Additive Manufacturing of Micro-Electro-Mechanical Systems

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The fabrication of MEMS through additive manufacturing processes applied to the microscale is described in detail in this entry, where the presently available building methods are analyzed.

Keywords: additive manufacturing ; 3D printing ; MEMS ; microstructures ; smart structures

1. Introduction

Additive manufacturing (AM) and 3D printing are consolidated processes for the production of components at the macroscale at the industrial level, although many optimization issues still remain open and motivate academic research. Instead, the AM of microstructures and MEMS (micro-electro-mechanical systems) is based on dedicated processes that are still under development and validation. In particular, some relevant process performances such as accuracy, resolution, and repeatability are not fully consolidated, and materials availability is still limited. The AM processes are classified into seven categories according to the international standard: binder jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination, and vat photopolymerization. By starting from the original processes classification, many variations were introduced and original methods were developed. As a result, a very high number of fabrication methods are available today, with different levels of maturity and reliability. Similarly, many associated acronyms can be found, sometimes with the same meaning.

The development of a MEMS based on 3D printing and AM always needs a specific design approach. The knowledge of the available process typologies, combinations, performances, and available materials is mandatory to improve the manufacturability and sustainability of micro 3D-printed devices. The common advantage of all AM methods is the direct building from the digital geometry file or model (computer-aided design, CAD) to the real component. This conversion is possible with wider shape freedom than with conventional micromachining building processes. At the present level of development, some AM methods demonstrated resolutions up to the nanometer range and improved the quality of structures in terms of surface finishing and parts geometry. The integration of AM methods into high-performance technologies (nanoimprint lithography, roll-to-roll processing, etc.) is possible, as the development of combinations of different additive methods.

The AM available materials are increasing in number, increasing those ones with functional properties. The compatible materials are polymers (polyamide, acrylates, polylactic acid or “PLA”, acrylonitrile butadiene styrene or “ABS”, epoxy resins, polycarbonate), metals (titanium, aluminum and nickel alloys, stainless steel), ceramics (alumina, lead zirconate titanate or “PZT”, silicon carbide, titanium dioxide), and soft materials (hydrogel, liquid crystals, polydimethylsiloxane or “PDMS”). Many AM methods show recurring issues related to dimensional accuracy and thermal shrinkage, especially in polymer-based processes, ceramic green parts sintering, and metal parts fabrication.

The emerging AM technologies applied to the micro- and nanoscales demonstrate preliminary applications in mechanics, electronics (sensors, light-emitting diodes-LEDs), optics and photonics (filters, photonic crystals, meta-materials, diffractive elements), medicine and bionics. The rise of AM is expected in some emerging fields of microstructures such as wearable electronics, flexible batteries management, internet of things (IOT), printed bionics/biomechanics, lab-on-chip, and self-powered sensors.

2. Classification of AM Processes for MEMS

The comprehensive review of the presently available AM processes suitable for the microscale can be divided into four categories: powder-based processes, other laser-based processes, extrusion-based processes, and other processes. The next sessions report the description of these processes, the associated materials, and features size. The differences among the process variants are reported and the multitude of acronyms available in the literature are disambiguated.

The nomenclature of AM processes is subjected to frequent revisions and updates, under the guidelines given by ASTM standards. However, many acronyms used in the past, although formally outdated, are still commonly used in scientific papers and technical reports due to their clear technological significance. For example, the *selective laser melting (SLM)* process has been re-named as *laser-based powder bed fusion of metals (PBF-LB/M)* and *laser-based powder bed fusion of polymers (PBF-LB/P)*. In this entry, the AM processes nomenclature cited is not limited to the international standards presently active and also includes widely used terms and definitions.

The powder-based AM processes refer to the presence of powder bed or powder injection feedstock. The laser-based processes (excluding those already described in the first category) refer to laser power sources. The extrusion-based processes identify the building growth through extruded layers of materials. Finally, the other processes not included in the previous categories are reported. The block diagram below reports the AM processes for the microscale organized in their respective categories.

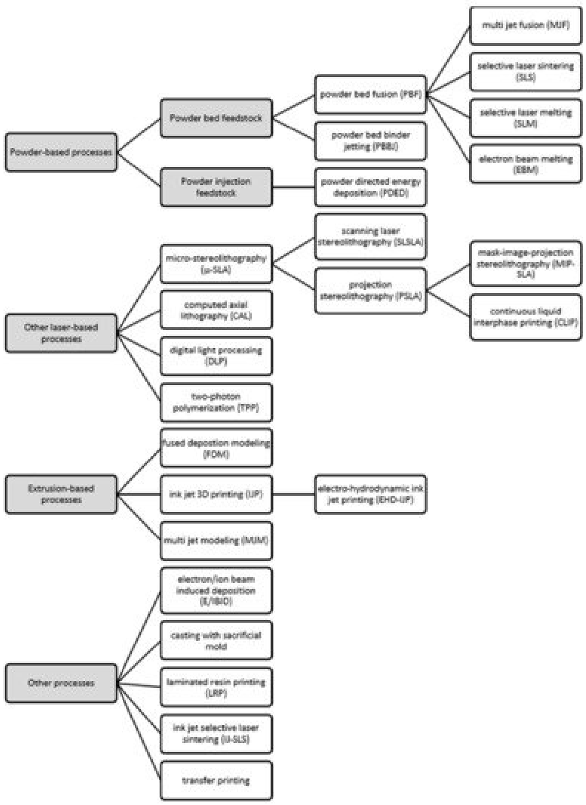

Figure. Classification of the AM processes for MEMS fabrication.