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Laser Induced Forward Transfer: a Digital Additive Manufacturing solution for electronics processing and packaging

Ioanna Zergioti, National Technical University of Athens June 28 2022, Grenoble



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AM families according to the American Society for Testing and Material (ASTM)

7 Families of Additive Manufacturing				7 Families of Additive Manufacturing			
VAT Photopolymerization	Pawder Bed Fusion (PBF)	BINDER JETTING	MATERIAL JETTING	SHEET LAMINATION	MATERIAL Extrusion	DIRECTED ENERGY DEPOSITION (DED)	HYBRID
Alternative Names: SLA [™] - Stereolithography Apparatus DLP [™] - Digital Light Processing 3SP [™] - Scan, Spin, and Selectively Photocure CLP [™] - Continuous Liquid Interface Production	Alternative Names: SLS [™] - Selective Laser Sintering; DMLS [™] - Direct Metal Laser Sintering; SLM [™] - Selective Laser Metting; EBM [™] - Electron Beam Metting; SHS [™] - Selective Heat Sintering; MJF [™] - Multi-Jet Fusion	Alternative Names: 30P™-30 Printing ExOne Voxeljet	Alternative Names: Polyjet™ SCP™ - Smooth Curvatures Printing MJM - Multi-Jet Modeling Projet™	Alternative Names: LOM - Laminated Object Manufacture SDL - Selective Deposition Lamination UAM - Ultrasonic Additive Manufacturing	Alternative Names: FFF - Fused Filament Fabrication FDM [™] - Fused Deposition Modeling	Alternative Names: LMD - Laser Metal Deposition LENS TM - Laser Engineered Net Shaping DMD TM - Direct Metal Deposition (DM3D) LENS TM - Laser Engineered Net Shaping DMD TM - Direct Metal Deposition DM3D,	Alternative Names: AMBIT [™] - Created by Hybrid Manufacturing Technologies
Description: A val of liquid photopolymer resin is cured through selective exposure to light (via a laser or projector) which then initiates polymerization and converts the exposed areas to a solid part.	Description: Powdered materials is selectively consolidated by melting it together using a heat source such as a laser or electron beam. The powder surrounding the consolidated part acts assupport material for overhanging features.	Description: Liquid bonding agents are selectively applied onto thin layers of powdered material to build up parts layer by layer. The binders include organic and inorganic materials. Metal or ceramic powdered parts are typically fired in a furnace after they are printed.	Description: Droplets of material are deposited layer by layer to make park. Common varieties include jetting a photeurable resin and curing it with UV light, as well as jetting thermally molten materials that then solidity in ambient temperatures.	Description: Sheets of material are stacked and laminated together to form an object. The lamination method can be adhesives or chemical (paper/ plastics), ultrasonic welding, or brazing (metals). Unneeded regions are cut out layer by layer and removed after the object is built.	Description: Material is extruded through a nozzle or orifice in tracks or beads, which are then combined into multi-layer models. Common varieties include heated thermoplastic extrusion (similar to a hot glue gun) and syringe dispensing.	Description: Powder or wire is fed into a melt pool which has been generated on the surface of the part where it adheres to the underlying part or layers by using an energy source such as a laser or electron beam. This is essentially a form of automated build-up welding.	Description: Laser metal deposition (a form of DED) is combined with CNC machining, which allows additive manufacturing and 'subtractive' machining to be performed in a single machine so that parts can utilize the strengths of both processes.
Strengths: • High level of accuracy and complexity • Smooth surface finish • Accommodates large build areas	Strengths: • High level of complexity • Powder acts as support material • Wide range of materials	Strengths: • Allows for full color printing • High productivity • Uses a wide range of materials	Strengths: • High level of accuracy • Allows for full color parts • Enables multiple materials in a single part	Strengths: - High volumetric build rates Relatively low cost (non-metals) - Allows for combinations of metal foils, including embedding components.	Strengths: Inexpensive and economical Allows for multiple colors Can be used in an office environment Parts have good structural properties	Strengths: Not limited by direction or axis Effective for repairs and adding features Multiple materials in a single part Highest single-point deposition rates	Strengths: Smooth surface finish AND High Productivity Geometrical and material freedoms of DED Automated in-process support removal, finishing, and inspection
Typical Materials UV-Curable Photopolymer Resins	Typical Materials Plastics, Metal and Ceramic Powders, and Sand	Typical Materials Powdered Plastic, Metal, Ceramics, Glass, and Sand.	Typical Materials Photopolymers, Polymers, Waxes	Typical Materials Paper, Plastic Sheets, and Metal Foils/Tapes	Typical Materials Thermoplastic Filaments and Pellets (FFF): Liquids, and Slurries (Syringe Types)	Typical Materials Metal Wire and Powder, with Ceramics	Typical Materials Metal Powder and Wire, with Ceramics





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Digital Additive Manufacturing

Material Jetting "Drop on demand": an additive manufacturing process in which droplets of build material are selectively deposited

- Inkjet printing
- Aerosol Printing
- Laser Printing

Powder Bed Fusion:

An additive manufacturing process in which thermal energy selectively fuses regions of a powder bed

- Direct Metal Laser sintering
 - Multi-Jet fusion
 - Electron Beam Melting
 - Selective Laser Sintering







Why is laser additive manufacturing a key-enabler for Industry

"Europe's age of light! How photonics will power growth and innovation" Photonics 21 Strategic Roadmap 2021-27

"Photonic technology is the bedrock of additive manufacturing" Laser Focus World, Sep. 21 2021





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Photonics and Laser AM Market size



"Photonics technologies are opening up new manufacturing paradigms, such as 3D additive manufacturing, which will secure renewed growth in European manufacturing" Photonics21 Multiannual Strategic Roadmap 2021-2027





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Laser Induced Forward Transfer for the fabrication of metallic micro patterns as components in flexible electronics





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Courtesy of Dr. Gari Arutinov



Selective Laser microSintering: transforming nanoparticle deposits to solid metal tracks











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Example I: HIgh PERformance Laser-Additive Manufacturing for Industrial electronic applications

Application 1: Laser printed RFID antenna



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nd Use case Ia. Laser printed and sintered linear Tech patterns for fingerprint sensors 2022 **Resulting conductive patterns** Laser printing process development (fingerprint sensors) Step (µm) Fluence 100 9.5 mm (mJ/cm^2) Droplet size 80 250 60 um 70 65 85 µm 340 60 Line Width: 80 - 90 µm 440 105 µm 55 Line Thickness: ~ 700 nm



540

750



130 µn

120 µm

130 µm

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High speed laser printing and sintering of flexible RFID antennas and fingerprint sensors, I. Theodorakos et al., Proc. SPIE 11267, Laser Applications in Microelectronic and Optoelectronic Manufacturing (LAMOM) XXV, 1126709 (11 March 2020)

Lines' width ~ 90 µm Lines' gap ~ 60 µm

Use case Ib. Laser printed, low-cost, flexible RFID antennas made of Cu nanoparticles

SLS of Cu nanoparticle inks

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a) b) Laser beam resistivity bulk resistivity inted pattern resistivity ($\mu \Omega^* cm$) laser path Scanning step substrate c) scanning step (µm) 25 40 50 30 20 10 50 vertical scanning step (µm) 200 µm

"Copper micro-electrode fabrication using laser printing and laser sintering processes for on-chip antennas on flexible integrated circuits", O. Koritsoglou et al., Opt. Mater. Express 9, 3046-3058, (2019),



Resulting conductive patterns (RFIDs)

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01/05/2020-30/10/2023 Topic: H2020-DT-NMBP-18-2019 (IA)

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Use case IIa. Flexible, ITO-free OPVs

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R@LA-FLEX

Laser printing and laser sintering of metal grids as transparent and conductive electrodes of OPVs



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Photocurrent mapping of resulting inverted OPV devices



S. Pozov *et al.* "Highly Efficient Indium Tin Oxide-Free Inverted Organic Photovoltaics using Laser Induced Forward Transfer Silver Nanoparticle Embedded Metal Grids, accepted for publication, ACS Appl. Electron. Mater. 2022" 12



Use case IIb. Conformal laser printing & sintering for OTFT gate electrodes

Resulting gate electrode lines

150 um



OTFTs with LIFT printed and laser-sintered gate electrodes exhibited comparable performance with respect to standard fabrication steps

Performance evaluation comparison







20 um



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ROLA-FLEX

SYN-LASER: Assembly and wire-bonding of electronic circuits using laser printing processes



SYN-LASER aims at the development of new processes for the assembly and the wire bonding of electronic circuits with digital laser printing and sintering technology, in order to integrate them into industrial processes of packaging and production of electronic circuits.

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Laser beam

The project has been co-financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH - CREATE -INNOVATE with budget 857.679,30 € (project code:T1EDK-00814)





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Example IV: Laser EnAbled TransFer of 2D Materials: "LEAF-2D"

Introduction of Laser Direct Transfer processes (LIFT, LIBT) as a novel nano-manufacturing platform for the direct transfer of pixels of 2D materials onto various substrates for Si emitters and Graphene touch sensors. (FETOPEN-1-2019-2022)





Use case IV: LIFT of single layer graphene pixels



Scanning Electron Microscopy

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in 2D Materials, 8(4), 045017, (2021).



Upscaling example: LASER DIGITAL TRANSFER OF 2D MATERIALS **ENABLED PHOTONICS: FROM THE LAB 2 THE FAB** "L2D2" - EIC Transition



National Technical University of Athens





Graphenea



materials pixels in a single step-process, enabling wafer scale integration and new applications in photonics

Development	Upscaling-Piloting	TRL6 Validation	<u>Graphene and 2DM</u> High – quality single layer Graphene, MoTe ₂ , WS ₂ , grown on 8-inch wafers
		COMPLIANCE	LDT Process Laser Digital Transfer upscaling in terms of throughput and yield for 8-inch wafers processing
			LDT printing prototype An automated printing system implementing the LDT process in pre-industrial setting
			<u>Chiplets with integrated emitters</u> On-chip Si emitters enabled by 2DM
Sector Contraction of the sector of the sect	 nique elling roposition 	SPIN-OFF COMPANY	<u>Business case</u> Securing the IP of the LDT technology Identify the unique selling proposition Founding of a spinout

Horizon Europe-EIC-2021-Transition-OPEN-01





Within L2D2, we will upscale the laser transfer of intact and

pristine Gr and 2D



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Thank you! Questions?





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