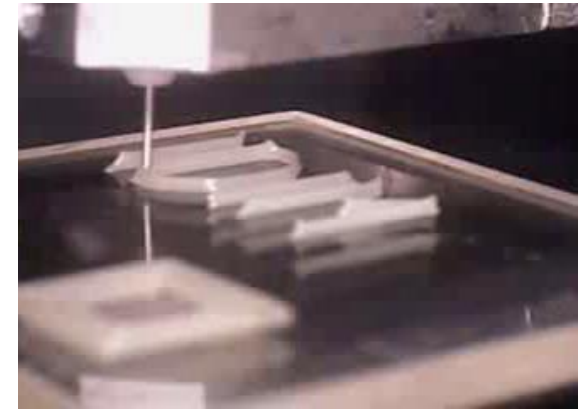


Today's class

Scale	Example	Additive process	Subtractive process
macro/meso (100 mm) 10^{-1}	 Mouse  CD-ROM  Mobile phone	 Deposition 3D Printing	 Precision machining
micro (100 μm) 10^{-4}	 Human hair ~ 60-120 μm wide  MicroElectroMechanical (MEMS) devices 10-100 μm wide  Red blood cells (~7-8 μm)	 Cold spray	 Laser machining
nano (100 nm) 10^{-7}	 Virus 1000 Å  Smoke  Protein	 Nano particle deposition  AFN printing	 Focused ion beam

#4 3D Printing

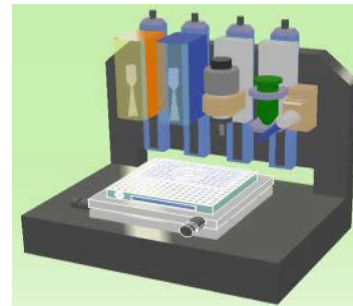
- **Type: Additive**
- **Scale: 200 μm ~ 100 mm**
- **Metal : polymer, composite**
- **Characteristics: precision stage, micro-nozzle**



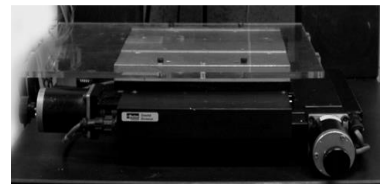
Composite deposition system



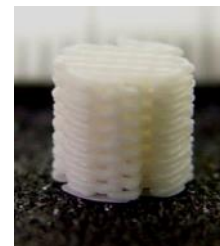
**Micro nozzle,
f 100 μm**



Machining process



**Precision micro stage,
1 μm resolution**



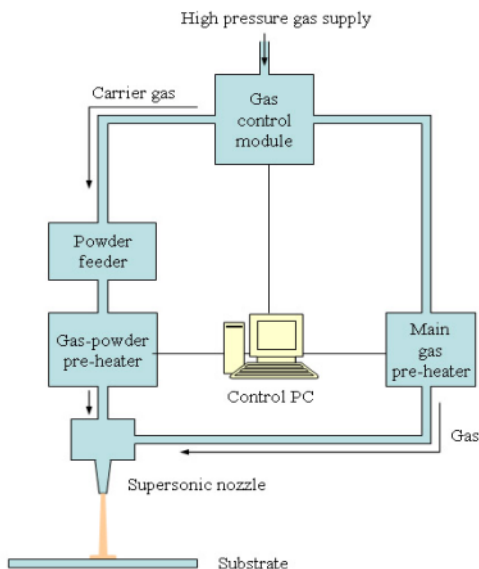
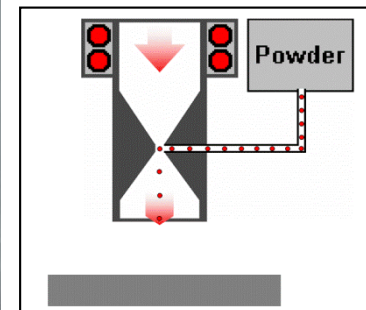
Scaffold



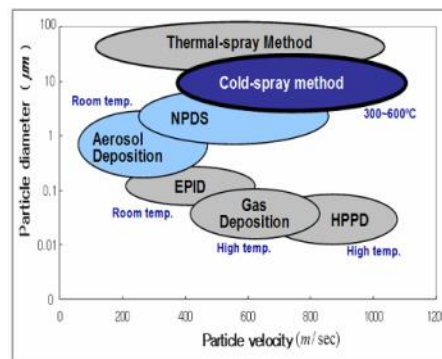
Stape

#5 Cold spray (저온분사적층)

- **Type: Additive**
- **Scale: 10 μ m ~ 100mm**
- **Material: metal, ceramic, polymer**
- **Characteristics:**
 - **Supersonic gas flow**
 - **Micro-sized particle deposition**

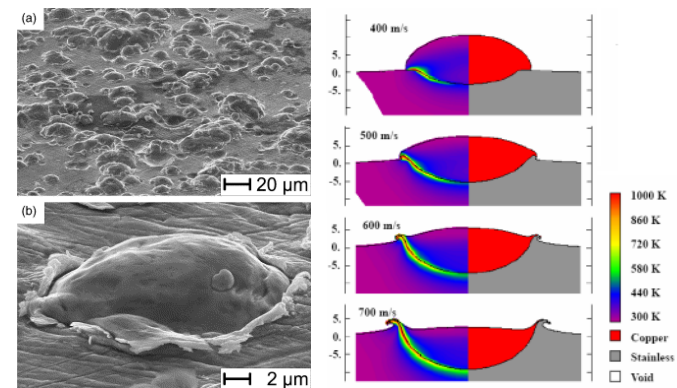


Cold spray system



Comparison of particle deposition processes

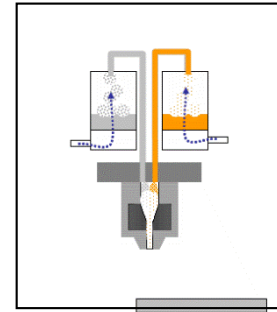
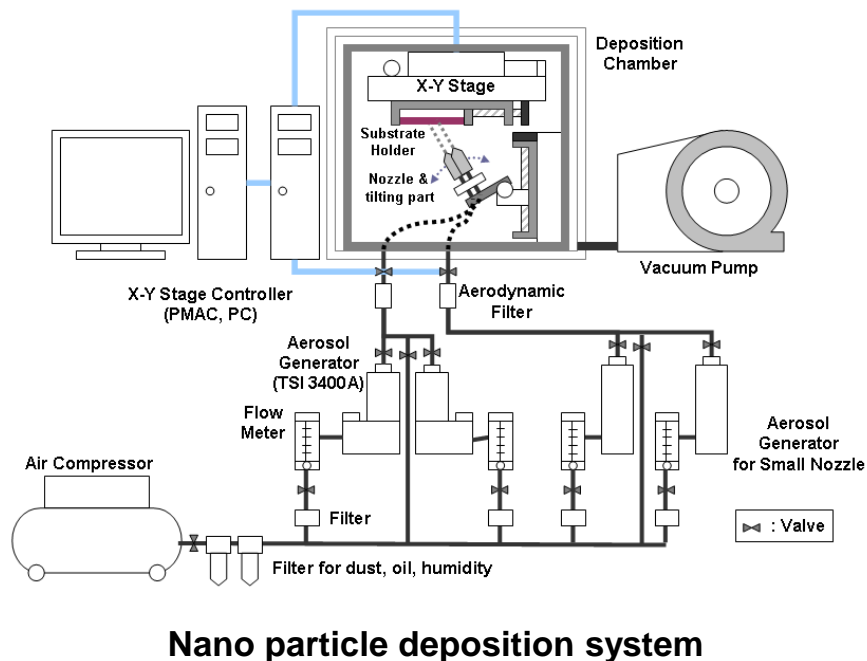
Machining process



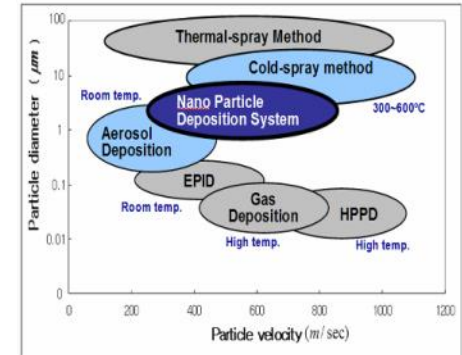
SEM image and numerical solution of bonded particle
(R. C. Dykhuizen, A. Hamidi)

#6 Nano particle deposition (나노입자적층)

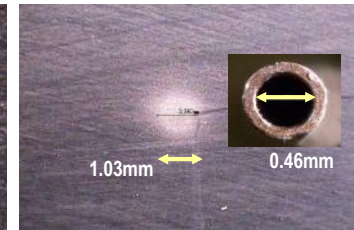
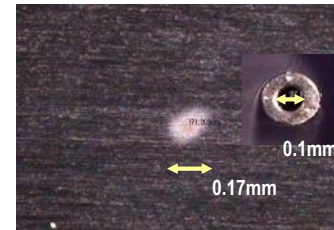
- **Type: Additive**
- **Scale : several μm ~ hundreds of μm coating**
- **Material : Mostly ceramic, partly metal**
- **Characteristics : Submicron ~ dia. 10 μm particle used**



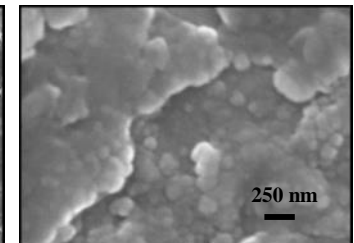
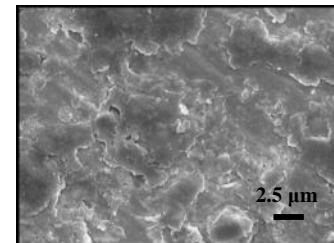
Machining process



Comparison of particle deposition processes



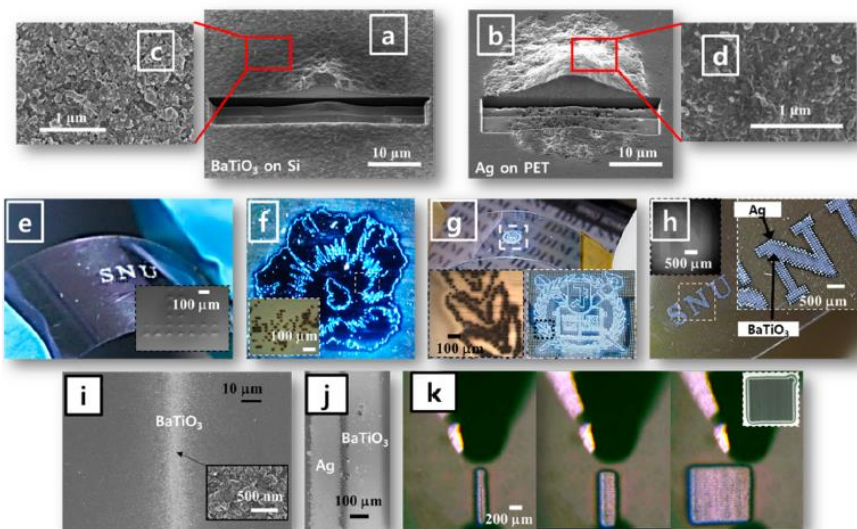
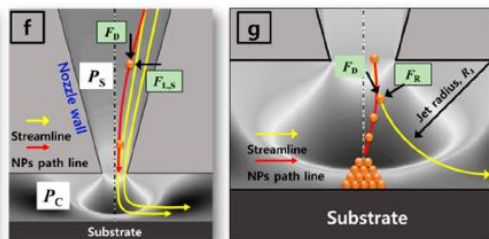
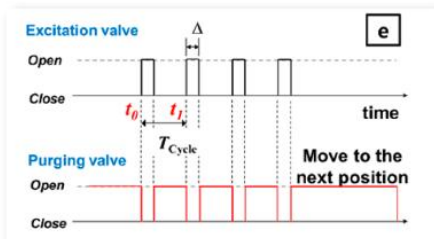
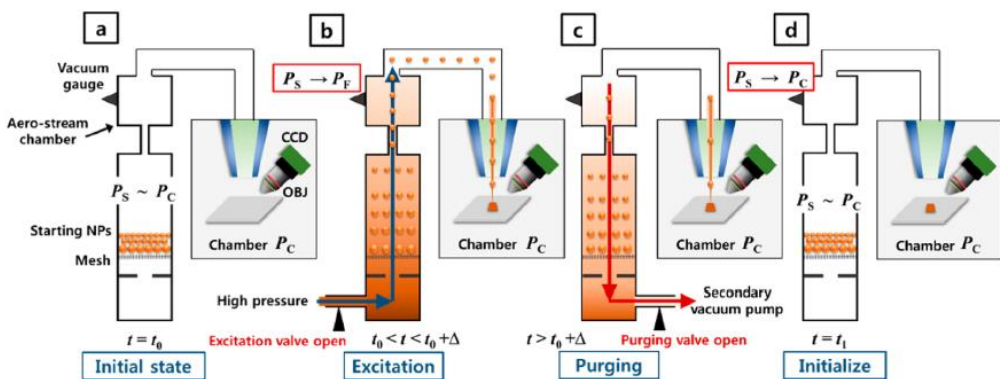
Mn-Zn ferrite coating on Al 6061 with needle



TiO₂ coating on Stainless steel

#7 Aerodynamically Focused Nanoparticle (AFN) Printing ⁸

- **Type: Additive**
- **Scale : several μm \sim hundreds of μm coating**
- **Material : metal, ceramic**
- **Characteristics : Direct patterning of the solvent-free inorganic nanoparticles**



Schematic diagram of the processing steps

Patterned images by AFN printing

Lee, G. Y., Park, J. I., Kim, C. S., Yoon, H. S., Jinkyu Yang, and Ahn, S. H., 2014, "Aerodynamically Focused Nanoparticle (AFN) Printing: Novel Direct Printing Technique of Solvent-free and Inorganic Nanoparticles," ACS Applied Materials and Interfaces, American Chemical Society (USA)

Presidential Issue



A once-shuttered warehouse is now a state-of-the-art lab where new workers are mastering the 3D printing that has the potential to revolutionize the way we make almost everything.

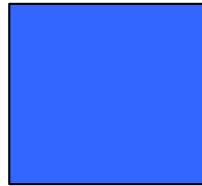
- B. Obama, president of USA



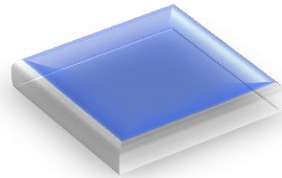
*Speech at the State of the Union Address,
USA (2013)*

3D printing technology has attracted worldwide attention

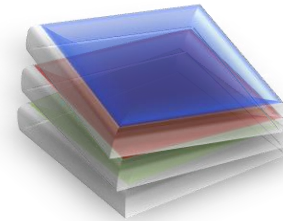
From 2D to 3D printing



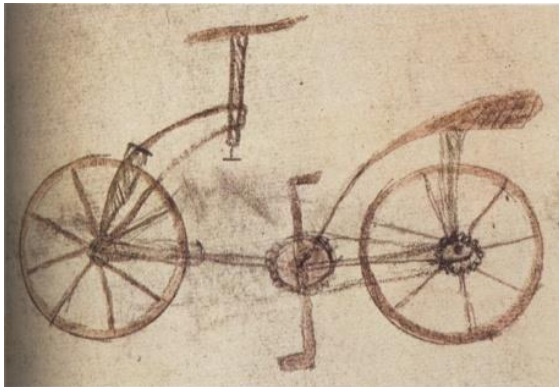
2D sheet



2.5D Prismatic plate



3D structure



3-D solid model
representation



CAD

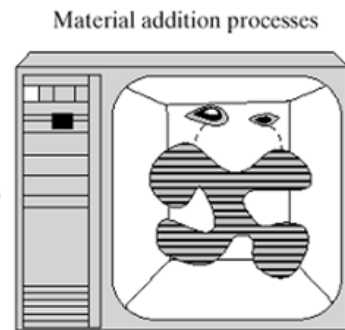
Data
exchange
format

- Slicing
- Trajectory planning



Automatic process planner

Motion
control
trajectories



Automated fabrication machine

Introduction to 3D Printing

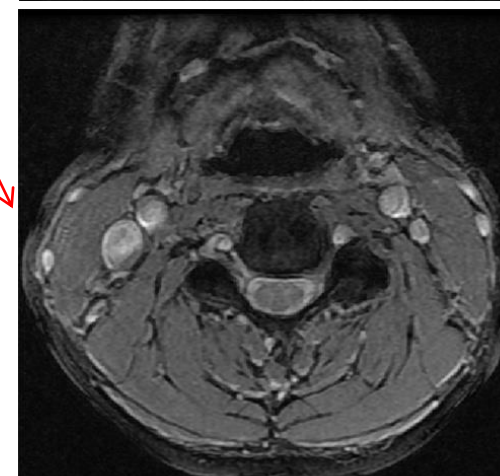
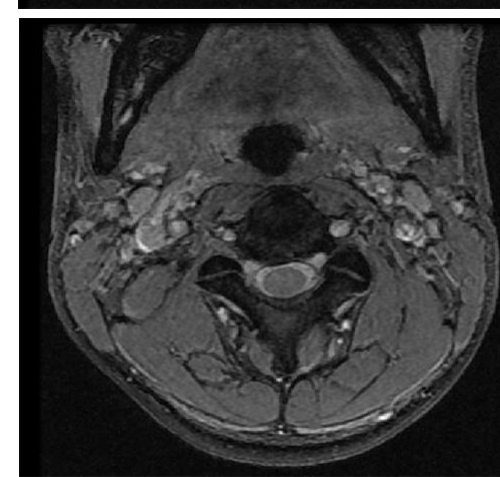
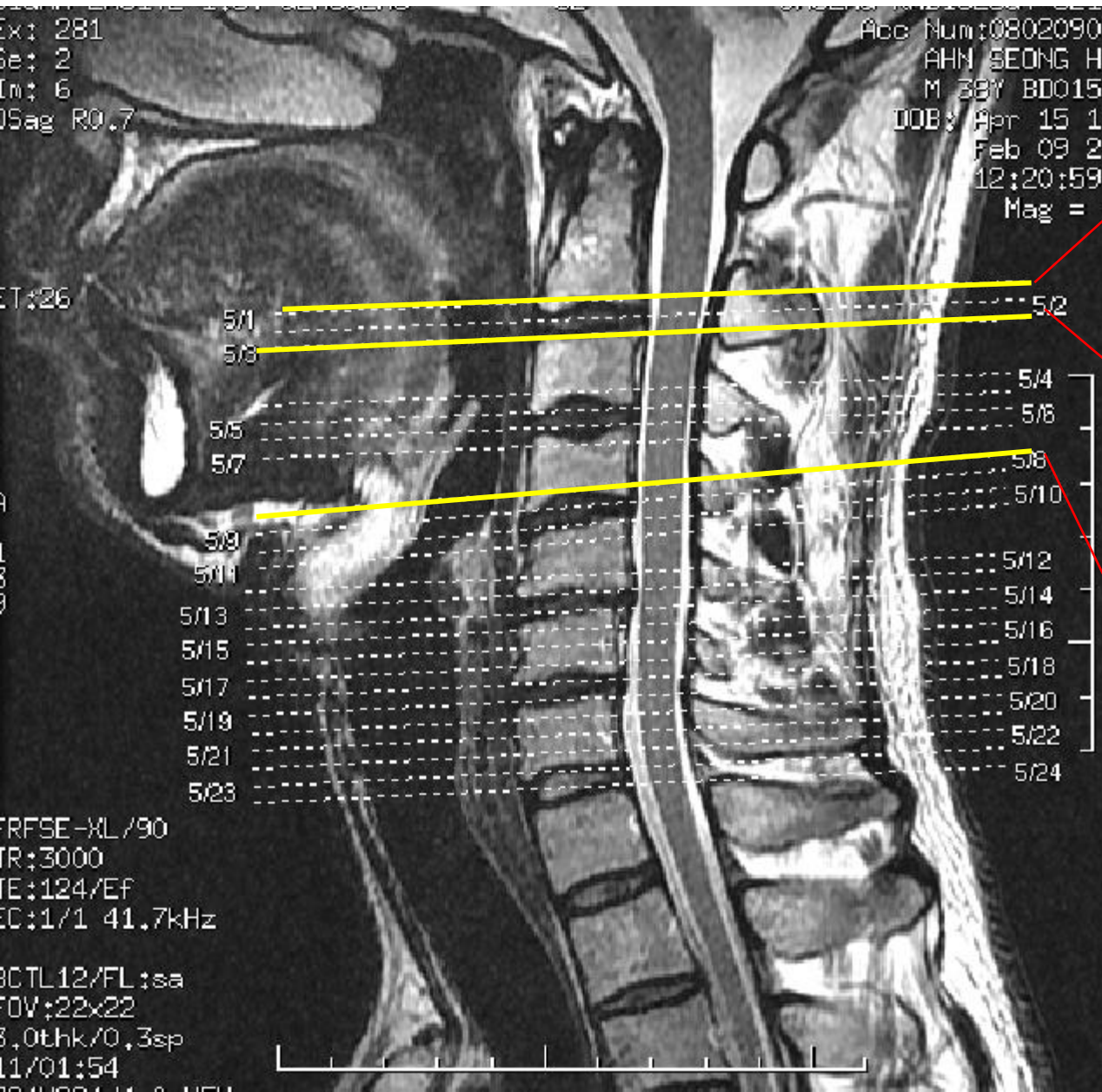
- Other name of 3DP
 - Rapid Prototyping (RP)
 - Layered Manufacturing
 - Rapid Prototyping and Manufacturing (RP&M)
 - Solid Freeform Fabrication (SFF)
 - **Additive Manufacturing (AD)**

- Group of related technologies that are used to fabricate **physical objects** directly from **3D CAD data**

- Add and bond materials in layers to form 3D objects

- Offers advantages compared to subtractive fabrication methods

Magnetic Resonance Imaging

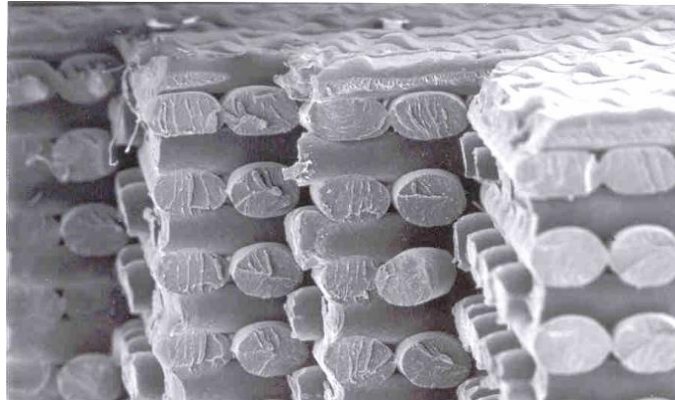


Advantages of 3D Printing

- No need to define a blank geometry
- No need to define set-ups and material handling
- No need to consider jigs, fixtures, and clamping
- No need to design mold and die

Issues in 3D Printed parts

- **Layered deposition** inherently creates interfaces between layers

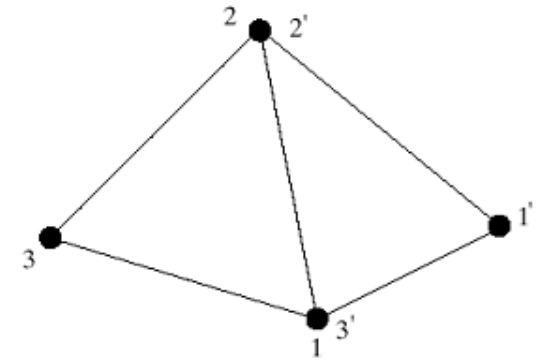
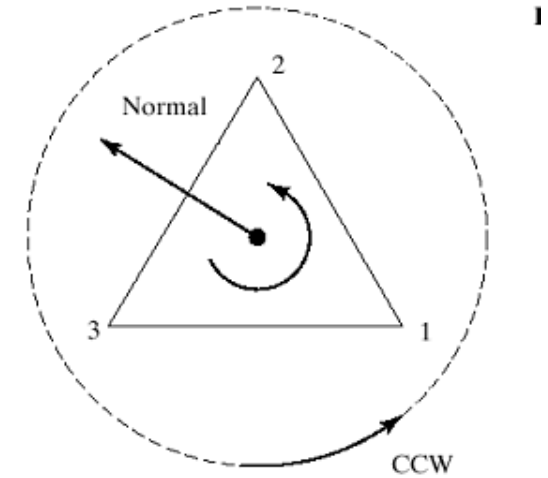


- **Functional** properties are not as good as bulk
 - Structural
 - Optical
 - Surface Roughness
 - Electrical
 - Thermal
 - Color
 -



STL File

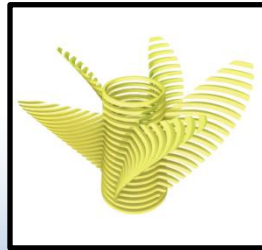
- Developed for **Streo**Lithography
- De facto standard for RP data
- Most CAD systems support STL format



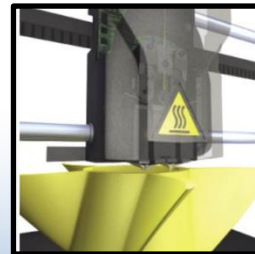
Classification of 3DP



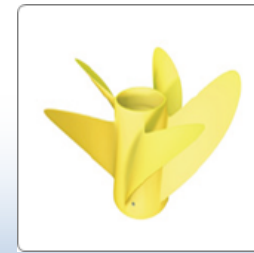
3D scanning/modeling



2D-sliced data



Forming thin layers



Additive manufacturing
(Layer-by-layer manner)

Considering potential for industrial applications, six types of 3DP technologies have been selected (excluding sheet lamination)

PP
(Photo-Polymerization)

디지털 스캔미러 (Digital Scanning Mirror) 레이저 광원 (Laser)
Z축 하강(조형판) Z Moving Table
모델(단면) Build(Section) 지지대 Support
조형판(Plate)

Stereolithography
Carima, 3D Systems

ME
(Material extrusion)

Support material filament, Build material filament, Filament feed, Extrusion nozzle, Filament support, Support material coil, Build material coil

Fused Deposition Modeling
Rokit, Stratasys

BJ
(Binder Jetting)

Liquid adhesive supply, Powder bed, Powder bed nozzle, Powder bed supply, Powder bed position, Model powder, Model chamber

3DP
3D Systems

MD
(Material Dispensing)

Jetting Head, X axis, Y axis, UV Light, Fulcure M (Model Material), Fulcure S (Support Material), Build Tray, Z axis

Polyjet
Stratasys

PBF
(Powder Bed Fusion)

Auto refill powder, Scanning mirror, Optical lens, CO₂ Laser, Powder bed, Z moving Building Platform

Selective Laser Sintering
EOS

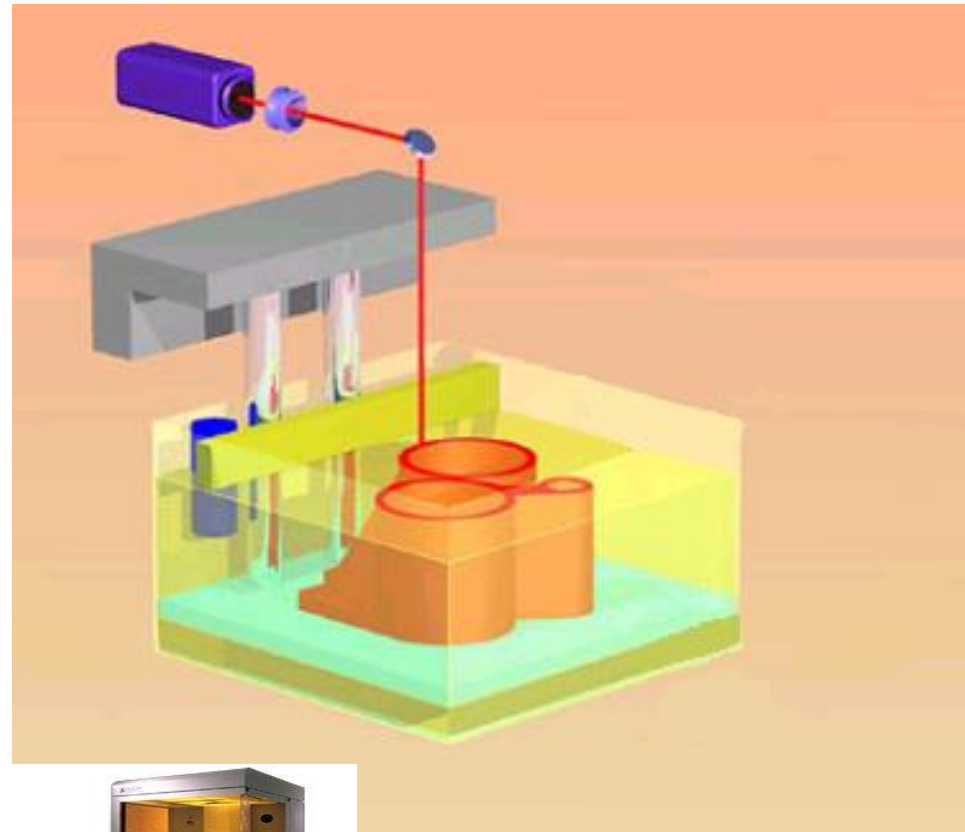
DED
(Direct Energy Deposition)

Process control system, Powder layer, Pre-deposit or seed material powder, Powder layer substrate, Molten metal drop guide, Direction of part motion

Direct Metal Tooling,
Insstek, Optomec

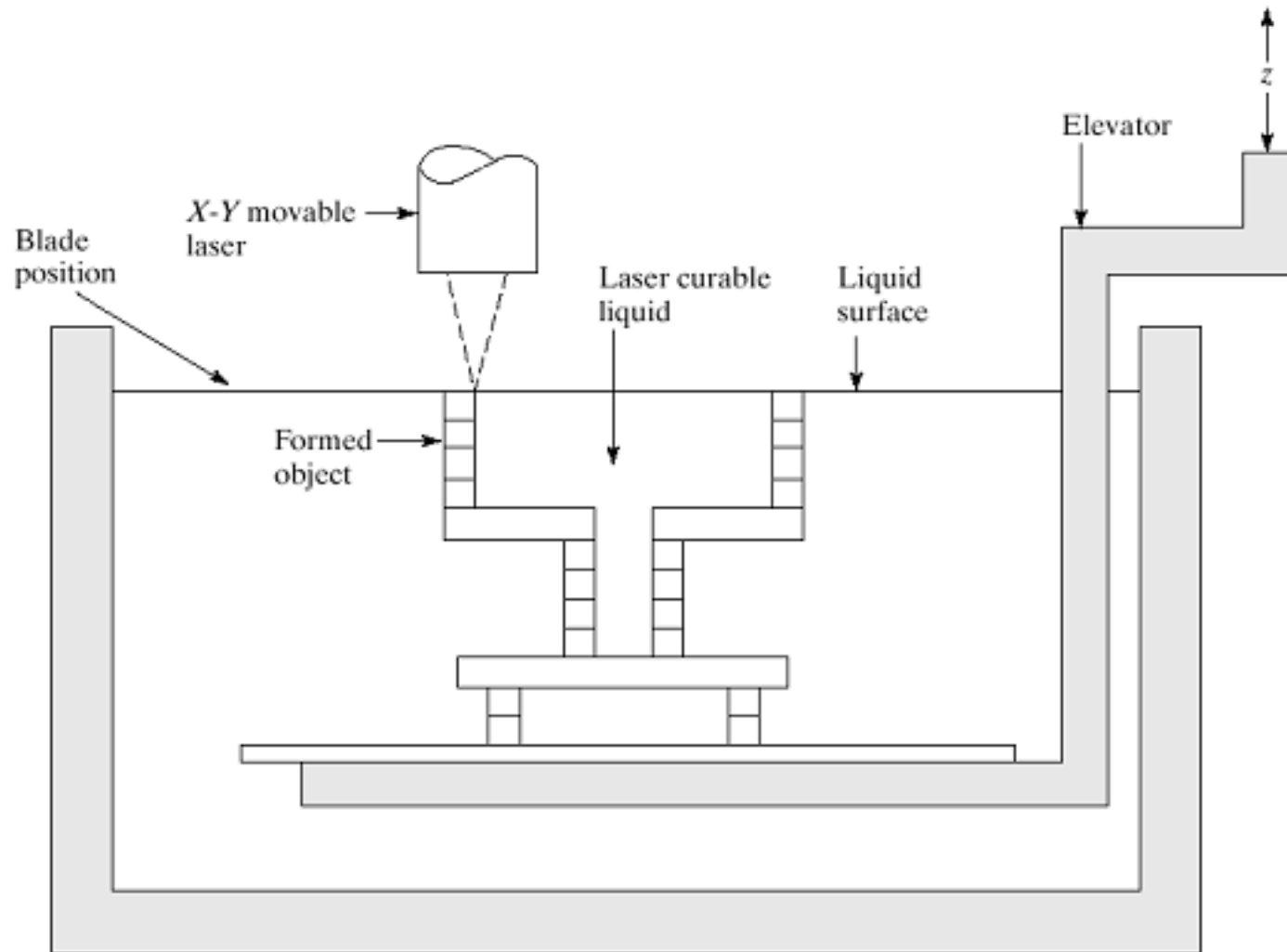
1. Stereo Lithography Apparatus (SLA) (1)

- Developed by 3D Systems, Inc.
- Laser beam will scan the surface following the contours of the slice



SLA-3500

1. Stereo Lithography Apparatus (SLA)

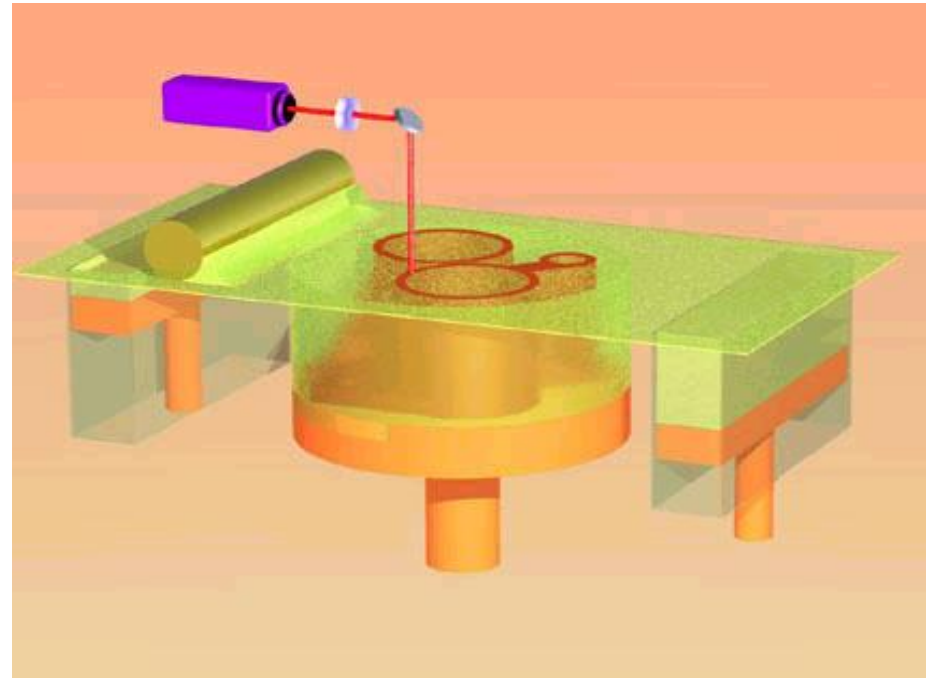


Stereo Lithography Apparatus (SLA)

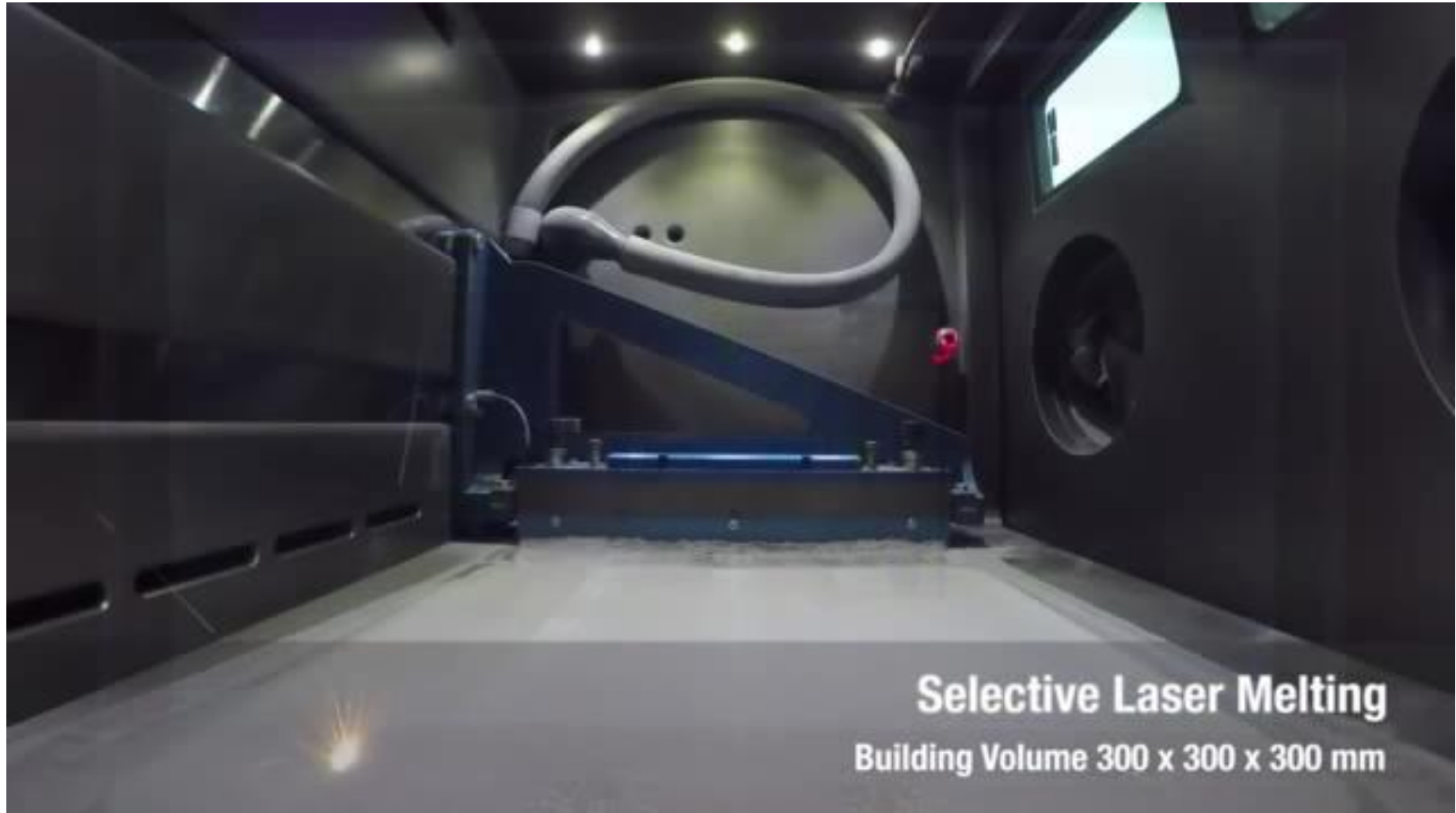


2. Selective Laser Sintering (SLS)

- Developed by The University of Texas at Austin
- Powders are spread over a platform by a roller
- A laser sinters selected areas causing the particles to melt and then solidify



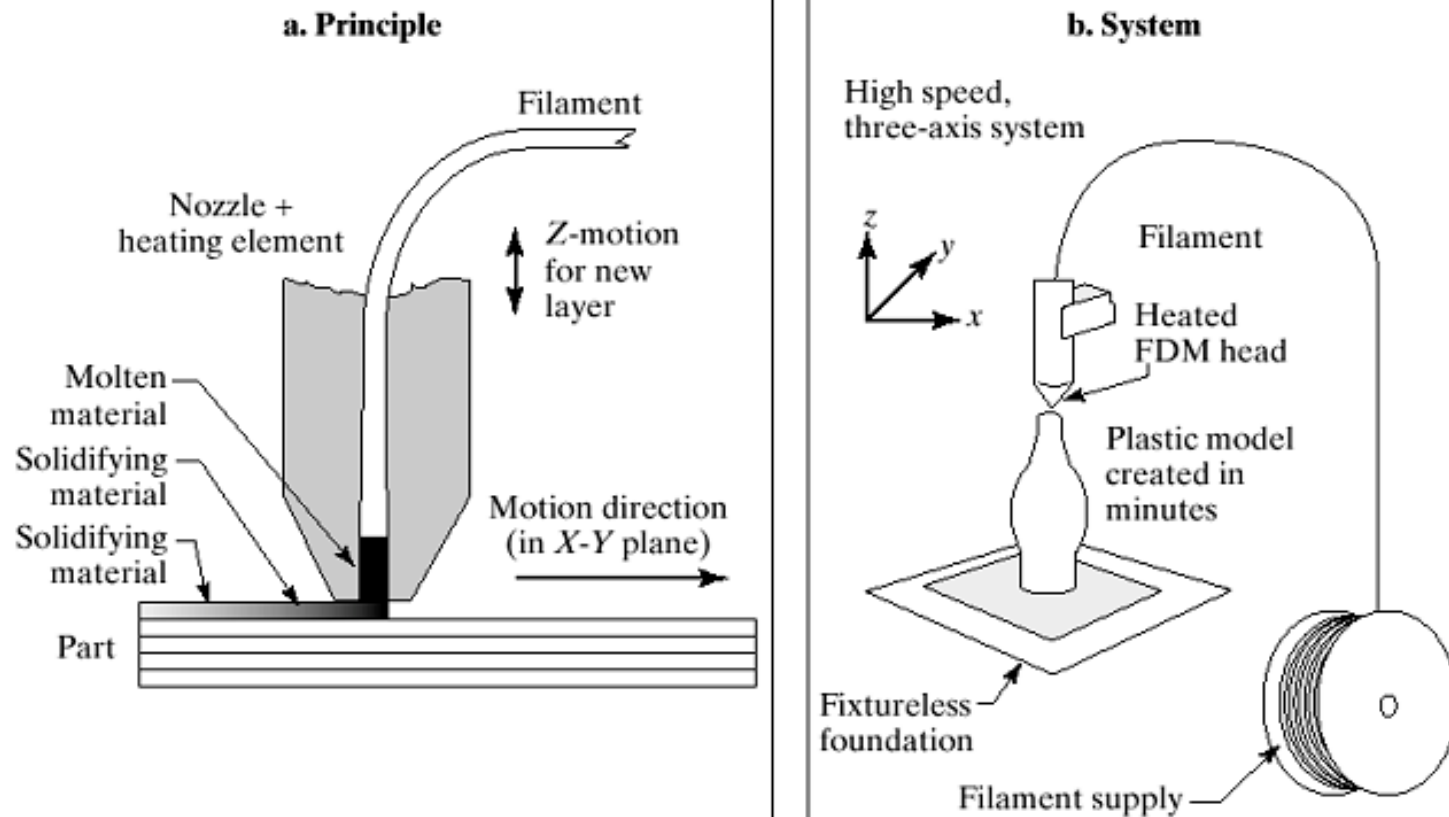
Metal 3D Printer



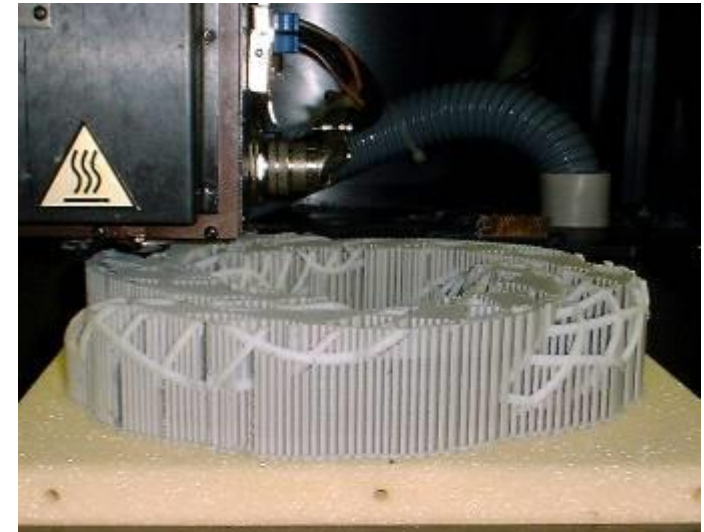
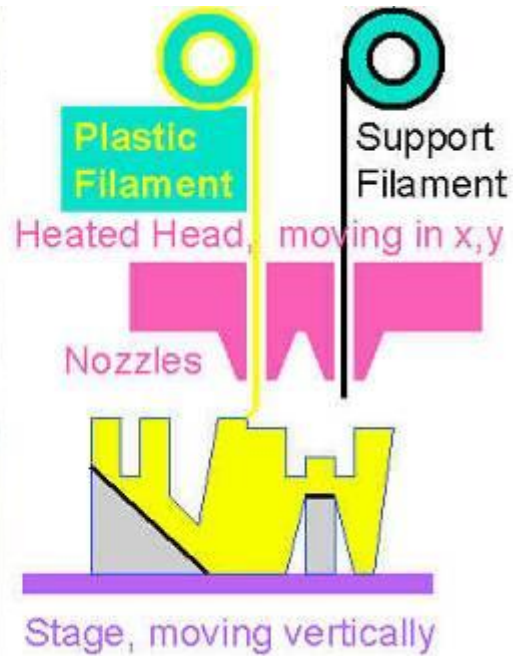
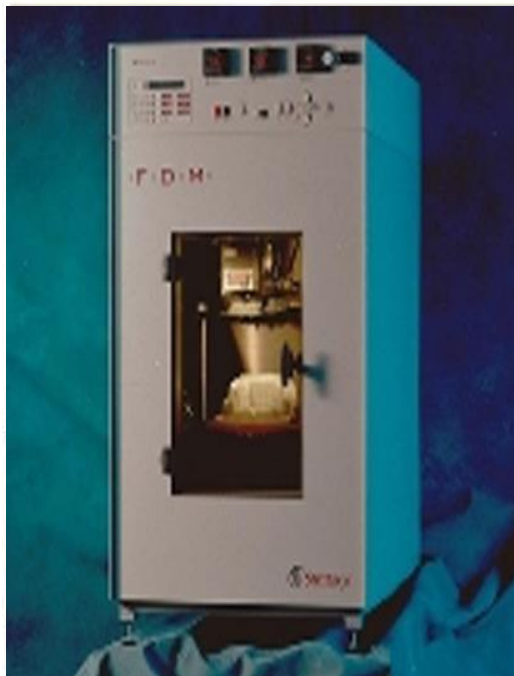
<https://www.youtube.com/watch?v=m1ryVsmjZBY>

3. Fused Deposition Modeling (FDM)

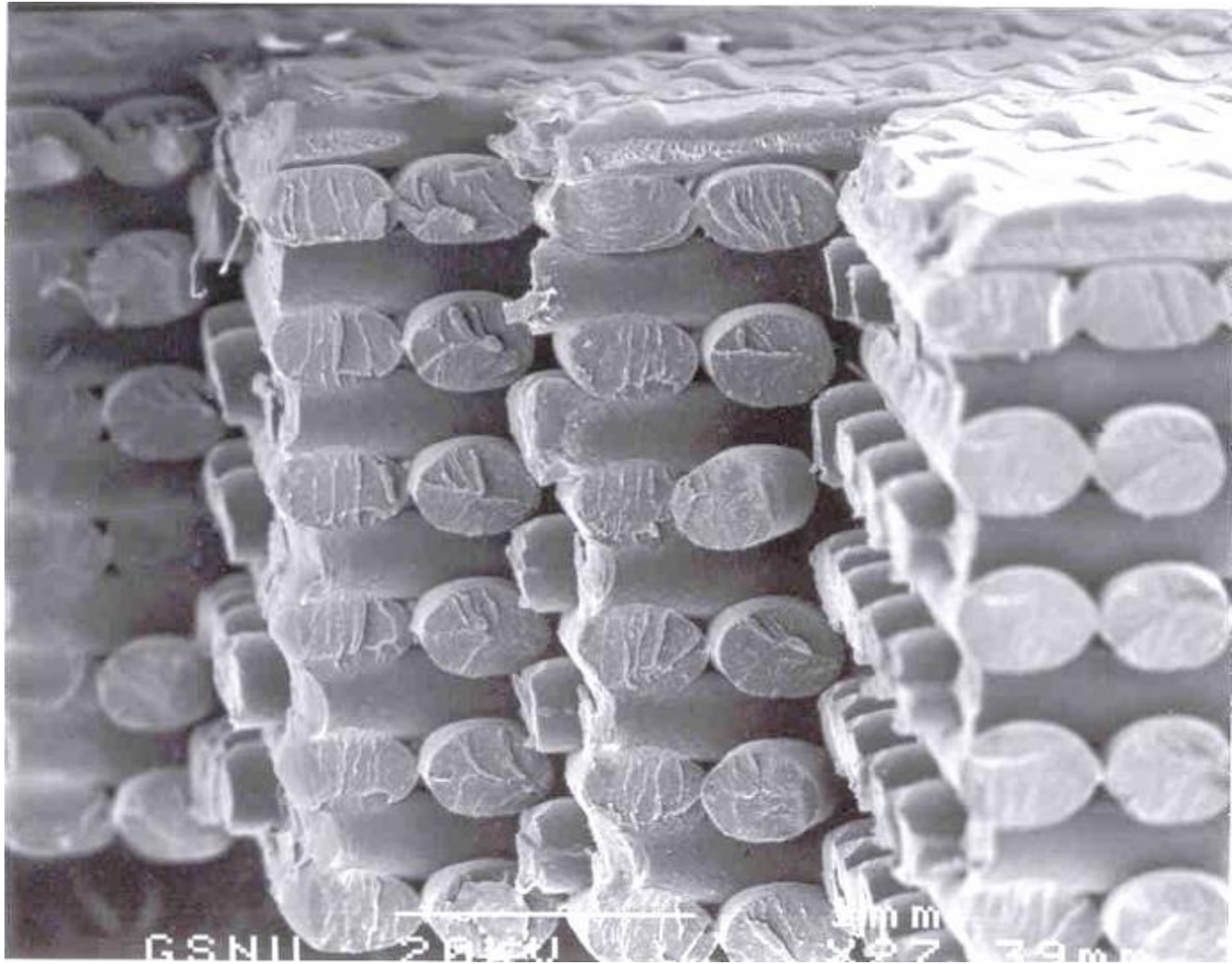
FDM



Fused Deposition Modeling (FDM)



Micro Structure of FDM



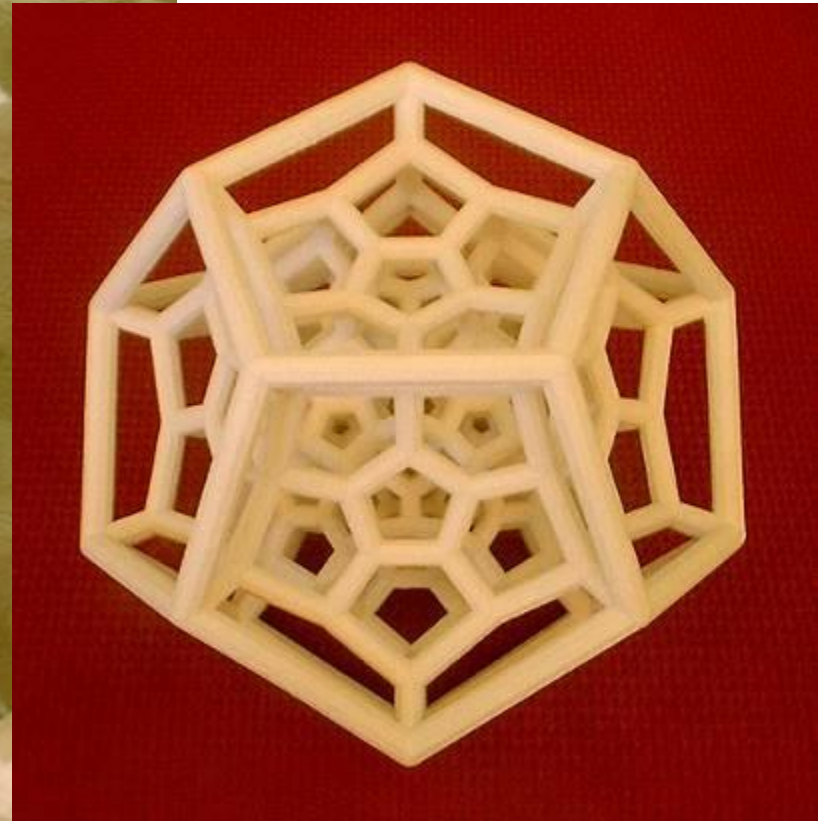
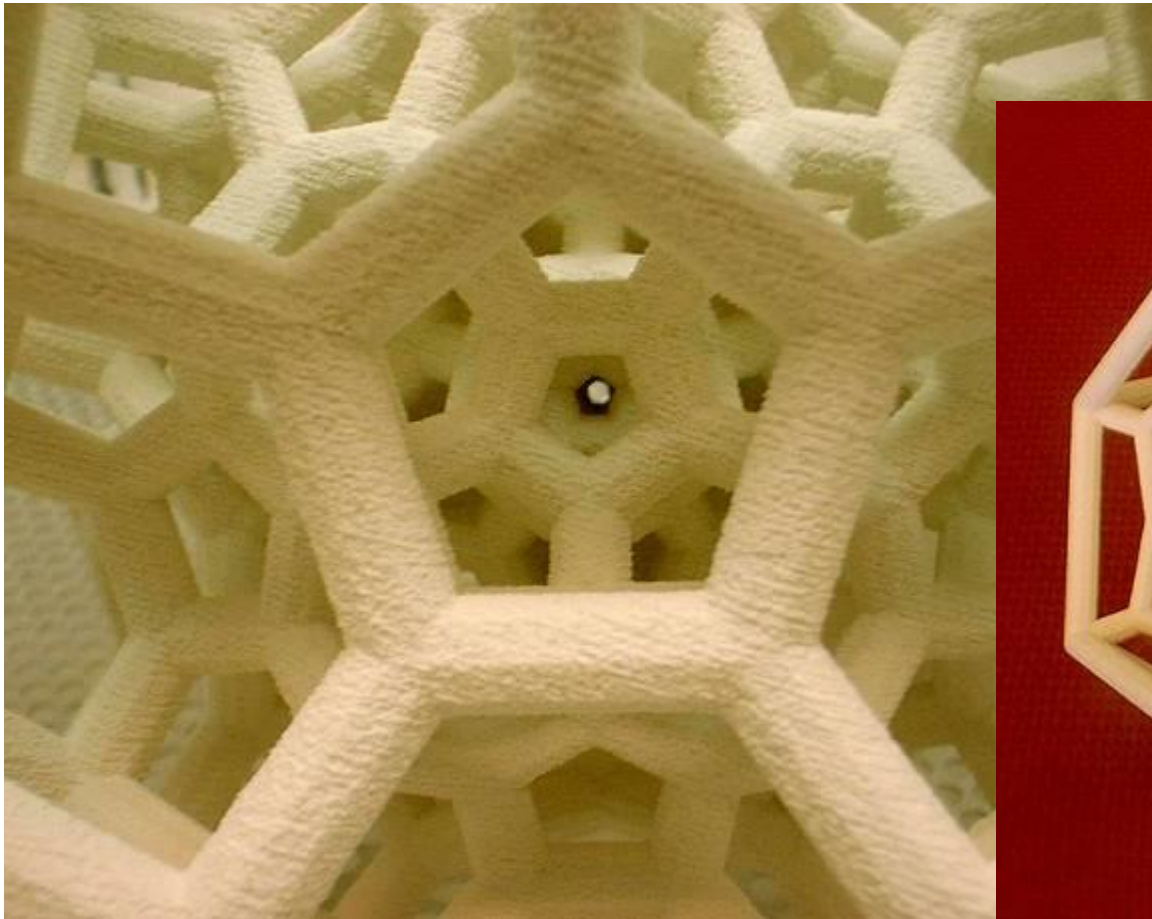
4. 3D Printer

- Developed at MIT
- Parts are built upon a platform situated in a bin full of powder material.



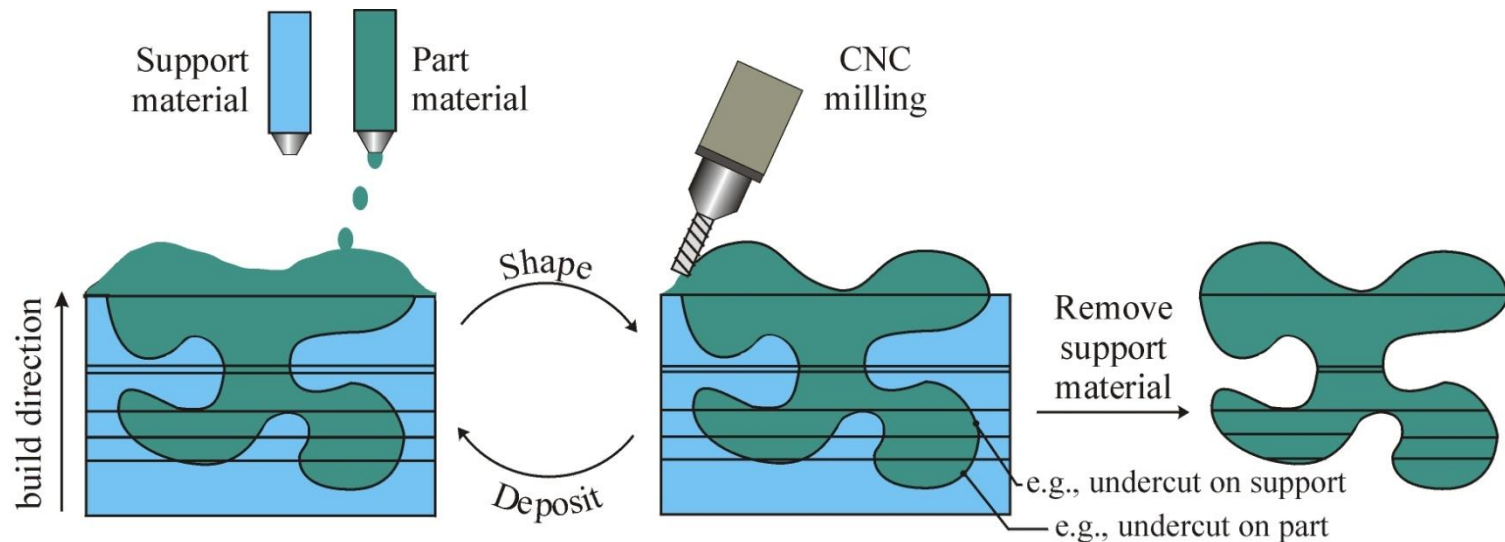
Gallery

- Z- corp (3D Printer)

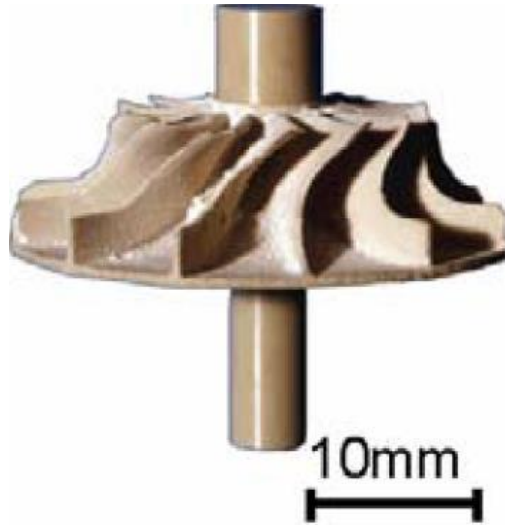


5. Shape Deposition Manufacturing (SDM)

- Developed by Stanford University/CMU
- Uses deposition and milling
- Provides good surface finish



Meso Structure of SDM Parts



Ceramic turbine

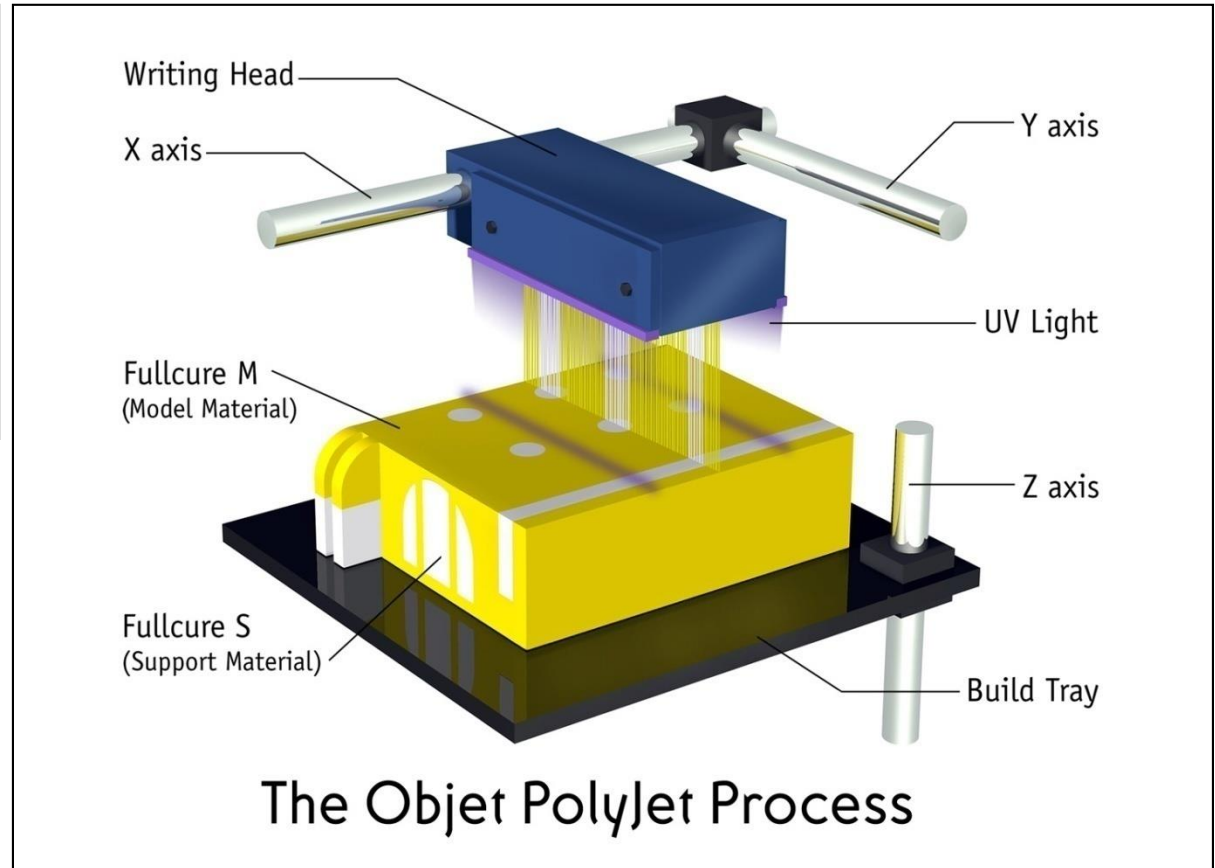
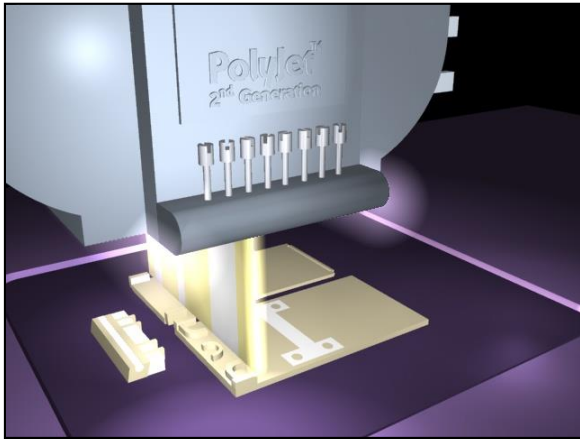


Miniature jet engine

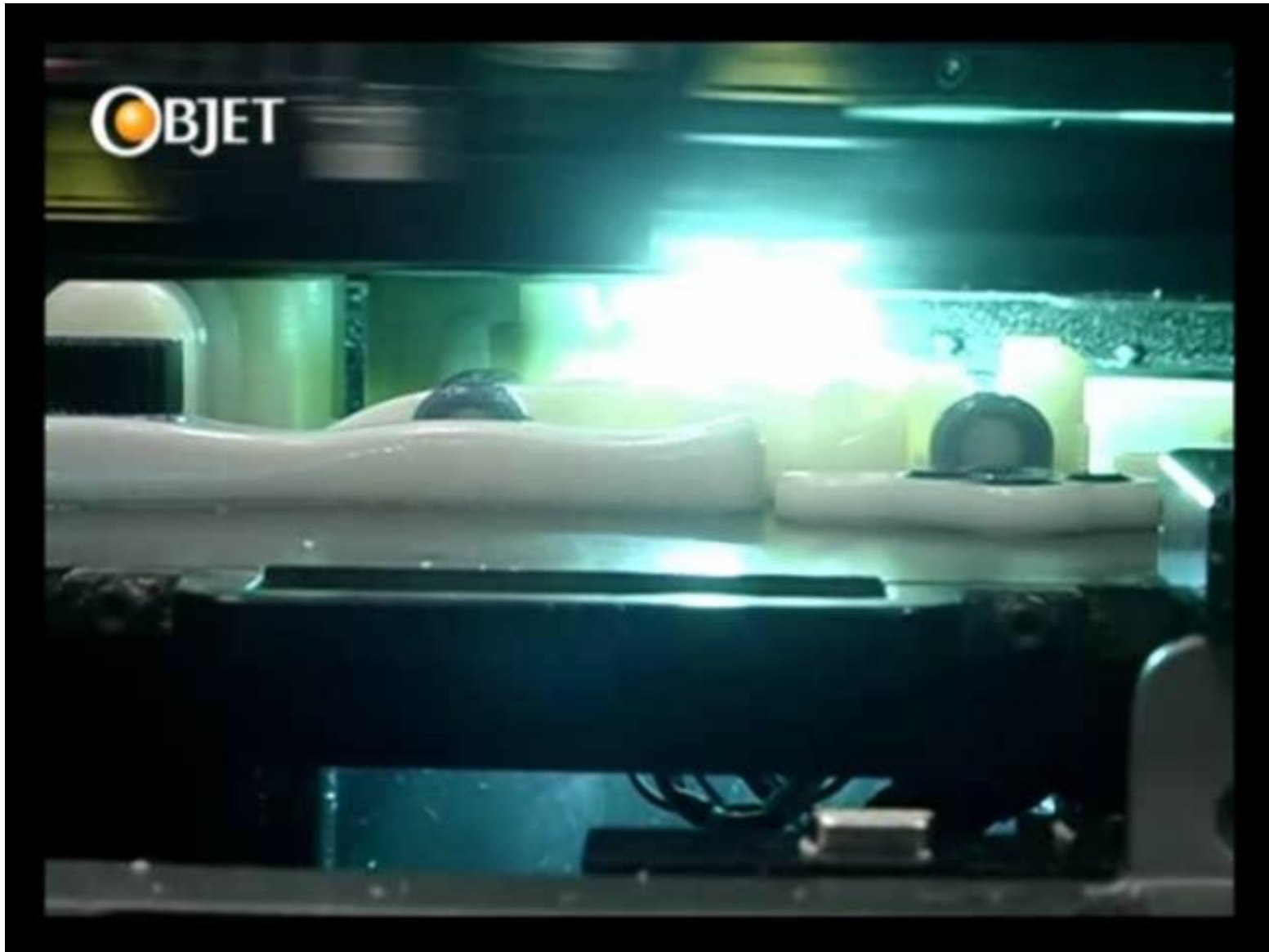


Silicon nitride parts fabricated using mold SDM process

6. Polymer Jetting (PolyJet)



Multi-Material 3D Printer



7. FIB-CVD: layered process

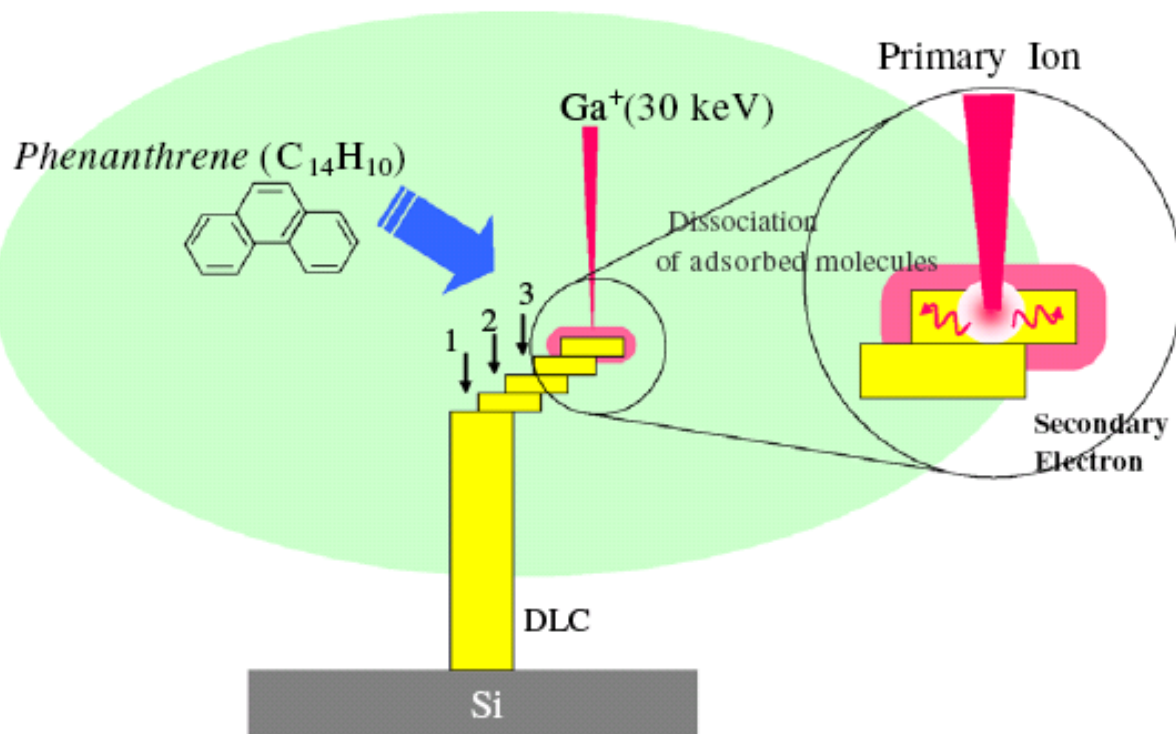
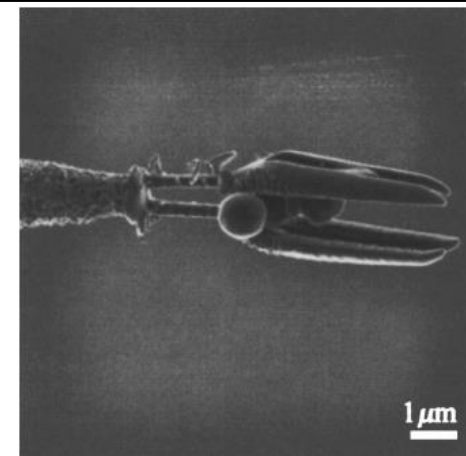


Fig. 1. Fabrication process for three-dimensional nanostructure by FIB-CVD.



R Kometani et al.
J Vac Sci Technol B 23 (2005) 298

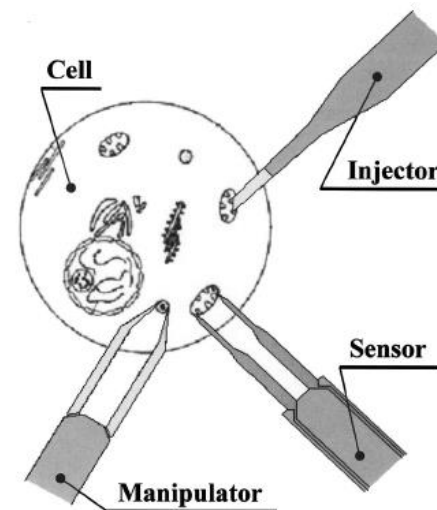
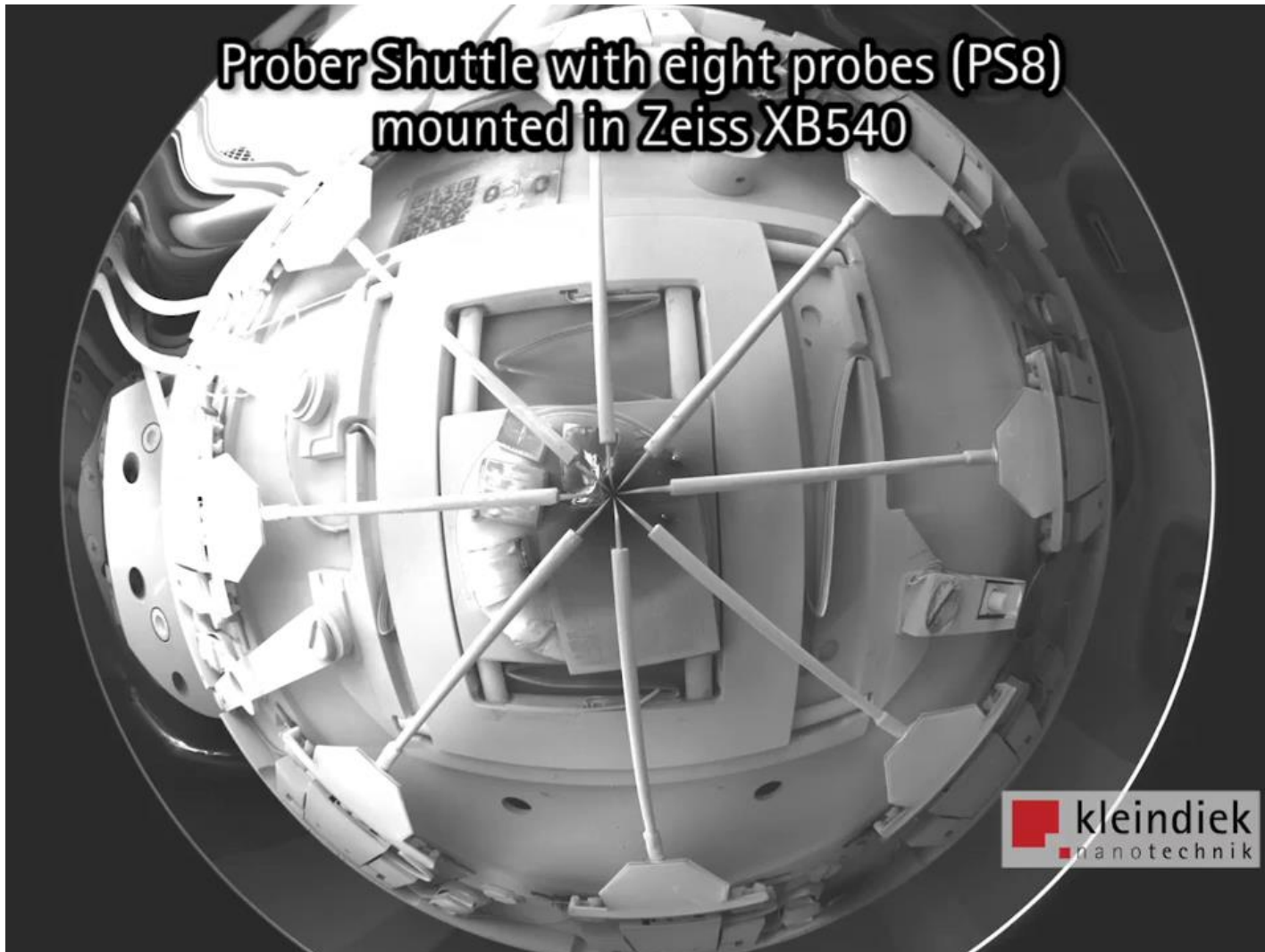
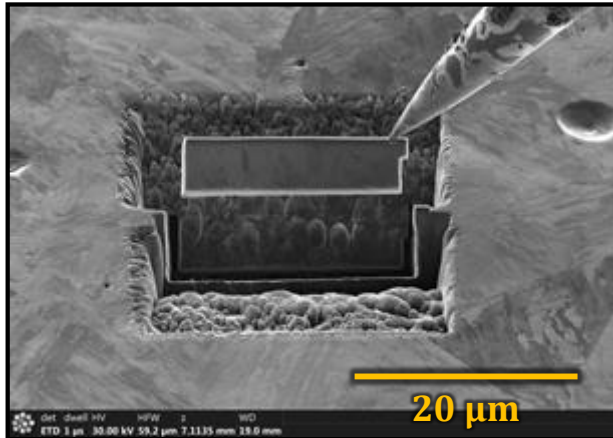


FIG. 1. Usage of bionanomaniipulator.

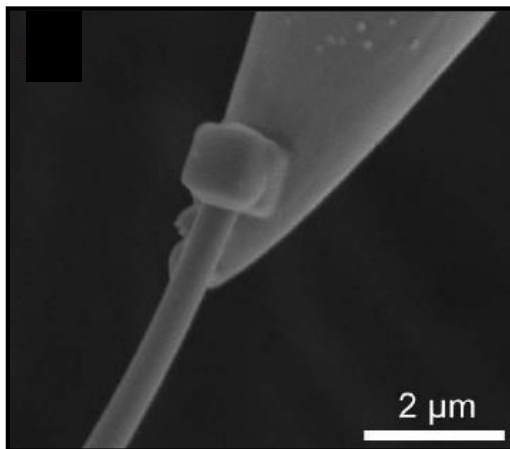
7. FIB-CVD: layered process



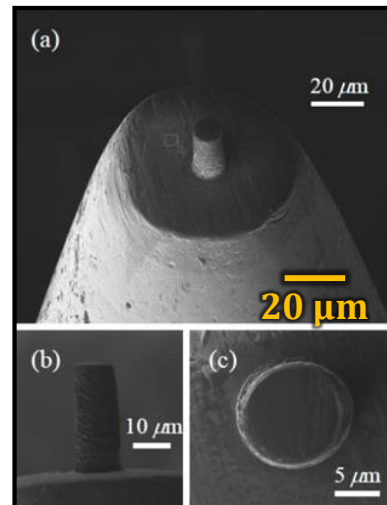
7. FIB-CVD: layered process



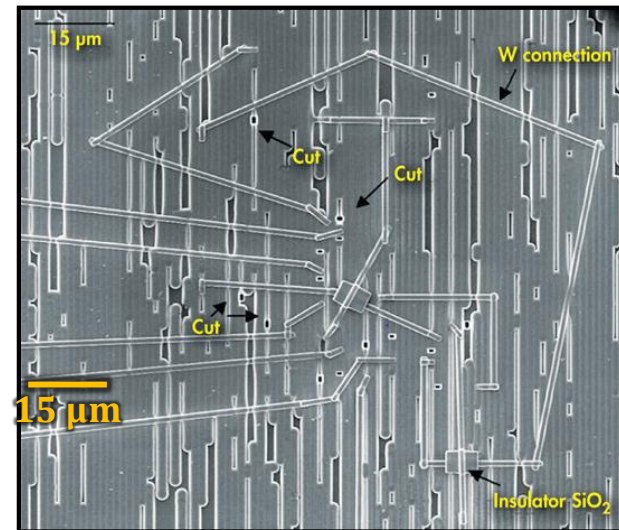
[TEM sample preparation]
(FEI corporation newsletter, 2015)



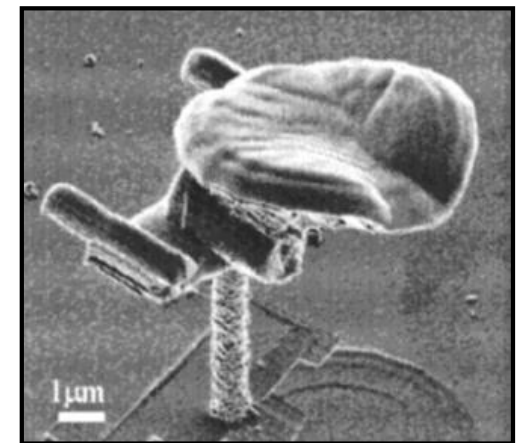
[fixation of NWs and tip by Pt deposition]
(Y.H. Kim et al., Applied Microscopy, 2015)



[Microelectrode Pt pillar]
(Dengji Guo et al., Procedia CIRP, 2016)



[Circuit repair]
(ElectronicDesign.com, 2014)



[microscale spaceship Enterprise]
(T. Hoshino et al., J VAC SCI TECHNOL B, 2003)

Conventional 3D printing Materials

Process	Materials
Stereolithography (SLA)	PMMA Styrene Methyl Methacrylate Copolymer
Fused Deposition Modeling (FDM)	ABS, ABS/PC PVC/PMMA, PES
Selective Laser Sintering (SLS)	PMMA, Aromatic Polyamide Metals
Laminated Object Manufacture (LOM)	Paper (Cellulose Based)
3D Printers	ABS, ABS/PC PVC/PMMA, PES, Elastomers
Solid Ground Curing (SGC)	PMMA Styrene Methyl Methacrylate Copolymer
FIB-CVD	Carbon, platinum, tungsten, silicon oxide

Computer-aided art – sculpture



Airplane

The image shows the cover of a NewScientist magazine. The cover has a dark blue background with a lighter blue horizontal band across the middle. The title 'NewScientist' is printed in white, bold, sans-serif font across the middle band. Below the band, the text 'First flight of 3D printed plane' is printed in a smaller white font.

NewScientist

First flight of 3D printed plane

Parts for aircraft



Hinges for the Airbus A320

conventional (background) and 3D printed (foreground)



The 3D printed jet engine



Parts of the 3D printed jet engine (GE)

Mold

▪ Rapid Tooling (RT)



Core and cavity sets produced by RapidTool[™]



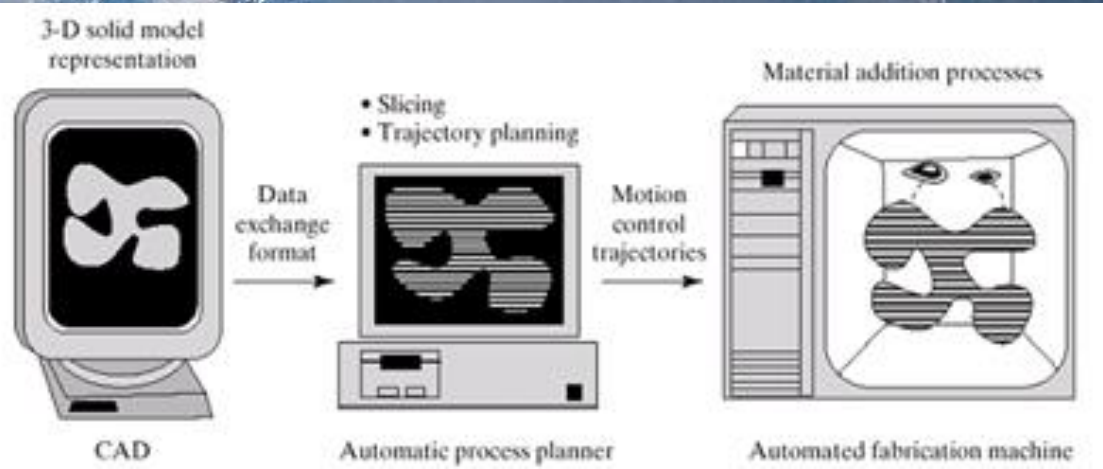
Smart Mold

DTM's RapidTool[™] process for rapid mold making

NASA: 3D Printing in Space

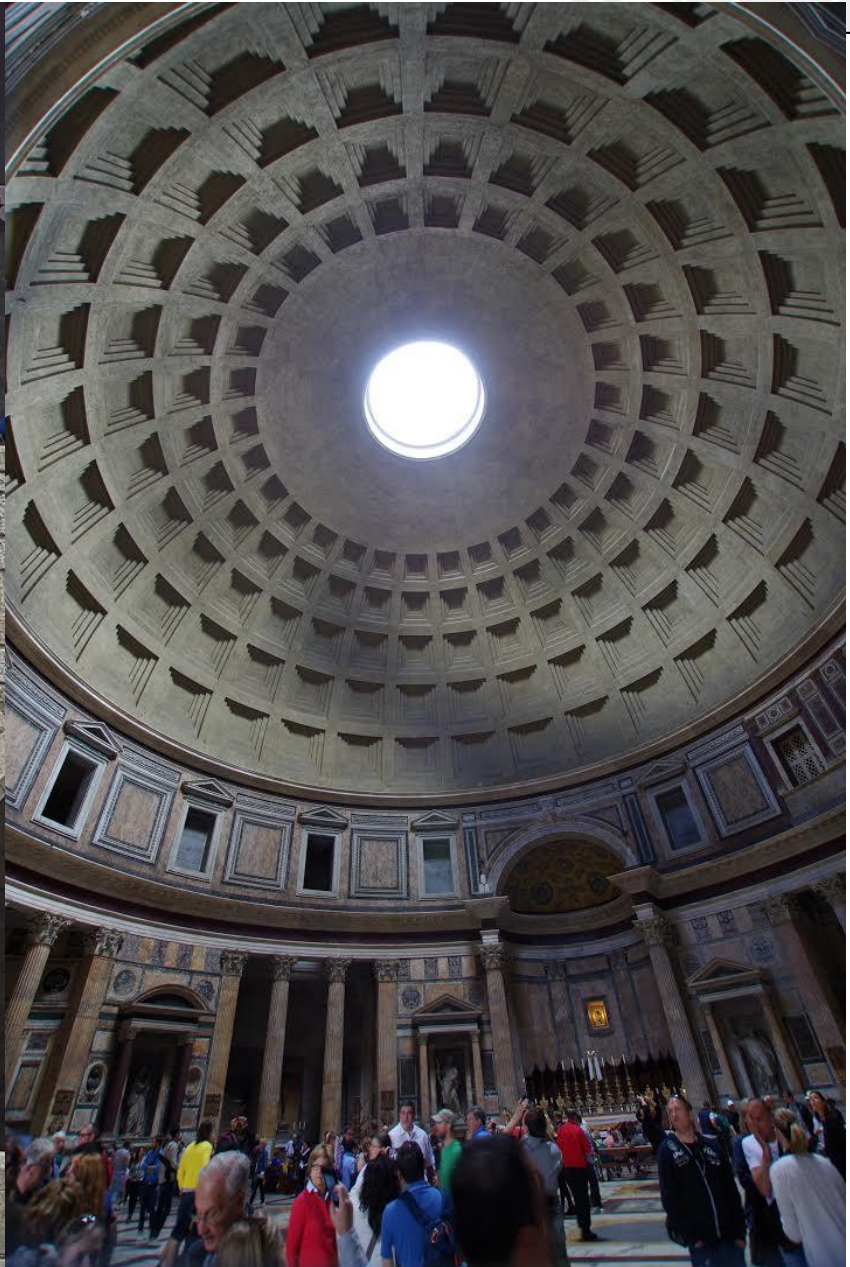


Emergency in 2008 summer



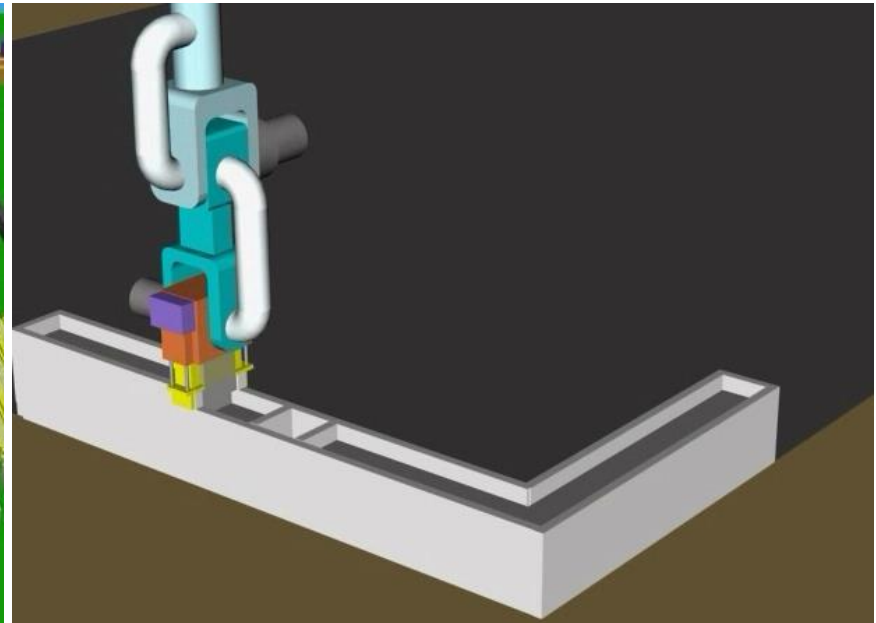
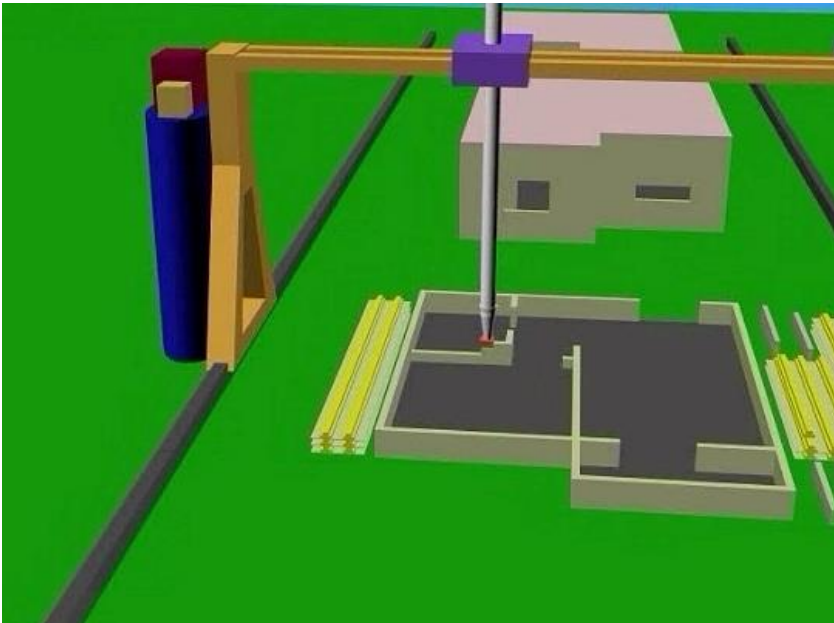
FDM1600 test at zero gravity
Johnson Space Center &
Marshall Space Flight Center
2000

Roman arch and dome



Building Construction by 3D Printer

- Architectures



A machine mounted on rails might be used to build multiple houses

Building Construction by 3D Printer



Building Construction by 3D Printer



Dubai Launches **World's First "Functional" 3D Printed** Office Building

Food

- Tony Cenicola/The New York Times
- 2013. 9. 22





FOODPRINTING

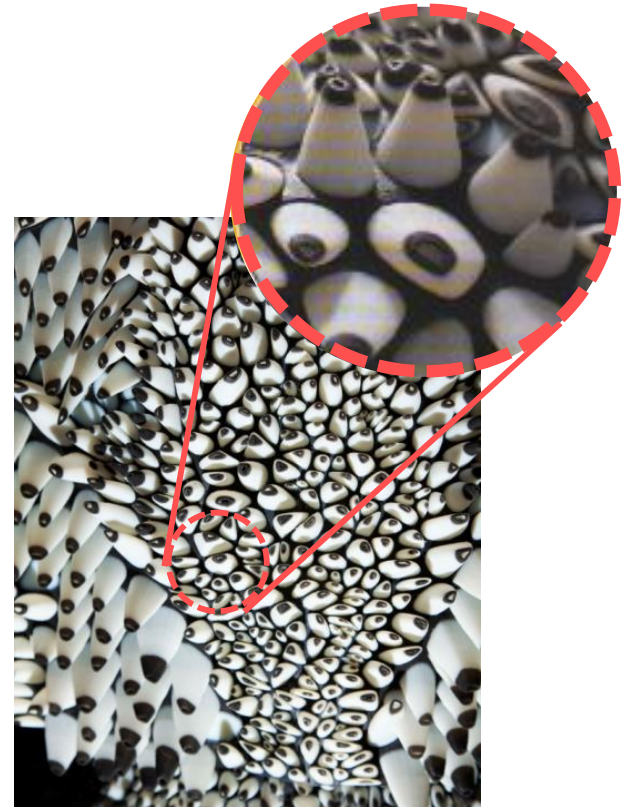
› **VARIOUS PRINTING METHODS**

3D printed prosthetic

- Design of the piece are fit to the individual



Fashion (Nari Oxman)





Car (Urbee)

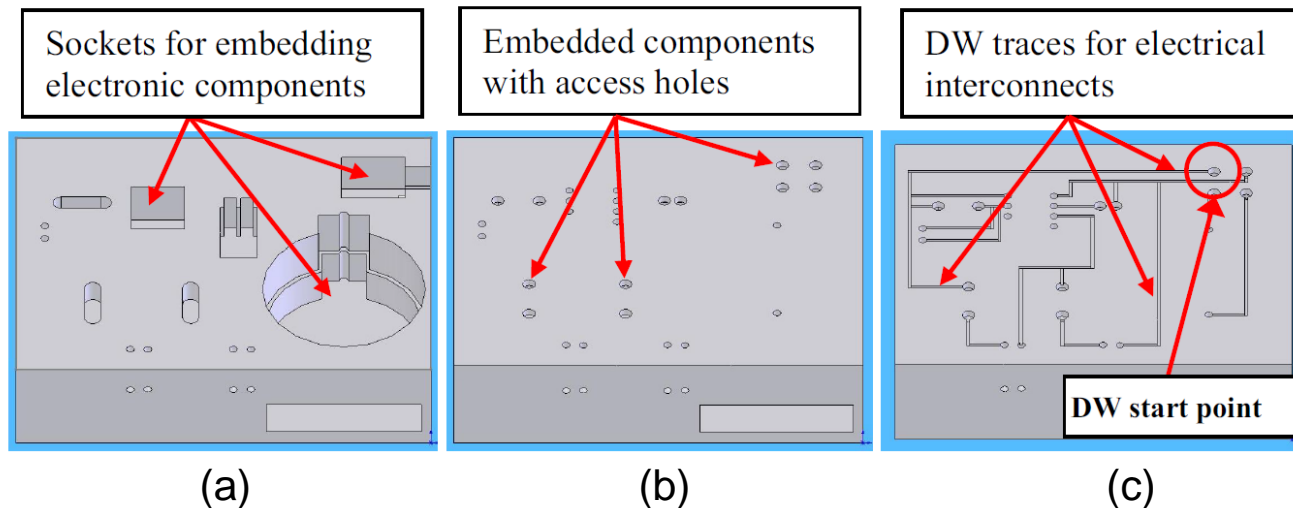


Local Motors

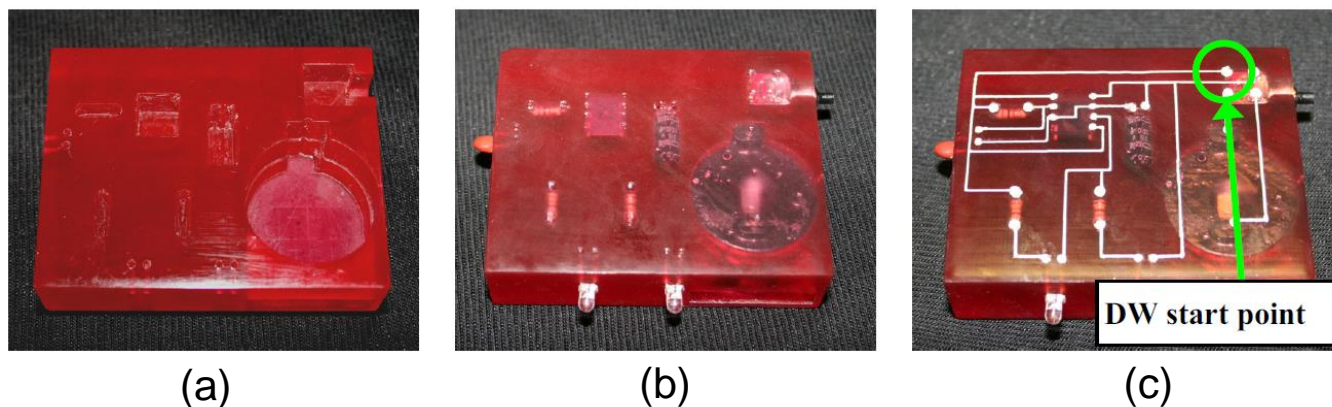


<https://www.youtube.com/watch?v=daioWlkH7ZI>

3D printing for Electronic System



(a) SL part with sockets for embedding electronic components, (b) Embedded components with access holes for DW, (c) DW traces for electrical interconnects.

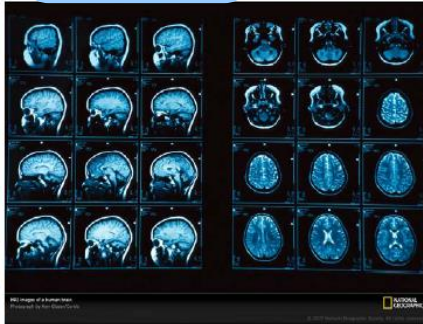


(a) SL part with sockets; (b) embedded components; (c) DW interconnects.

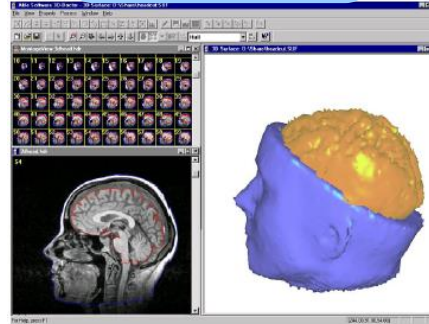
Biomedical

- 3D model creation process

3D Digital Image



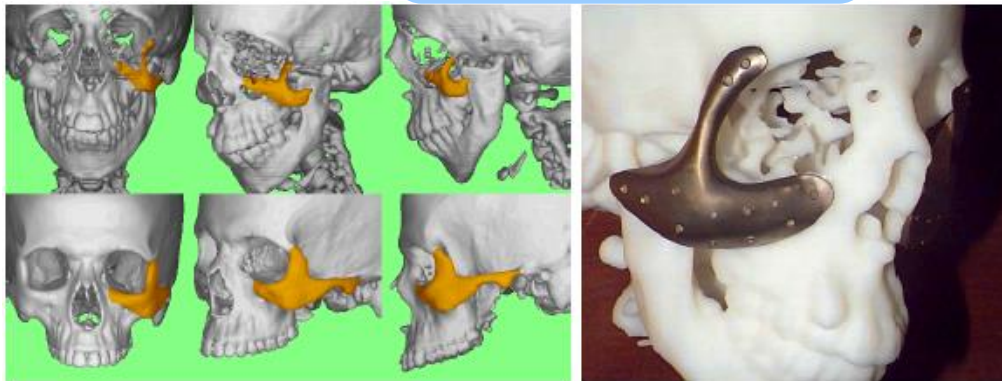
Data transfer process



Evaluation of Design

:Using CAD Program

3D Printing Medical model validation



3D Printing Medical model production

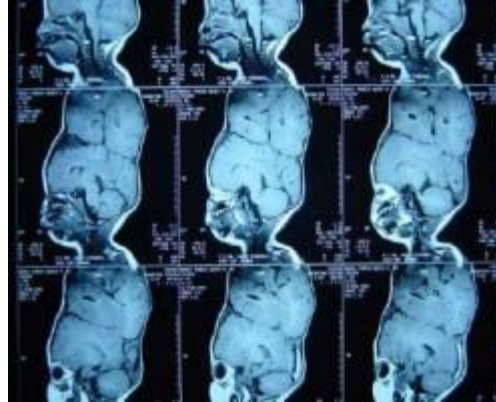


Medical simulation and operation

- Medical Domain



Before surgery



CT Scan



3D Printed part



After surgery



Virtual surgery

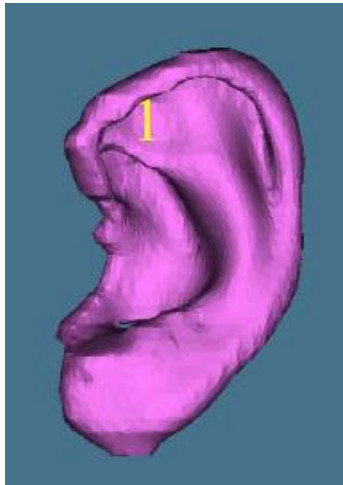


Tissue Engineering

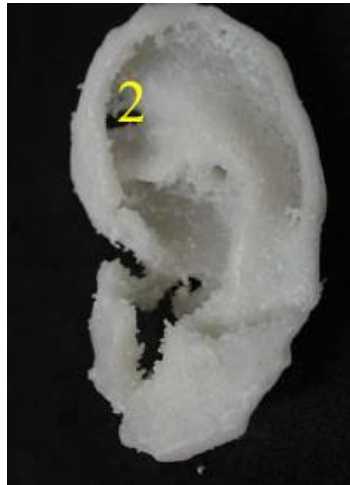
Vacanti, et al



Yan, et al



CAD modeling

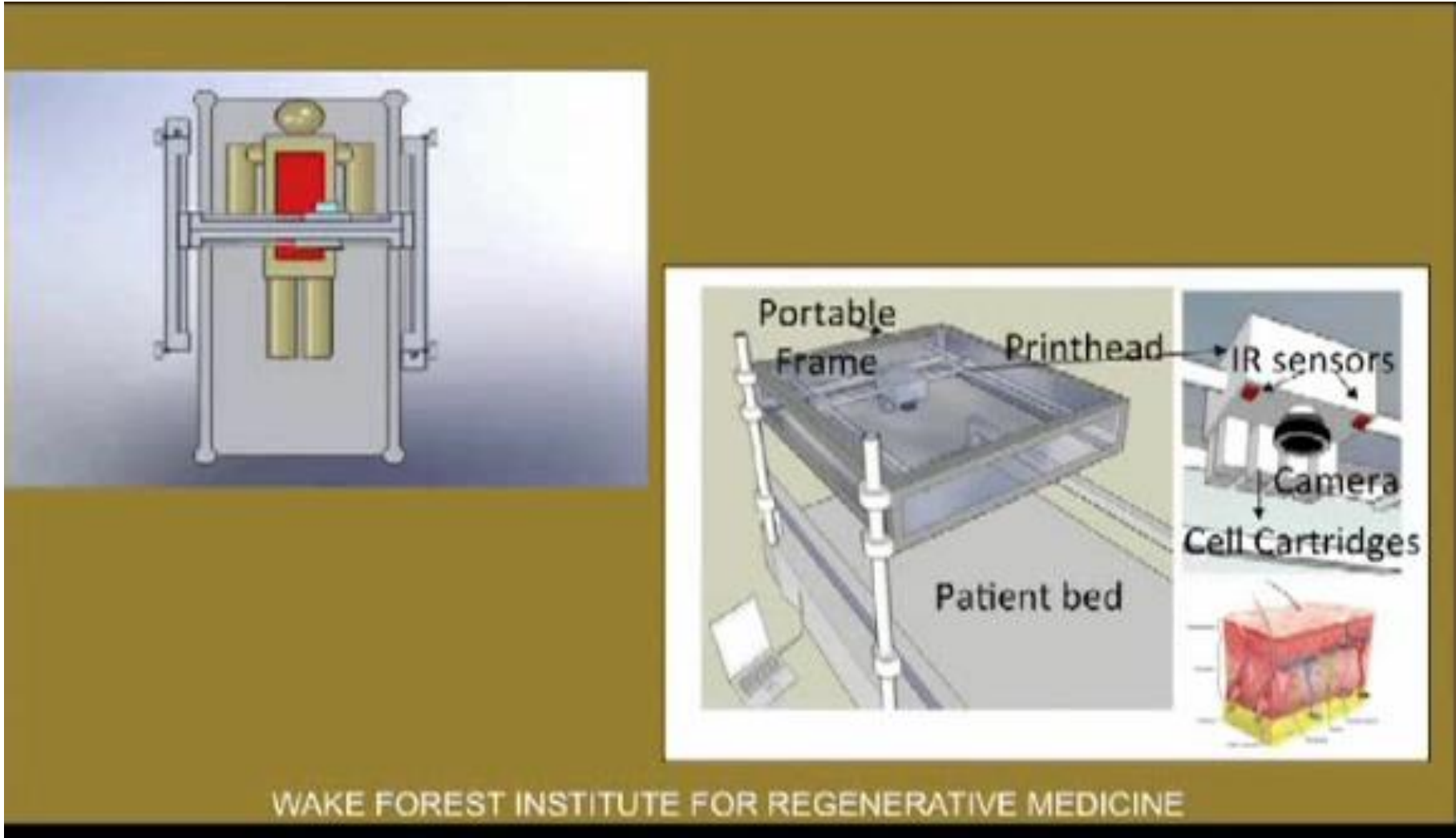


3D Printing part

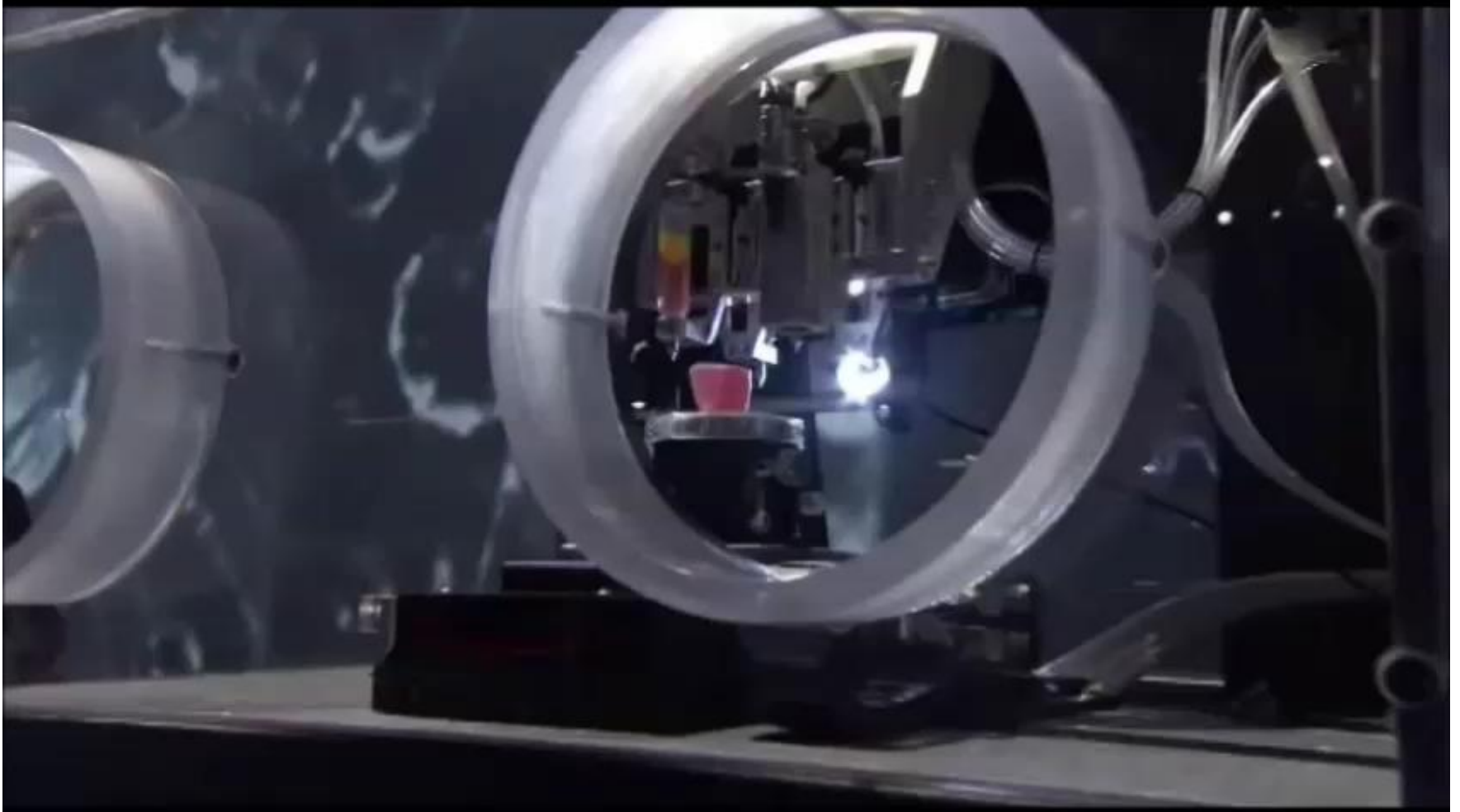


Rehabilitated ear

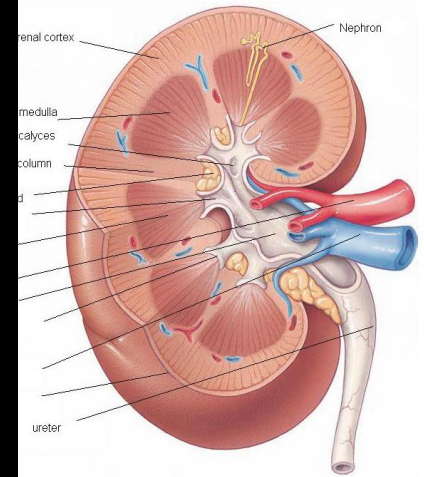
Skin Repairable 3D Printing



Artificial kidney



<https://www.youtube.com/watch?v=9RMx31GnNXY>



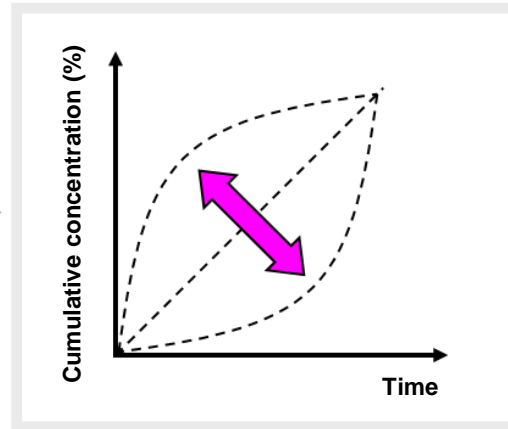
WAKE FOREST INSTITUTE FOR REGENERATIVE MEDICINE

TED talk capture, movie

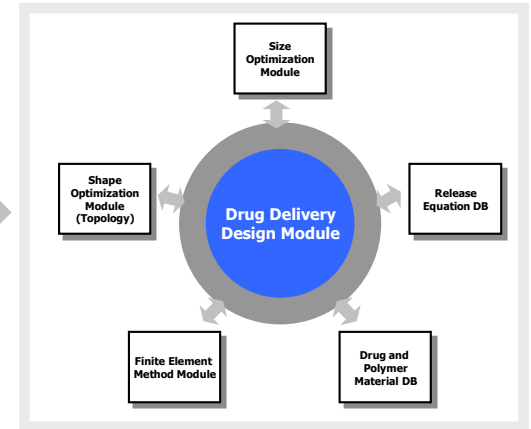
Drug Delivery System



Implant to patient



Prescription by doctor



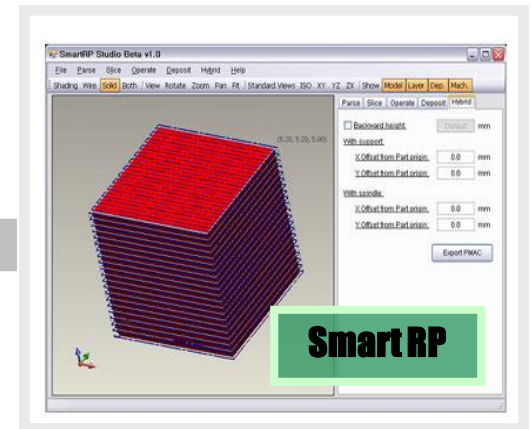
Drug Delivery Design System



Customized DDS



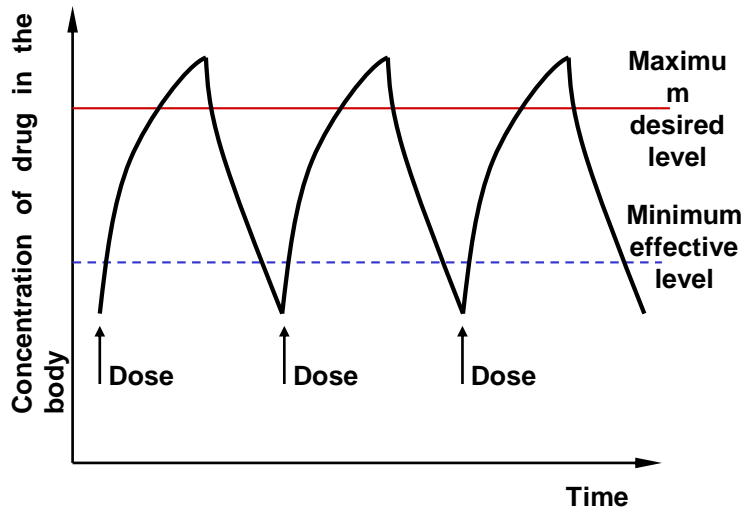
Drug delivery system fabrication



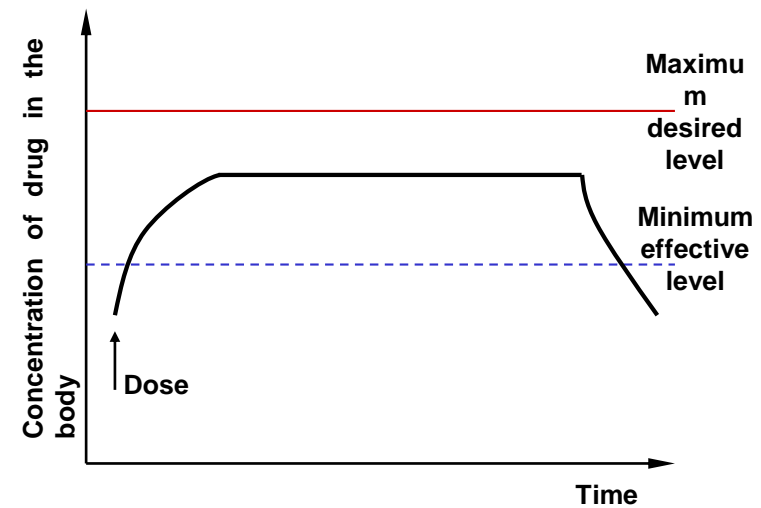
Process planning

Drug Delivery System

- Lower doses (delivered at intended sites)
- Lower side effects for highly potent drugs
- Replacing multiple injection/oral dosing
- Improving patients' quality of life



Conventional drug delivery

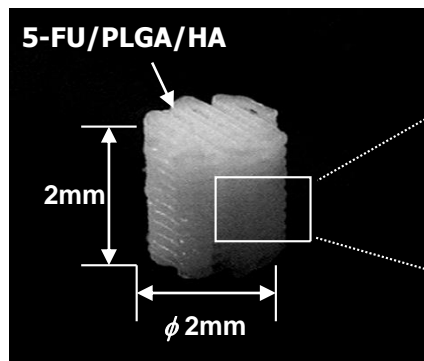


Controlled drug delivery

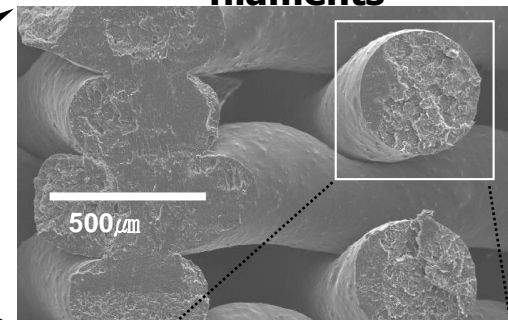
Functional Drug Delivery System

- Fabricated DDS and cross section of filament

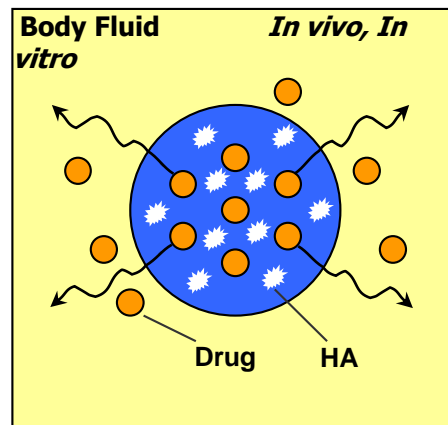
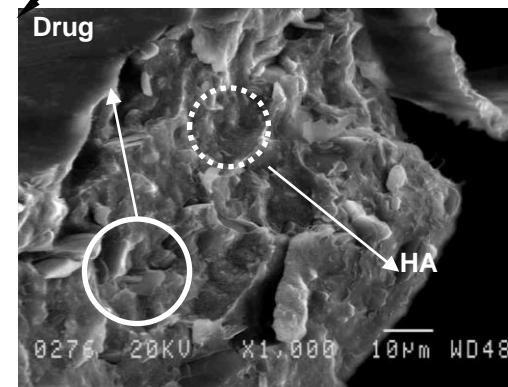
Fabricated Scaffold DDS



Magnified view of DDS filaments



Cross-section of DDS filament



Diffusion of drug

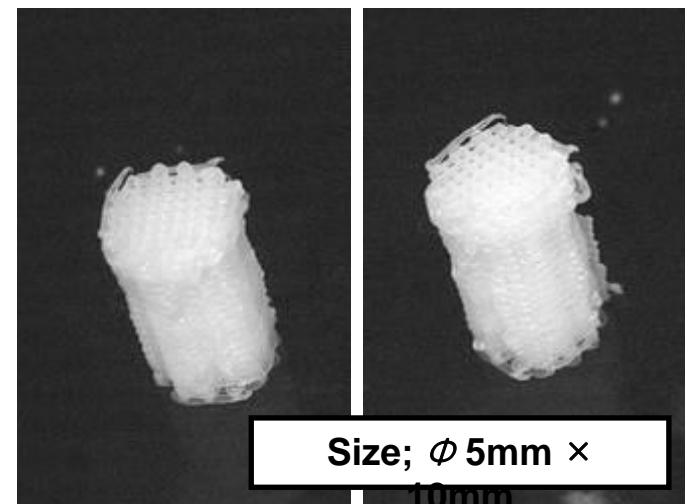
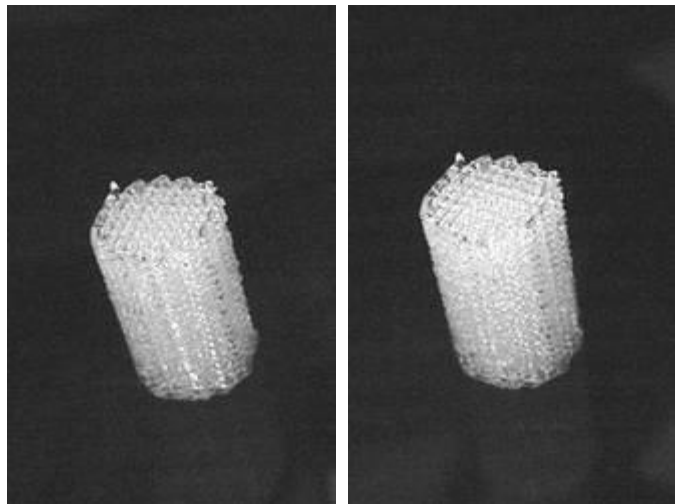
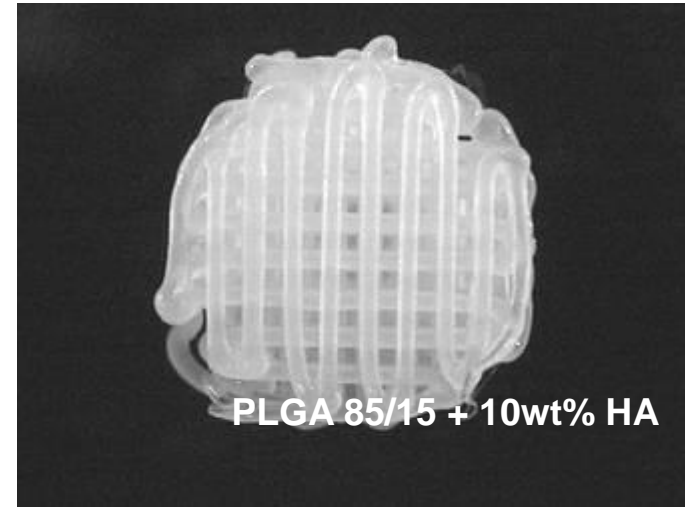
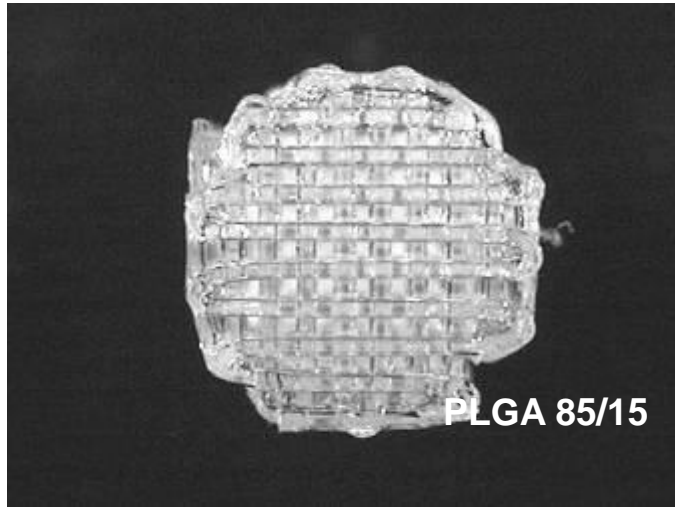
Composition of DDS material

Chu, Won Shik, et al. "Fabrication of bio-composite drug delivery system using 3D printing technology." Key Engineering Materials. Vol. 342. 2007.

Chu, Won-Shik, et al. "Fabrication of composite drug delivery system using nano composite deposition system and in vivo characterization." International Journal of Precision Engineering and Manufacturing 9.2 (2008): 81-83.

Scaffold for Bone Growth

Bio-degradable polymer



Evaluation *in vivo*

- Drug release test *in vivo*
 - Implantation and collection of DDS in the back of rat



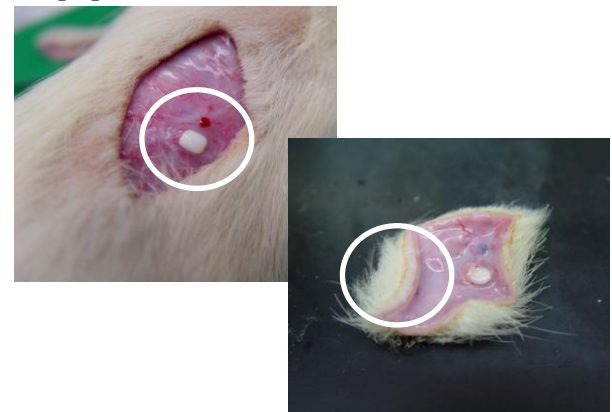
(a) Anesthetize mouse



(b) Insert the scaffold



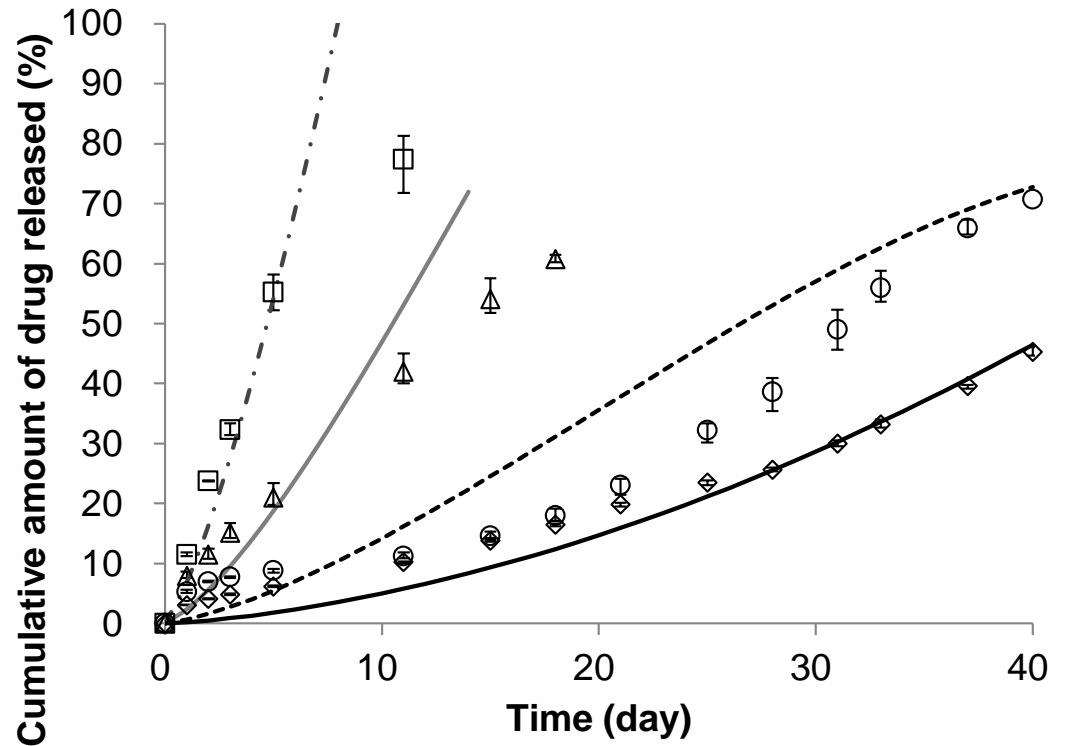
(c) Resection of back skin of rat



(d) Implanted DDS after in vivo test

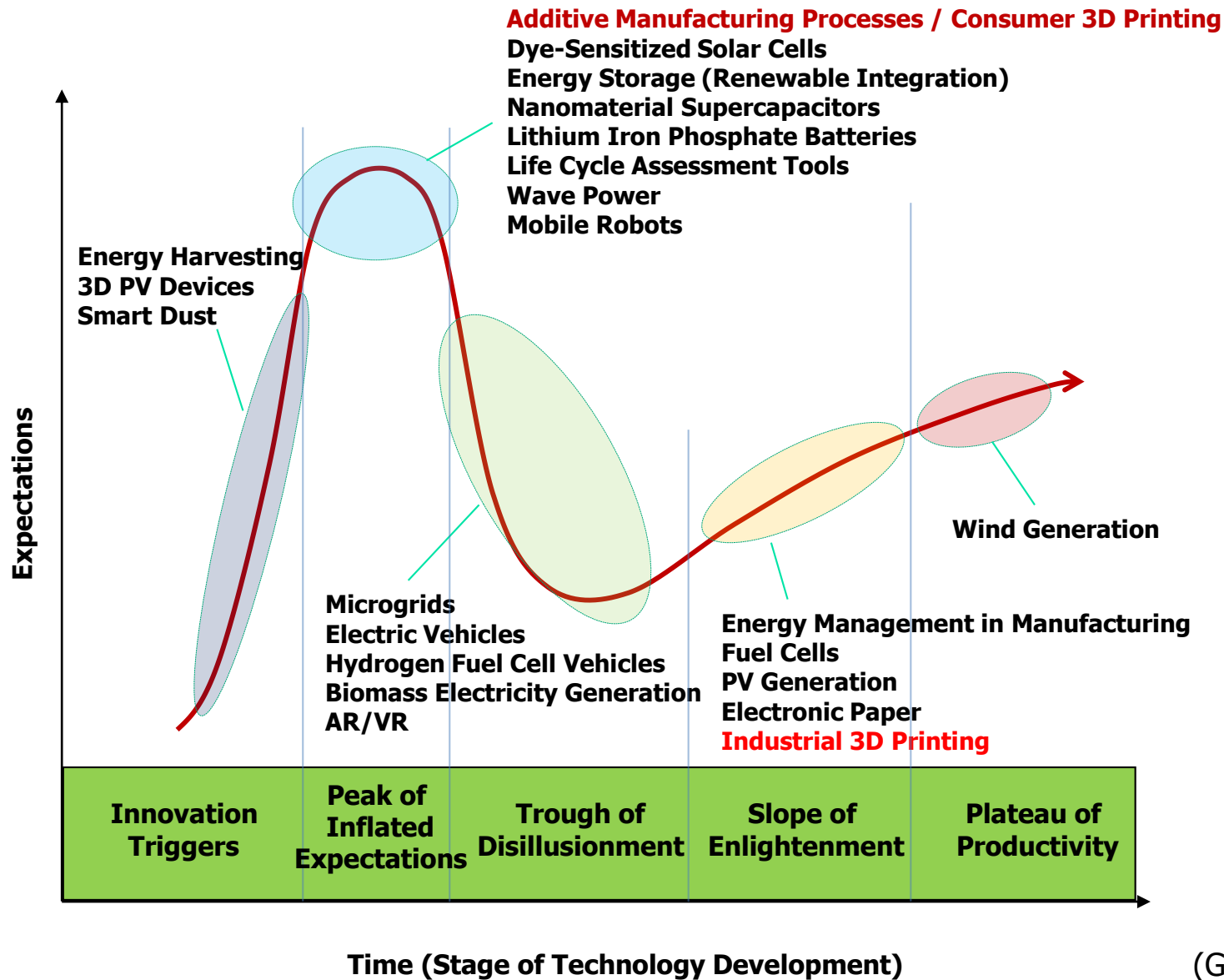
DFM: drug release of scaffold

- Comparison of model and experiment
 - Scaffold



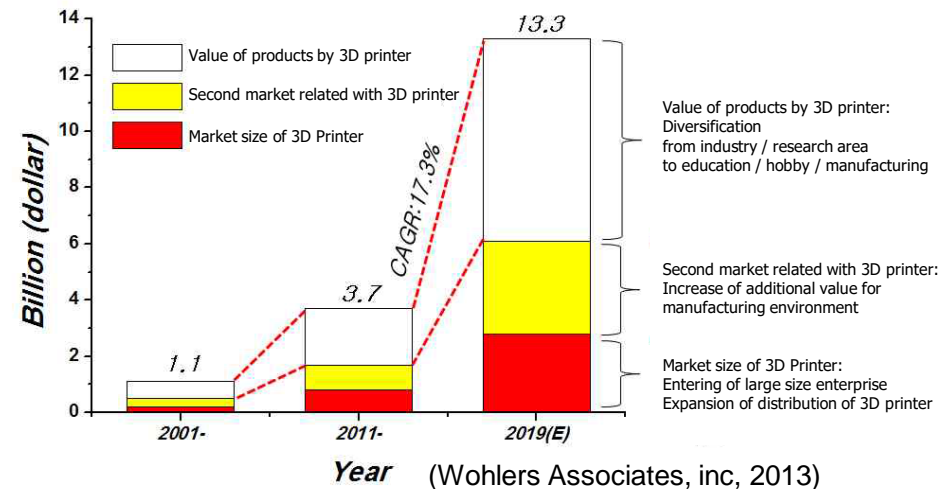
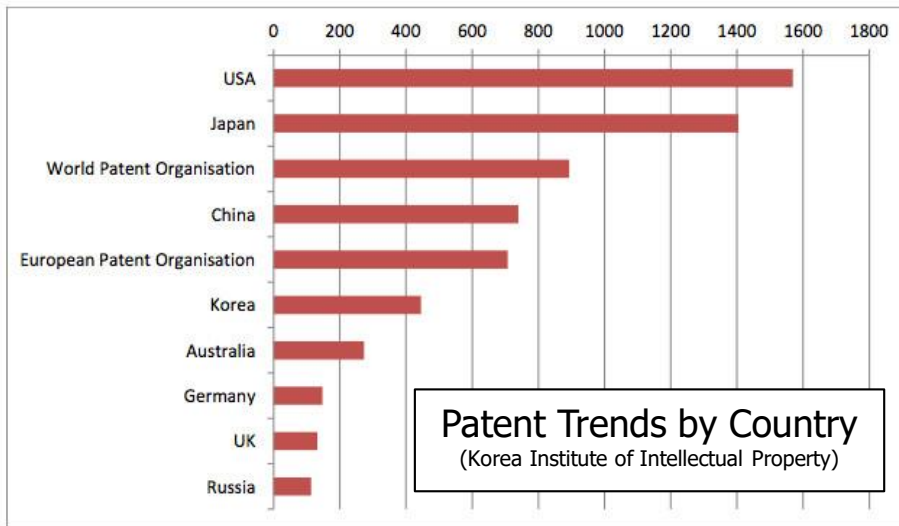
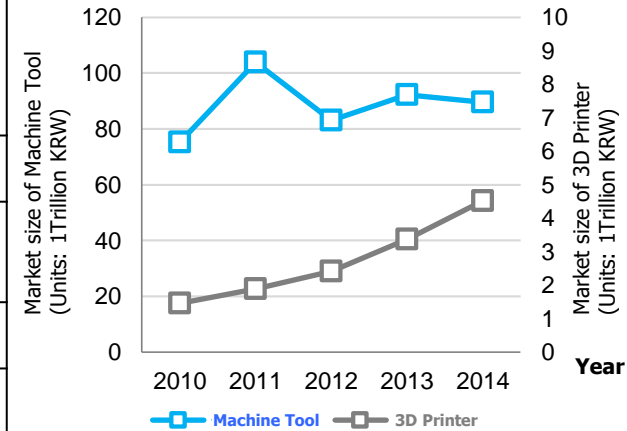
◇ 5% Experiment ○ 10% Experiment
△ 15% Experiment □ 20% Experiment
— 5% model eqn. - - - 10% model eqn.
— 15% model eqn. - · - 20% model eqn.

Hype Cycle

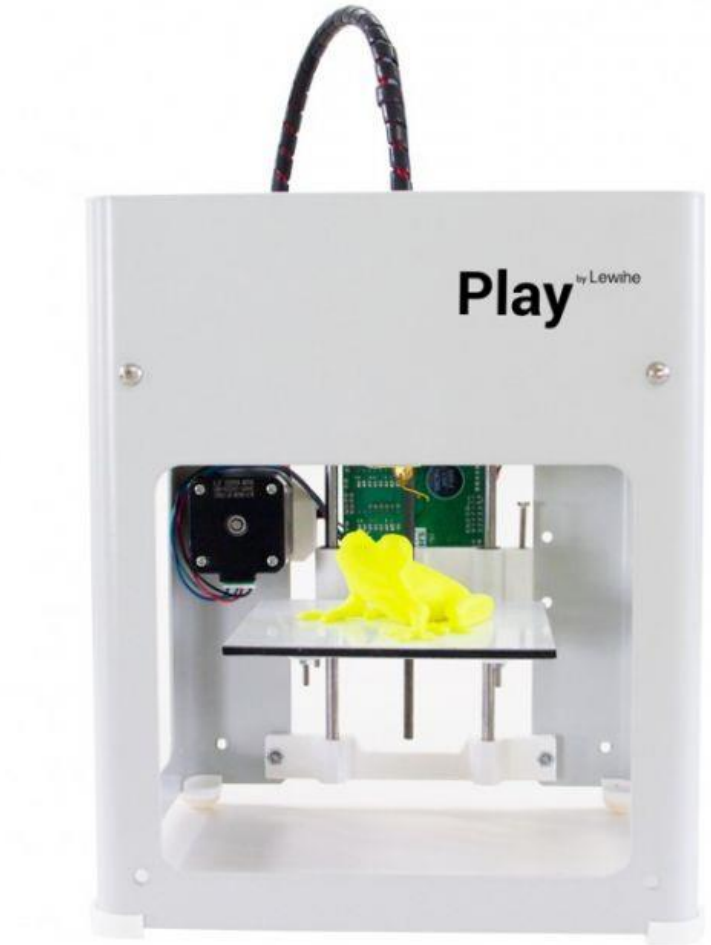
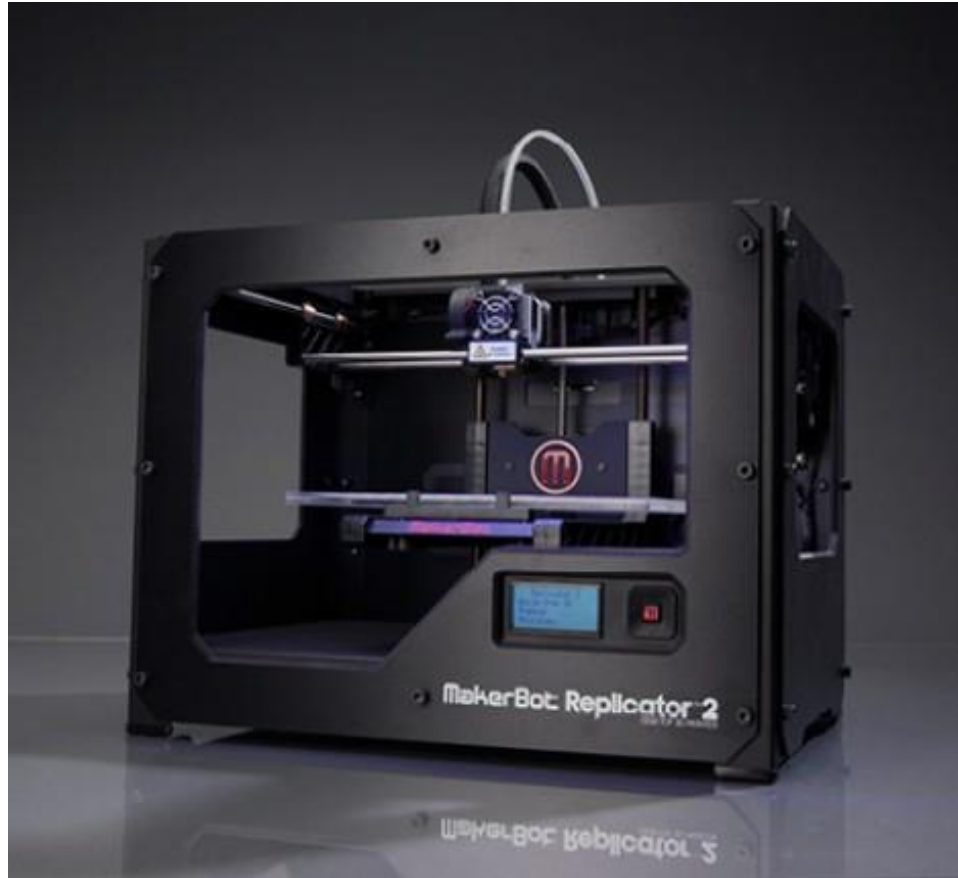


Effect of Expired Patents

Patents	Expire Dates	Expected Effect
SLA (USA)	Aug. 2014	First expiration of 3D printer patents: - Increase in interest - Decrease of cost
FDM (USA)	Oct. 2009	Popularization of 3D printer
SLS (USA)	Feb. 2014	Major Patents expiration of manufacturing process: - Further increase in interest
DMLS (USA)	Aug. 2014	Expectation of expansion of metal 3D printer
3DP (USA)	Sep. 2014	Expectation of expansion of true-color 3D printer



Low cost 3DP



CATEGORIES

[All Categories](#)[Gadgets](#)[Accessories](#)[Jewelry](#)[Art](#)[For Your Home](#)[Games](#)[Miniatures](#) Customizable

Price Range \$1 - \$2,500



MATERIALS

[Any Material](#)[Strong and Flexible](#)[Stainless Steel](#)[Frosted Detail](#)[Full Color](#)[Metallic Plastic](#)[Sterling Silver](#)[Bronze](#)[Precious Plated Metal](#)[Brass](#)[Gold](#)[Platinum](#)

Shapeways 3D Printing Marketplace

Most Popular

 Genghis Designs

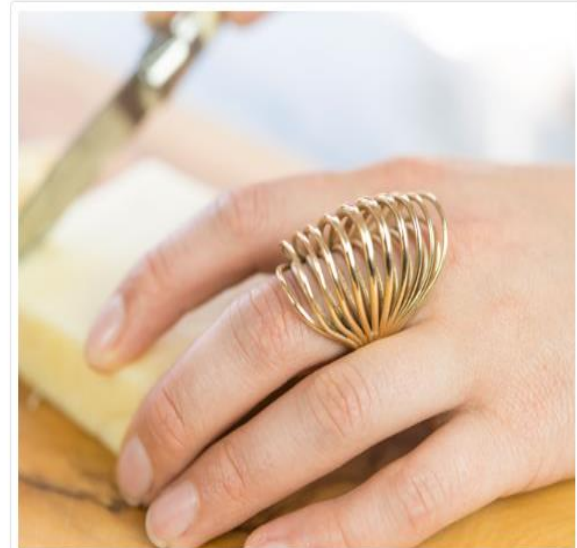
Accessories



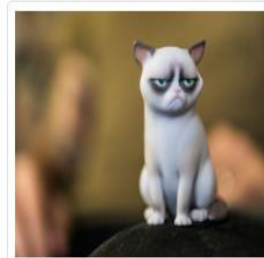
Games



For Your Home



Jewelry



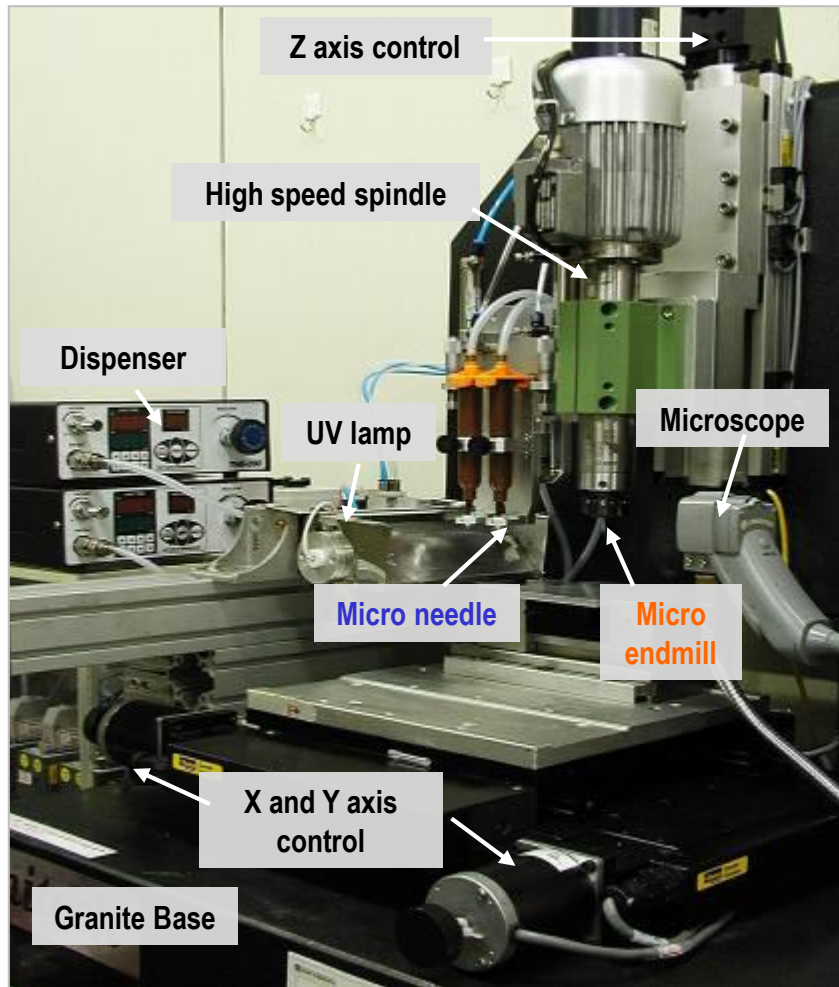
Miniatures



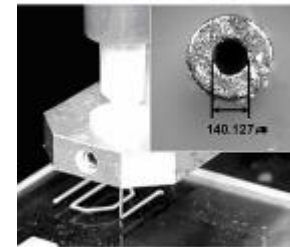
Art



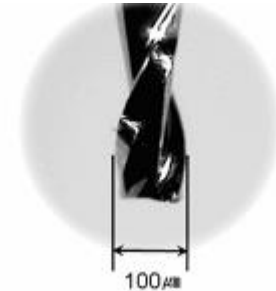
Hybrid 3D printing System



- ✓ *Deposition; 3D printing*
- ✓ *Cutting; Milling*
- ✓ *Hybrid; Both*



Micro needle

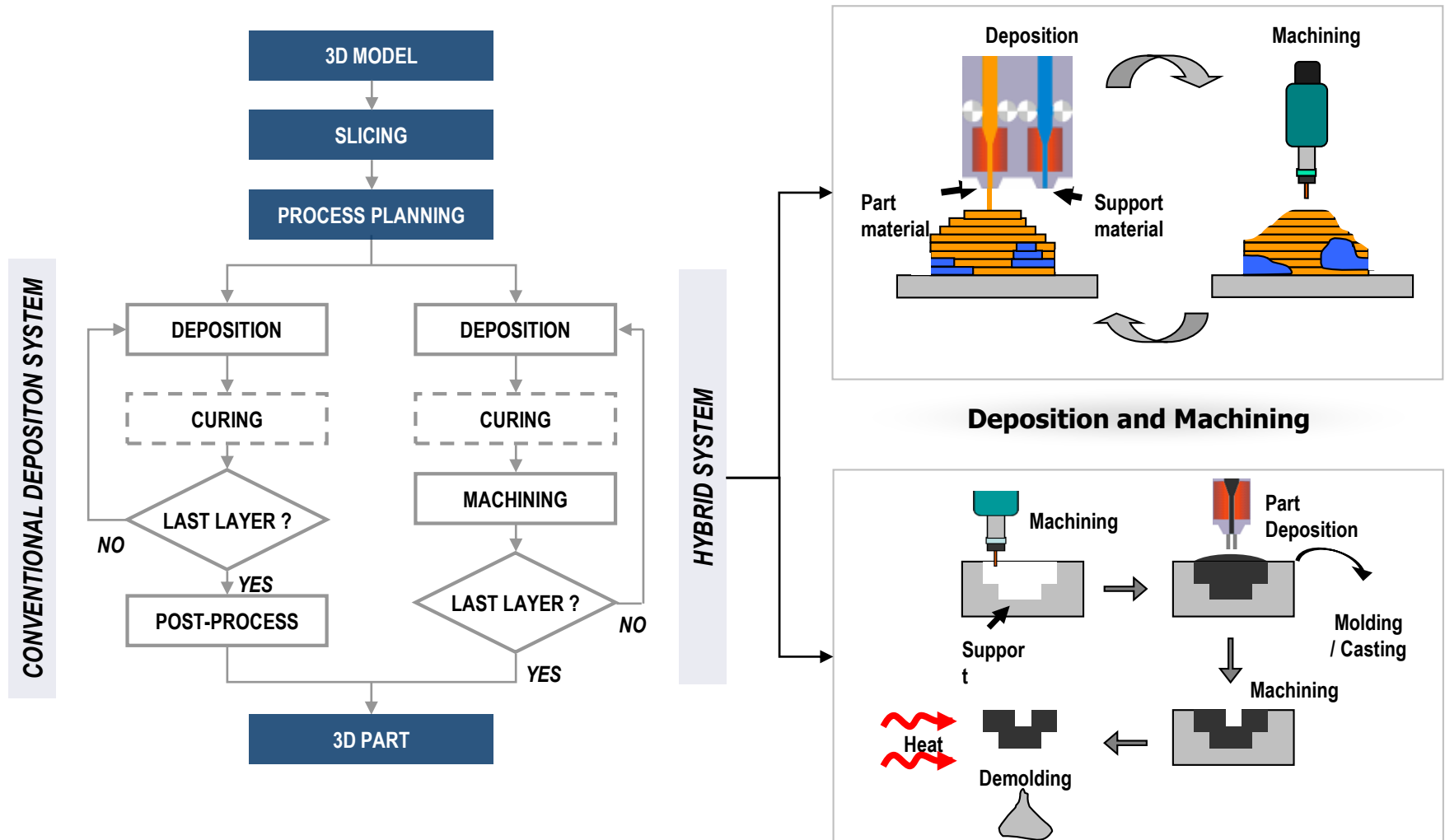


Micro endmill

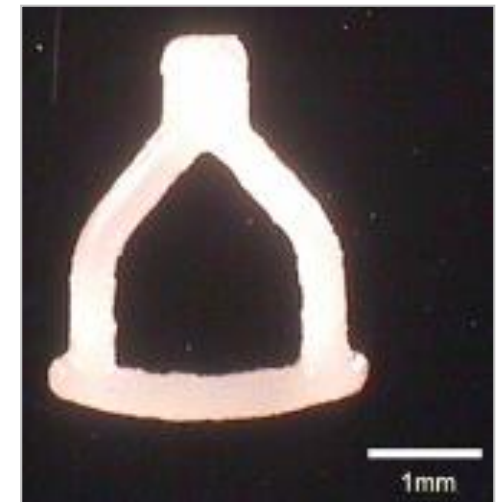
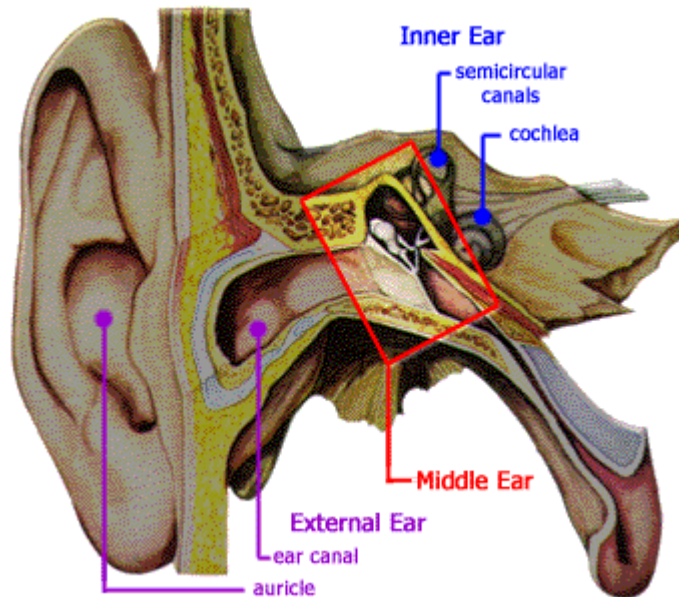
SPECIFICATIONS

3 Axes-stage	1 μm resolution
Dispenser	15 ~ 700 kPa
Micro needle	ϕ 140 μm ~ ϕ 800 μm
Micro tool	ϕ 100 μm ~ ϕ 1000 μm
High speed spindle	Max. 46,000rpm
UV curing system	0 ~ 400 W, λ = 365 nm
Controller	PMAC (Multi-tasking board)

Hybrid 3D Printing System (cont.)



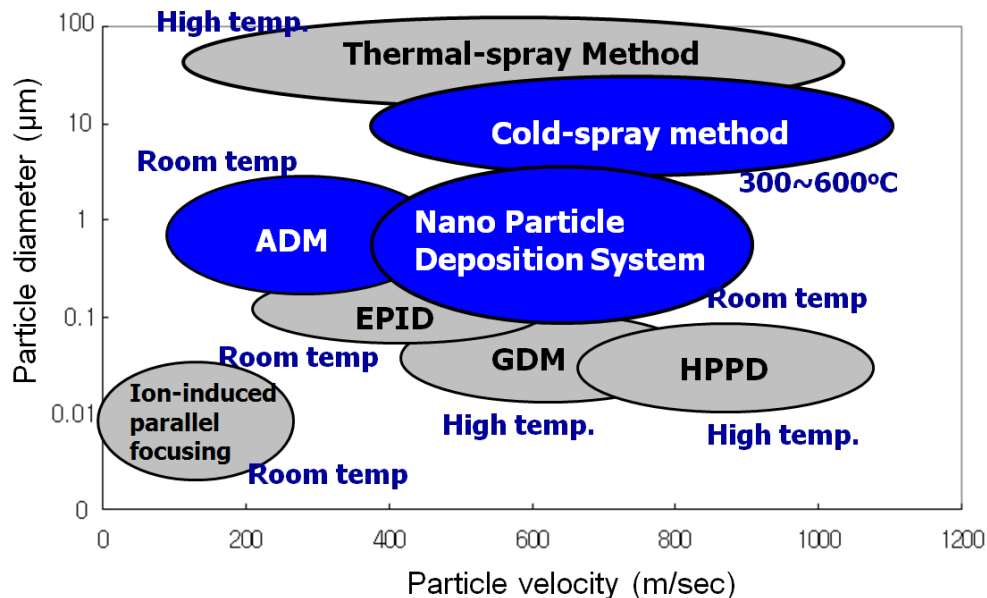
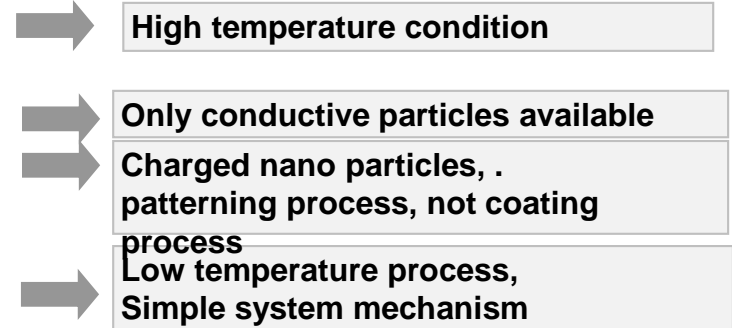
Bio-3D Printing



Examples of micro RP – stapes made of hydroxyapatite

Particle Deposition Methods

- Thermal spray
- Gas deposition method
- Hypersonic plasma particle deposition
- Electrostatic particle impact deposition (EPID)
- Ion-induced parallel focusing
- Cold spray
- Aerosol deposition method (ADM)
- Nano particle deposition system



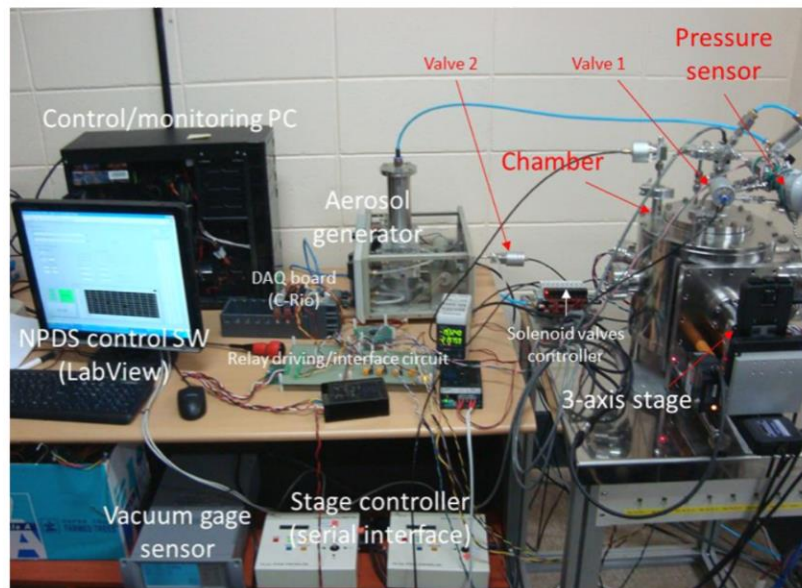
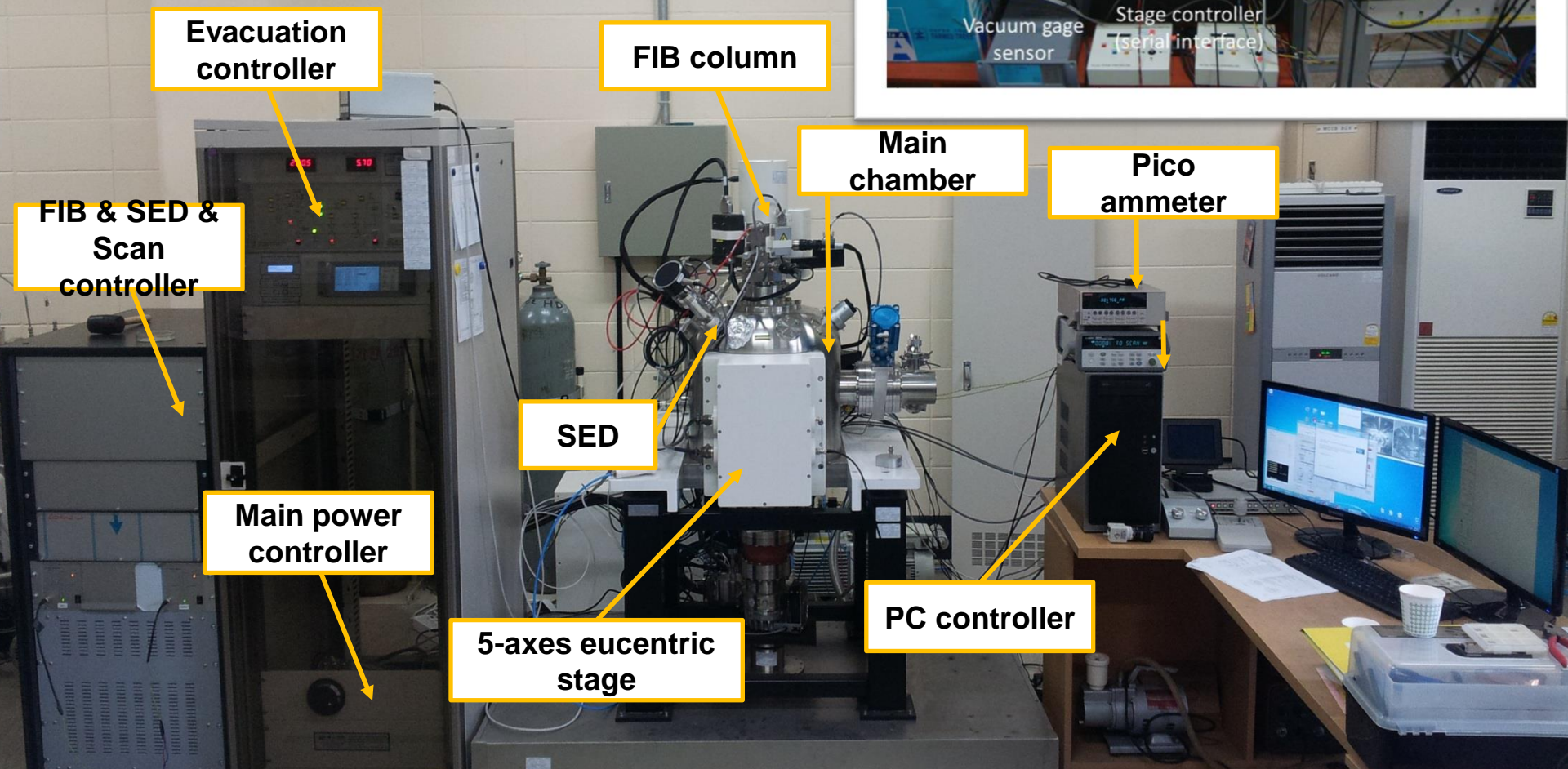
Nanoscale 3D Printing System

Seoul National University
Nano Printing Laboratory

Director: Sung-Hoon Ahn

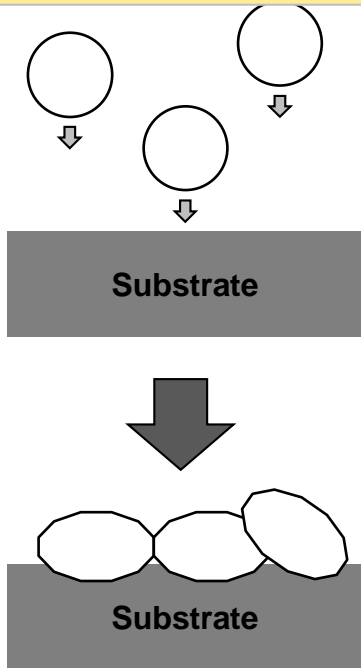
Co-directors: Kunwoo Lee & Caroline S. Lee

Hardware of Nano 3DP @SNU

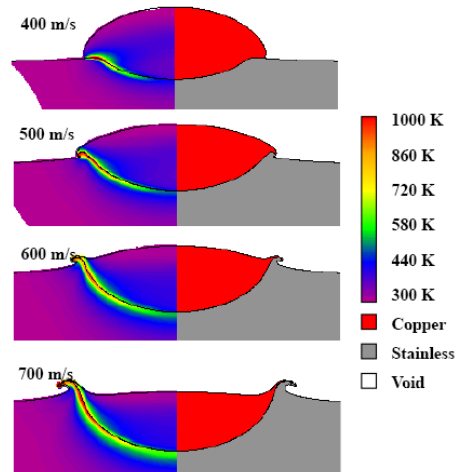


Deposition mechanism of NPDS

Metal particles

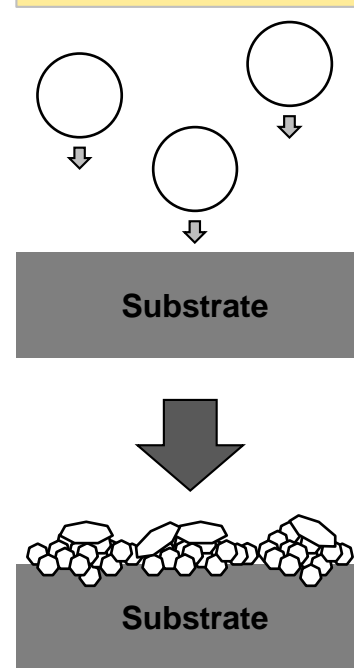


Deformation

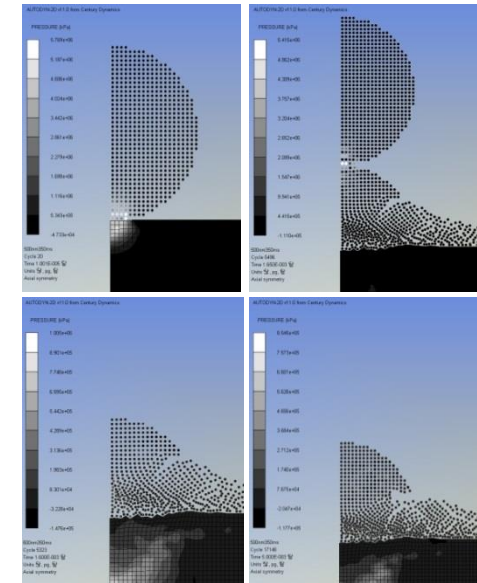


Cold spray splat shapes calculated by numerical solutions
(R. C. Dylke, Sandia lab, 1999)

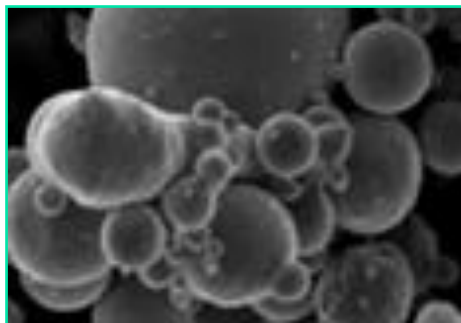
Ceramic particles



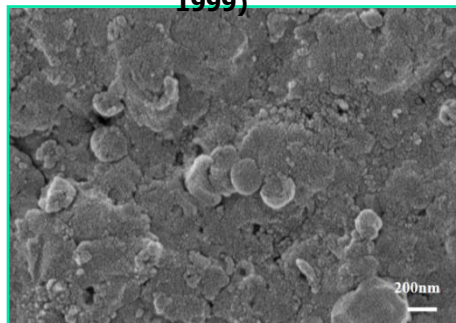
Fragmentation



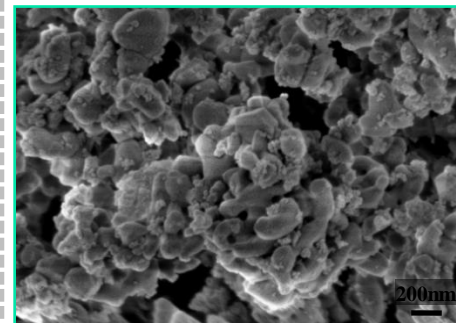
Dynamic analysis of ceramic Al_2O_3 particle impact



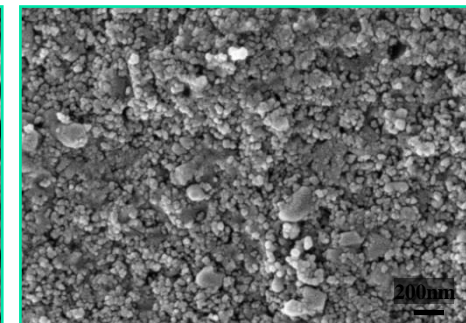
SEM image of metal (Sn) particle (Before deposition)



SEM image of metal (Sn) particle (After deposition)

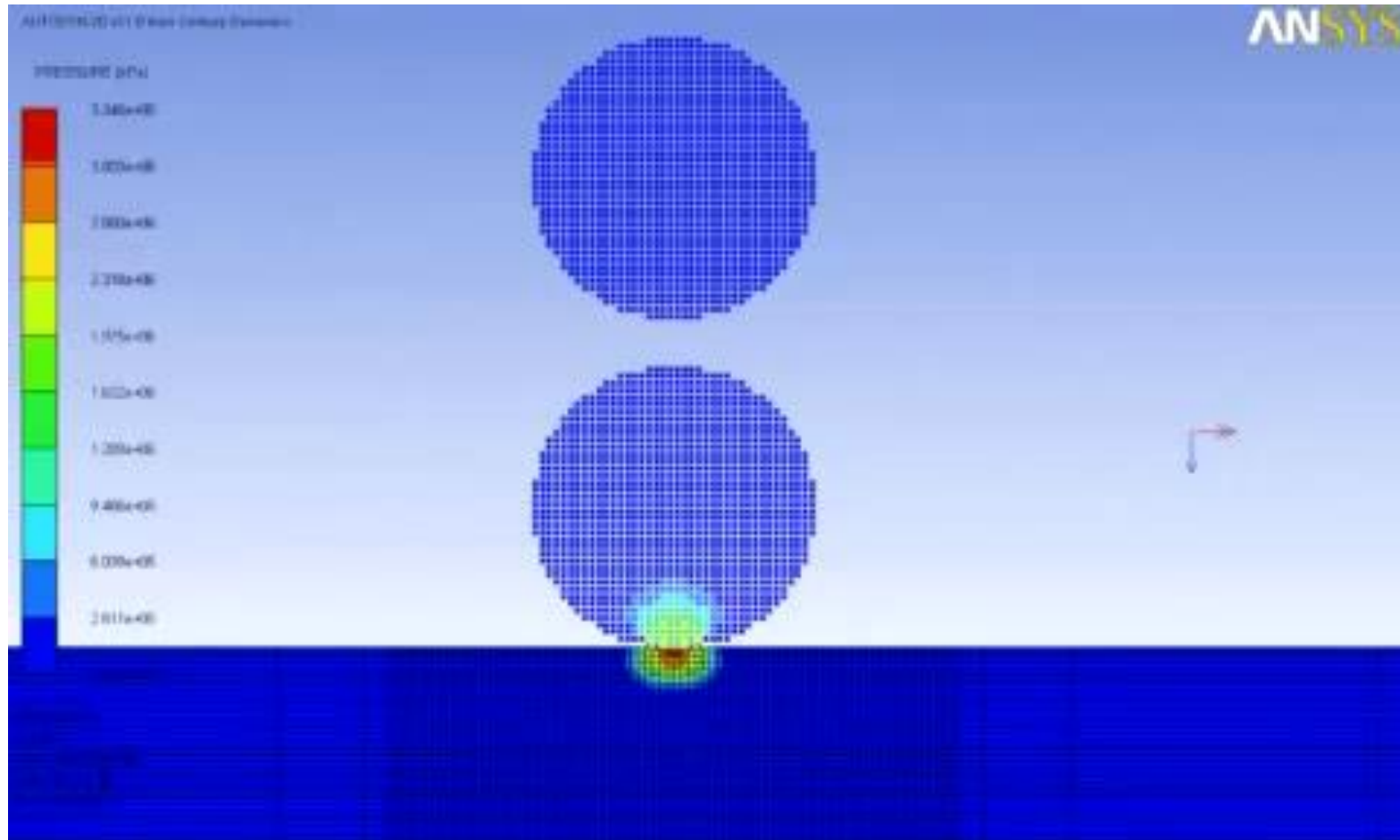


SEM image of ceramic (Al_2O_3) particle (Before deposition)



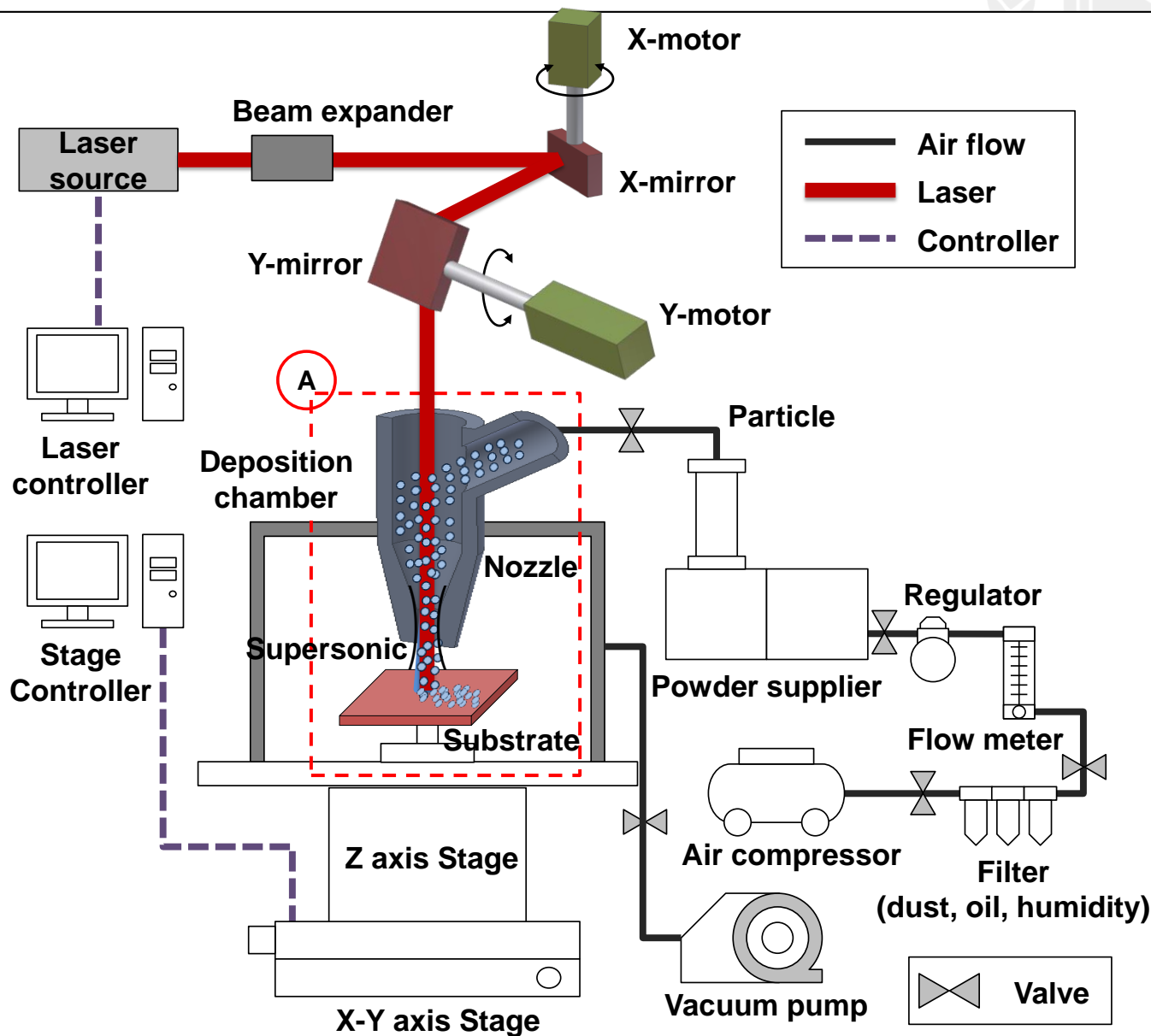
SEM image of ceramic (Al_2O_3) particle (After deposition)

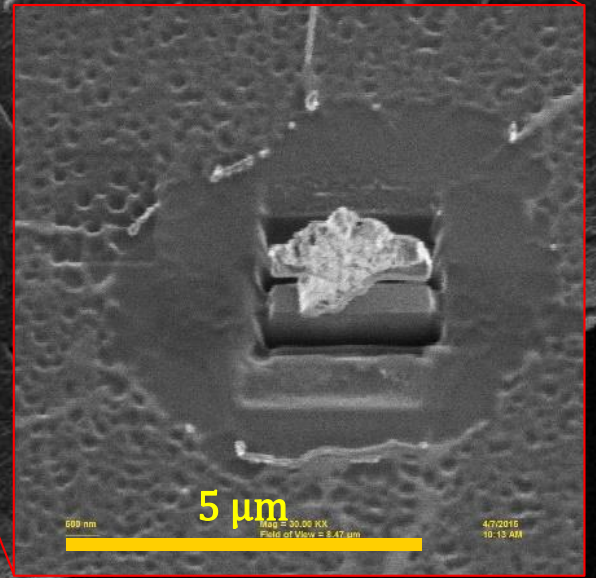
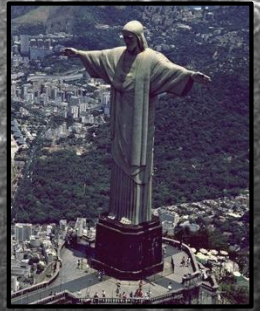
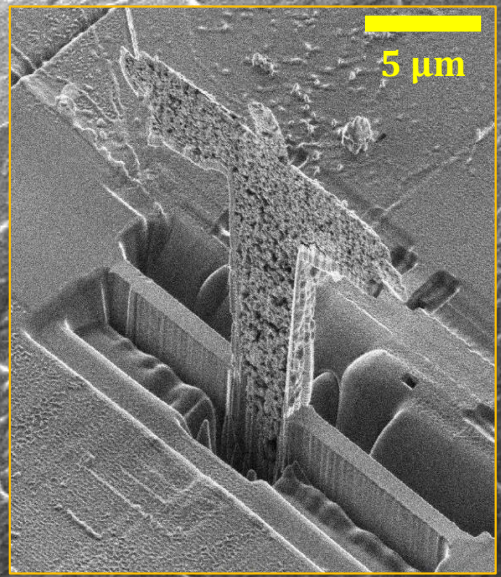
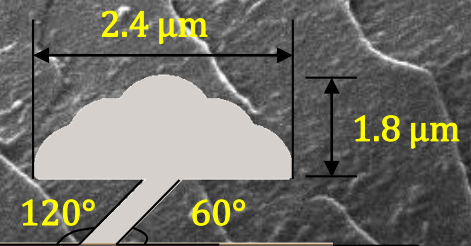
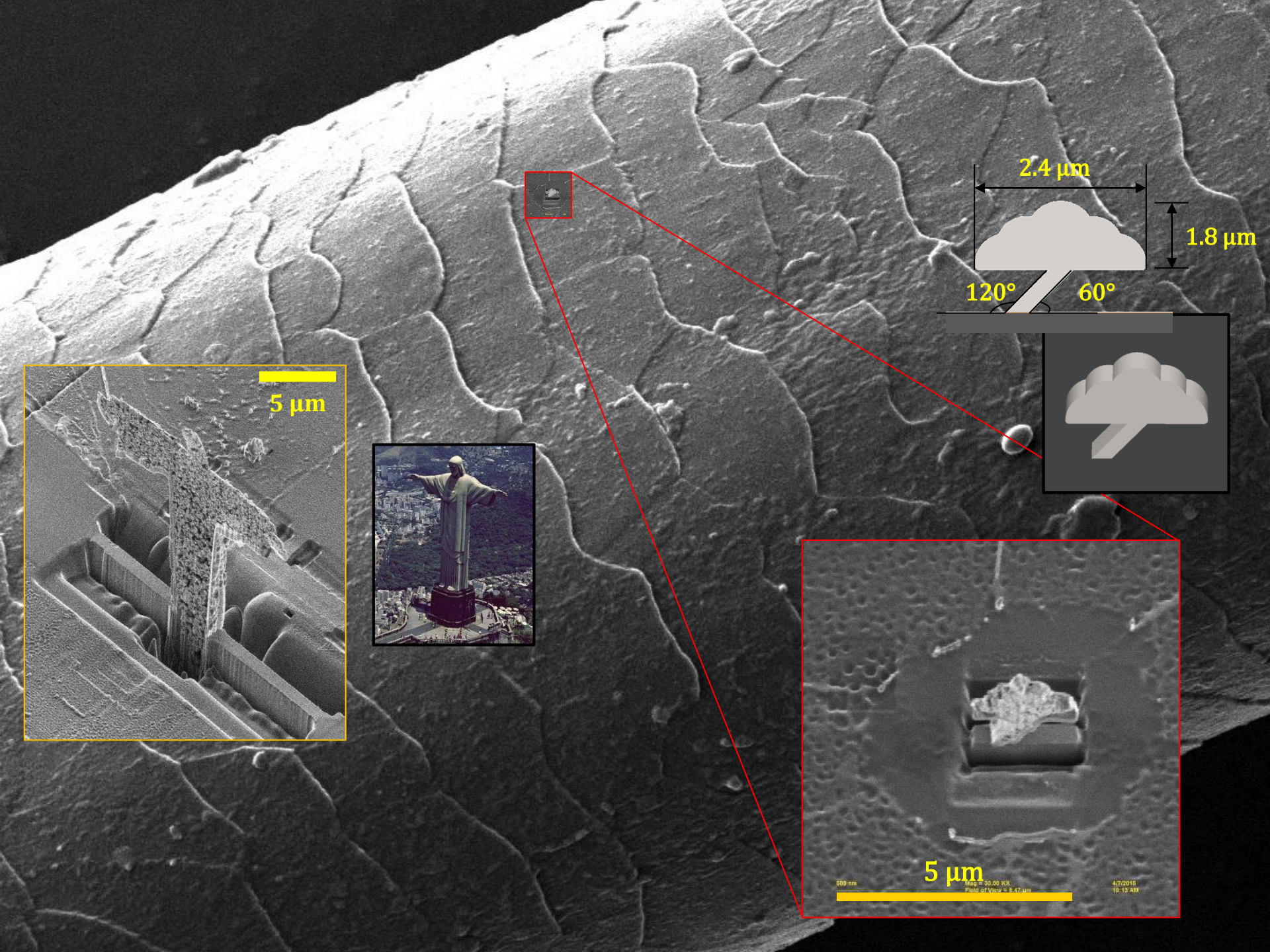
Impact of two Al_2O_3 particles on Al substrate



Movie of two Al_2O_3 particle impact on Al6061 substrate

Diagram of LaNPDS system





A vision of morphing structure

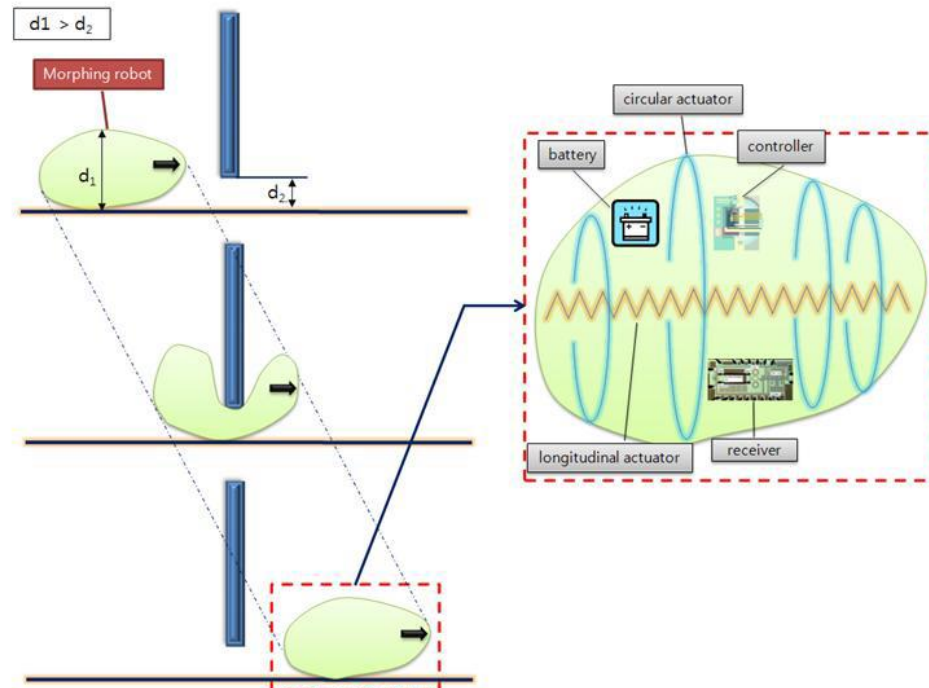


BMW GINI



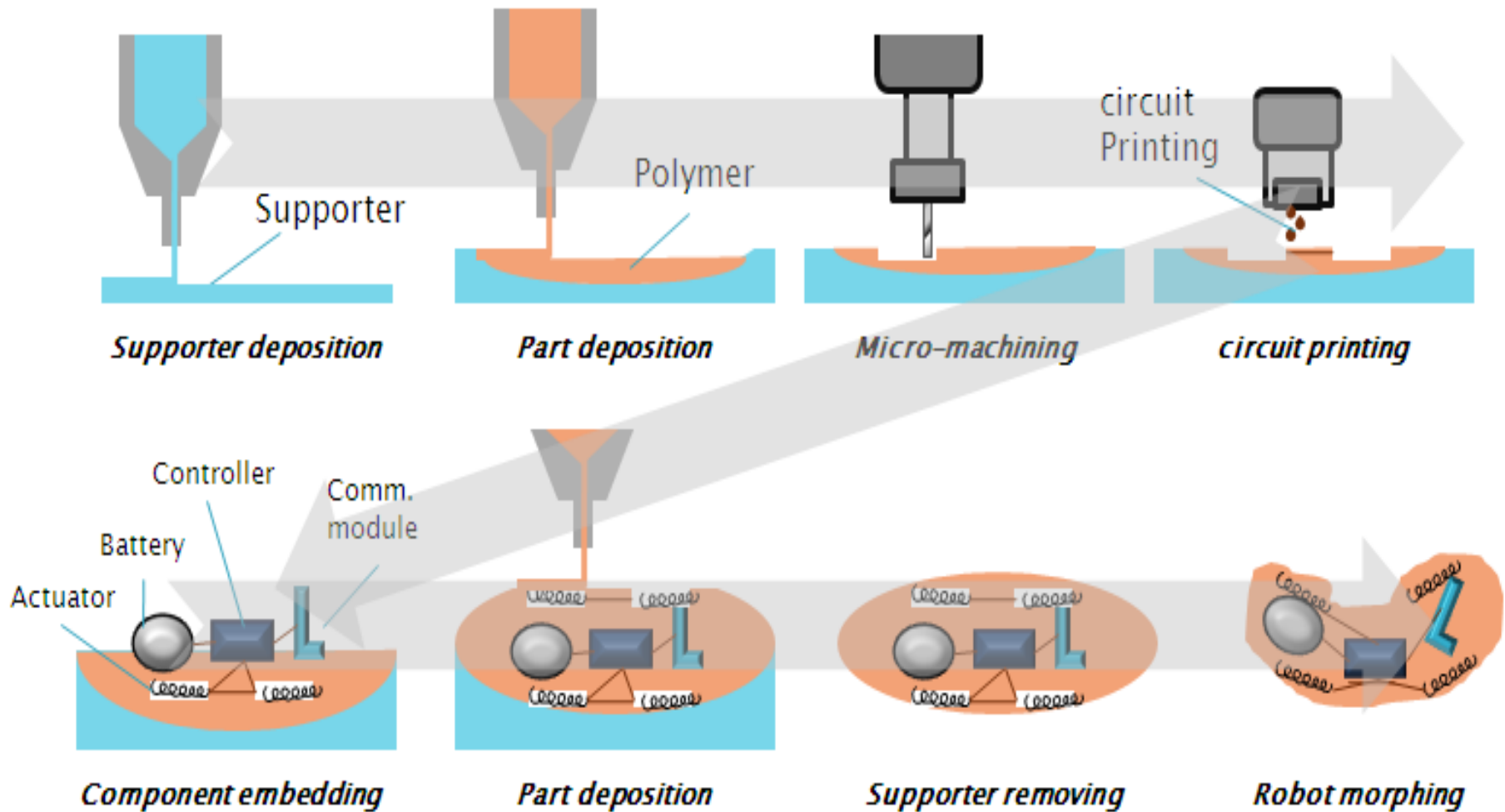
Soft Morphing @ SNU

- Technology for flexible shape deformation
 - Soft material
 - Autonomous large deformation
 - Reversibility



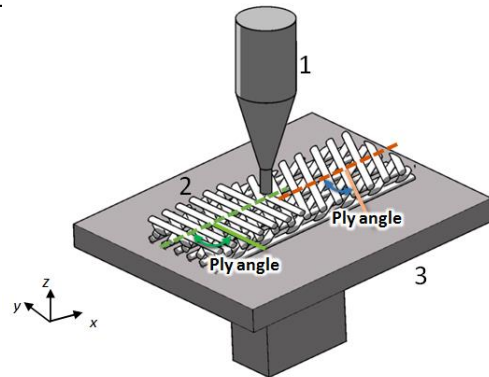
Concept of soft morphing technology

Manufacturing for Soft Morphing

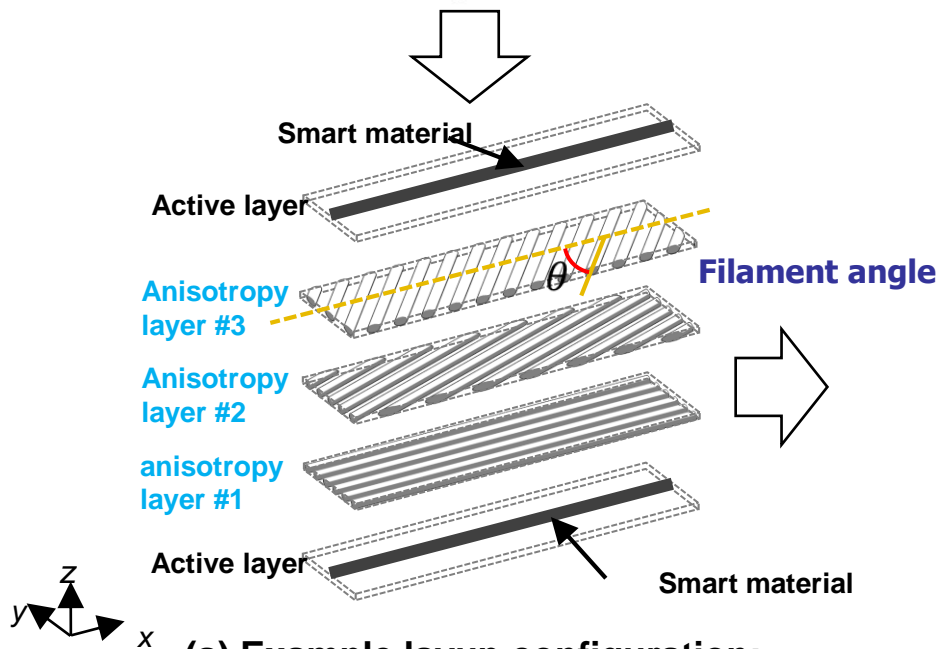


Manufacturing process for soft morphing

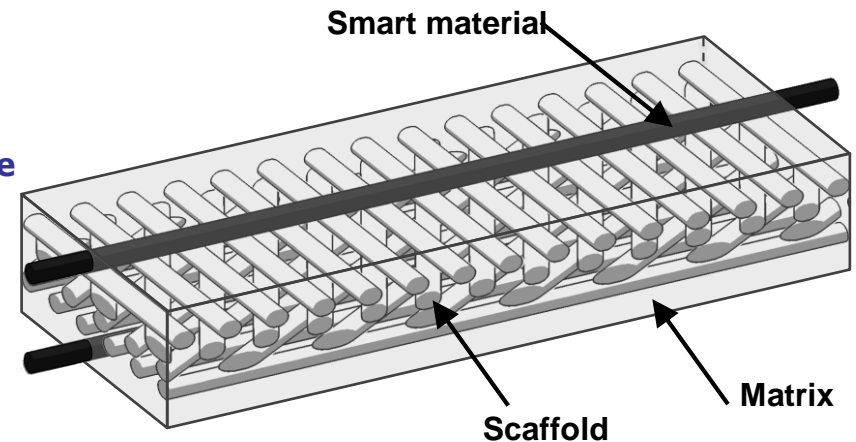
Smart Soft Composite (SSC) structure



- Smart material : SMA wire (Flexinol, Dynalloy)
- Scaffold : ABS (P400, Stratasys, 0.25 x 0.35 filament)
- Matrix : PDMS (Sylgard 184, Dow Corning)



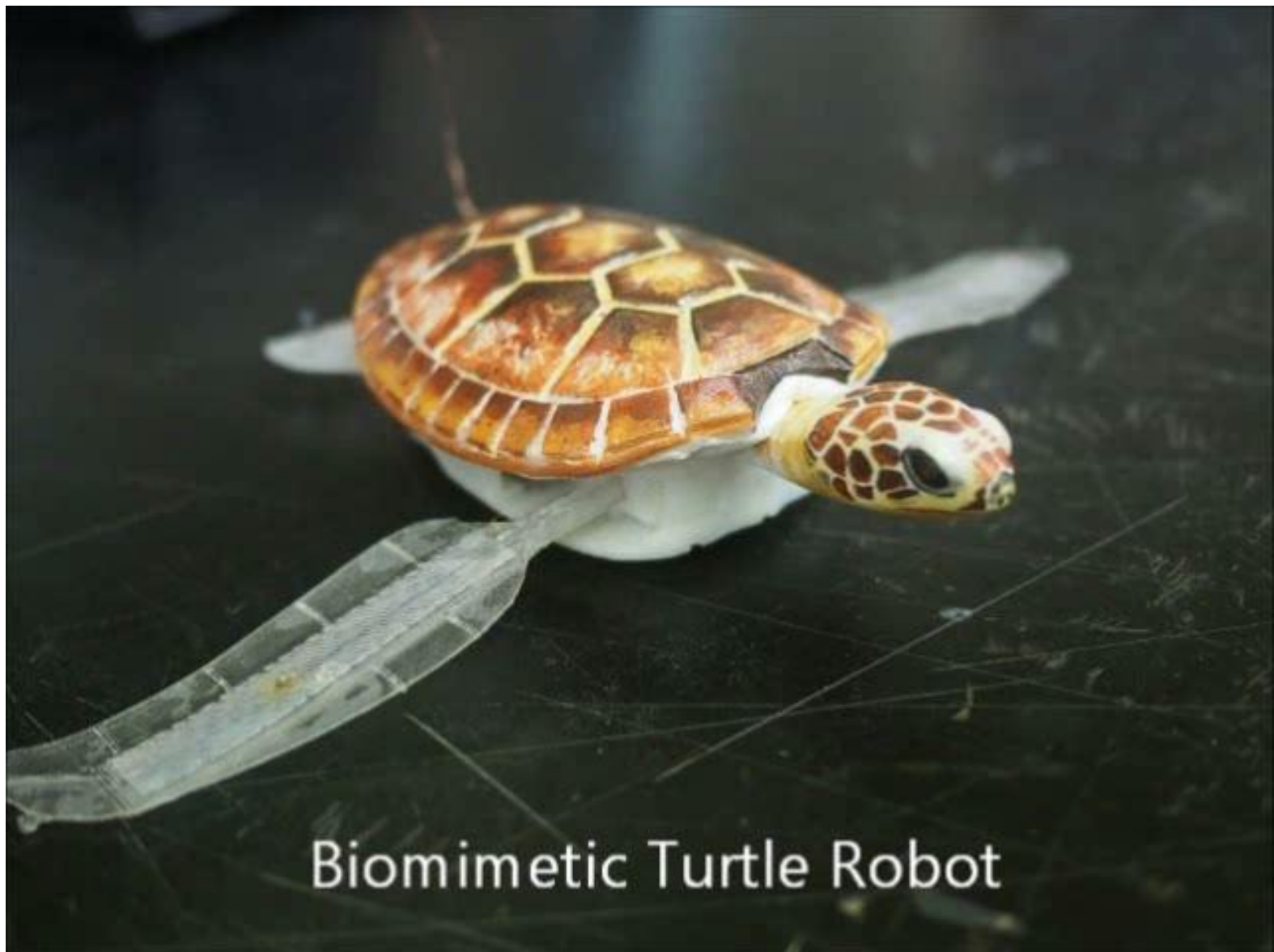
(a) Example layup configuration:
scaffold (3 layers) + 2 active layers



(b) Integrated model

Diagrams of smart soft-morphing structure ^[1]

Turtle Swimming Robot

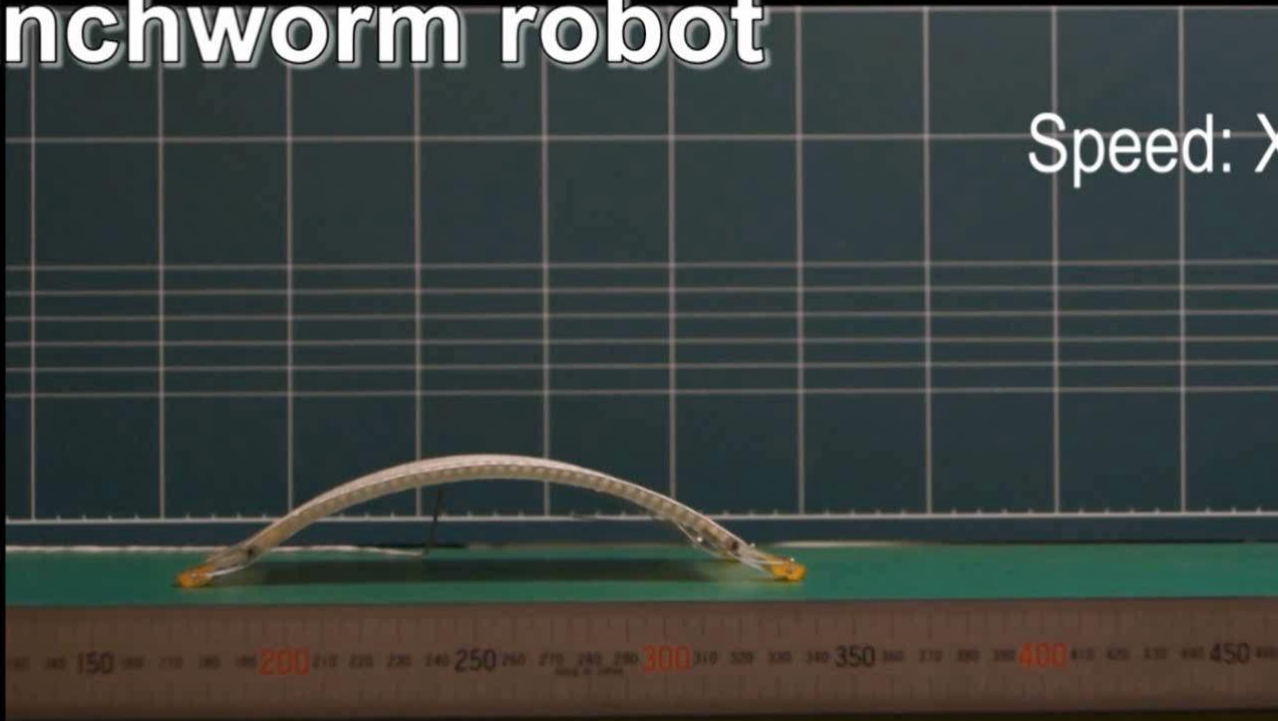


Biomimetic Turtle Robot

Inchworm-inspired Cellphone Robot

Inchworm robot

Speed: X4



Smart device using smart materials





<https://youtu.be/2DsbS9cMOAE>

Diagnosis:

Bereavement

Treatment:

**GRIEF
COUNSELING**

A REPORT ON
EFFECTIVENESS, SHORT
AND LONG-TERM

American Psychological Association
Task Force on the
Assessment and Treatment of
Grief

SECTION 1:
EFFICACY

Report prepared for the American Psychological Association
Task Force on the Assessment and Treatment of Grief



Injection Molding (사출성형)

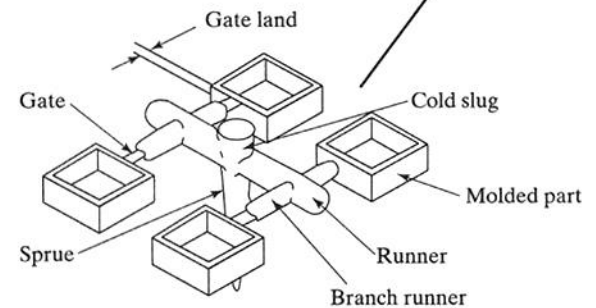
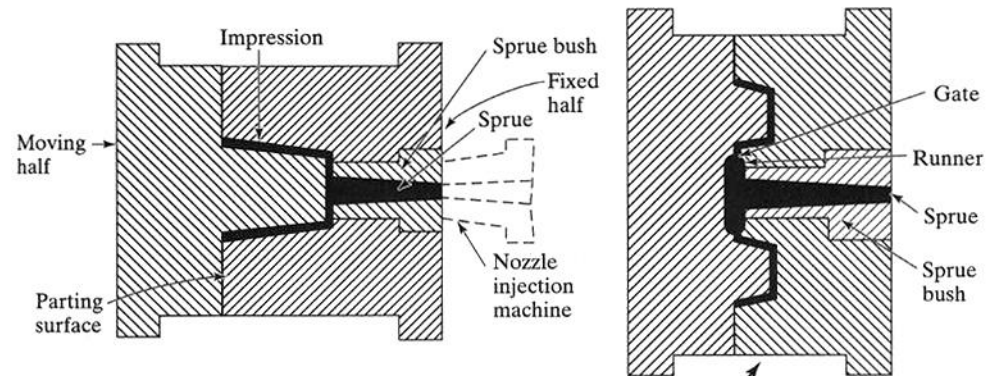
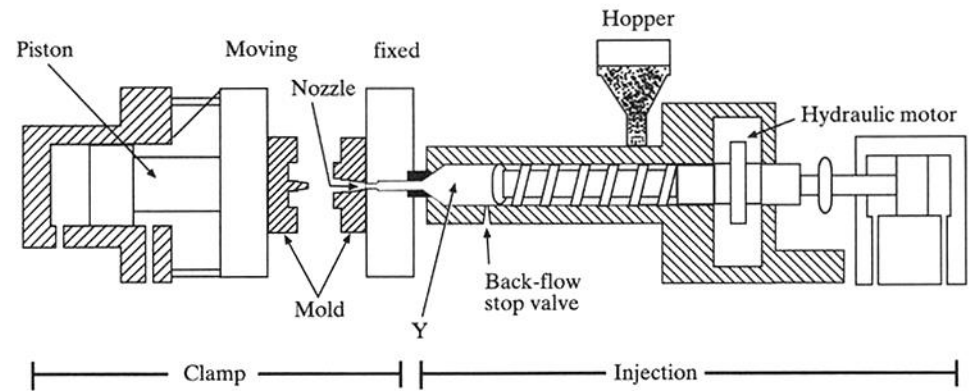
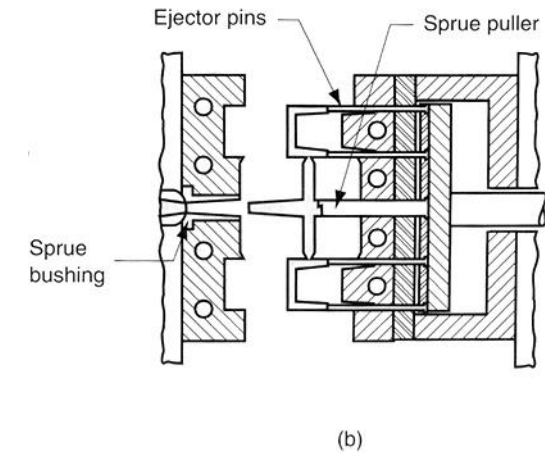
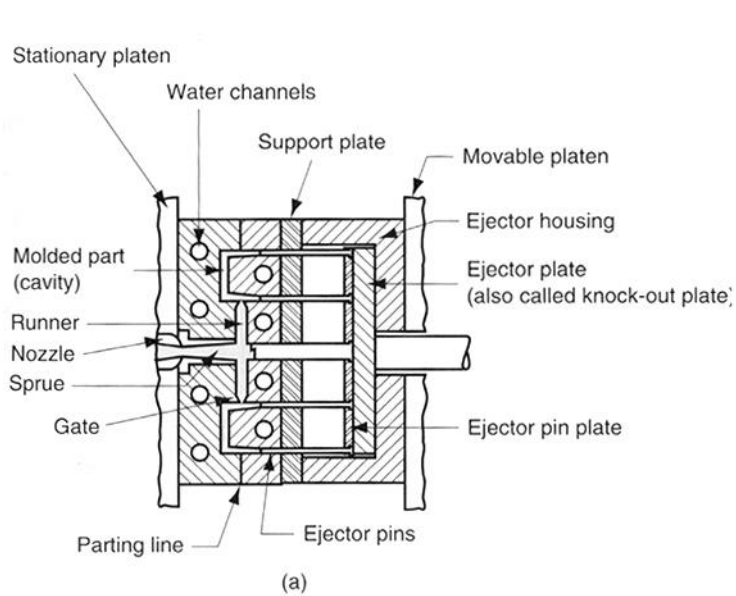
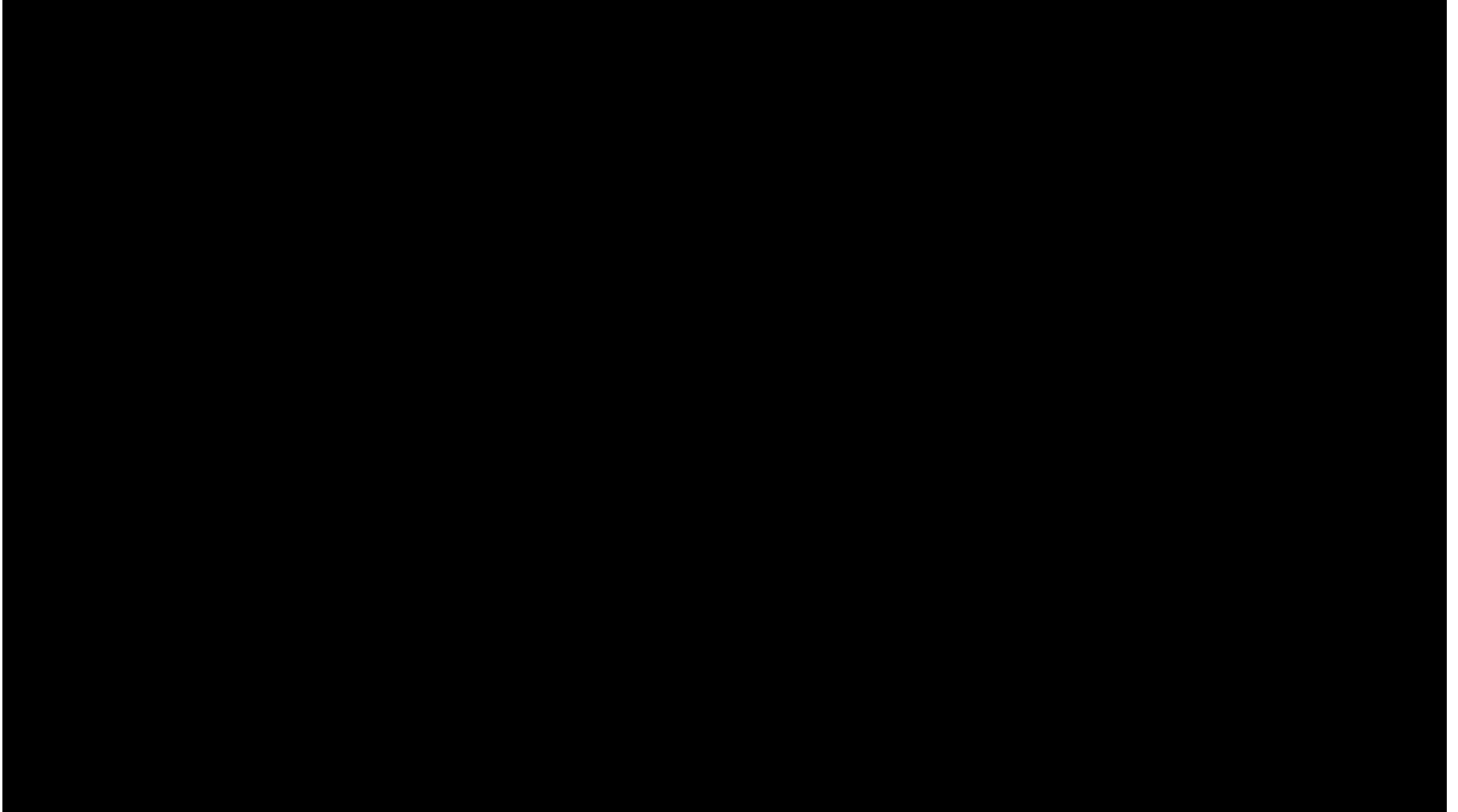


Figure 8.5 Injection molding with reciprocating-screw machine.

Injection Molding (사출성형)



<https://www.youtube.com/watch?v=b1U9W4iNDiQ>
<https://www.youtube.com/watch?v=y1Zhpdx-XtA>

DFM in Injection Molding (1)

1-3 성형품 설계 요령

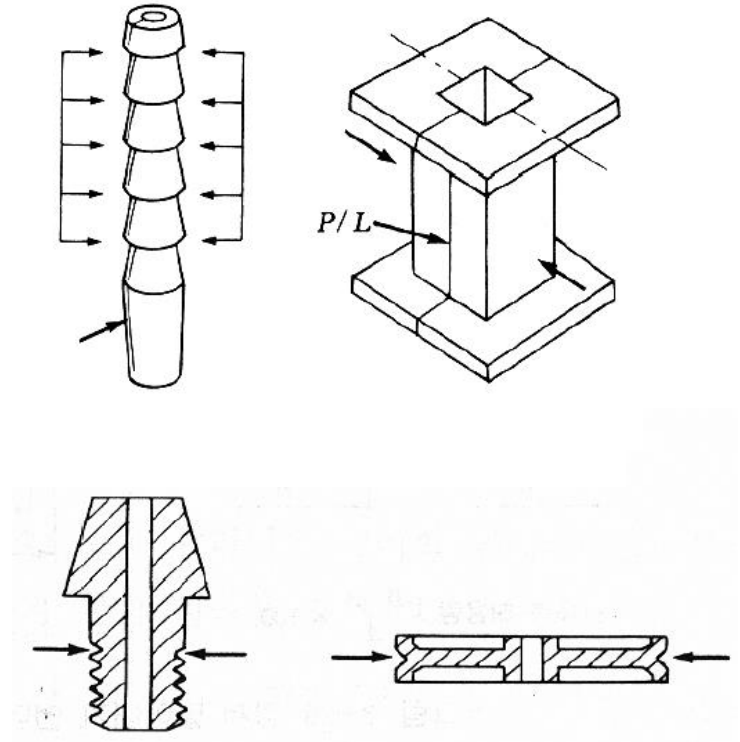
항 목	사용되지 않는 예	많이 사용하는 예	설 명
파팅라인			기울어진 보스 또는 형상은 금형의 구조가 복잡 및 대형으로 되기 때문에 파팅 라인에 대하여 직각이 되도록 한다.
코 어			코어에 비교적 큰 사이드 코어를 관통하면 고장의 요인이 되므로 두 방향에서 두 개의 코어를 맞당게 하는 것이 좋다.
성형 품 상			물결 모양의 이음부분의 끝은 금형으로서 예각이 되는 것을 피한다.
			뛰어나온 모양의 손잡이는 금형의 절삭 가공이 더 용이하다. 풀드 호빙가공의 경우는 마스터를 만들게 되므로 그 반대다 된다.
			깊은 부분은 되도록 제품의 한 방향으로 불도록 한다.
			금형에서 고정축 코어의 형상은 수축에 의한 휨좌를 피하도록 한다.

항 목	사용되지 않는 예	많이 사용되는 예	설 명
성형품 형 상			파들어 갈 때, 좌우 대칭의 형상은 쉽게 가공이 되지만, 그렇지 않을 경우는 가공이 곤란하다.
			모든 코너에는 최대의 R을 붙인다.
살 두께			살두께는 되도록 균일한 두께로 할 것
			단면의 살두께가 두꺼운 곳에는 보강 리브를 붙이고 살두께는 균일하게 한다.
			살이 얇은 단면 부분은 재료의 충전 부족이 되기 쉽다.
보 스			보스가 강도를 갖도록 리브를 만들고 귀통이에 R을 붙인다.
리 브			깊은 리브는 잘 빠지게 하기 위하여, 되도록 큰 빼내기 구배를 붙일 것

DFM in Injection Molding (2)



항 목	사용되지 않는 예	많이 사용되는 예	설 명
문 자			들어간 문자는 튀어나온 문자에 비하여 형가공이 곤란하다. 콜드호빙 가공한 경우는 그 반대가 된다.
성형 품 강 도			형에서 떨어질 때 코어편에 수축의 힘이 걸려서 굽어질 수 있으므로 리브를 만들면 좋다.
			구멍을 관통하기가 곤란한 때에는 적당한 위치로 하든지 또는 드릴 스폿만 얻는 것이 좋다.
인서트			성형을 할 때 인서트를 확실하게 고정시킬 수 있도록 인서트의 끝면에서 코어 편을 분할하여, 인서트가 움직이지 않도록 눌러준다.
			인서트 나사는 나사가 성형품에까지 닿는 것을 피하도록 하고, 평면부를 붙이면 매끈해진다.



Prevent undercut!

Conclusions

Additive processes were reviewed

3D Printing

Cold spray

Nano particle deposition system

Polymer processing

**Undercut is manufacturable in layer-based processes except for
injection molding**

Structures with hybrid materials are manufacturable