INDUSTRIAL PROCESS

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SESSION 8 ADDITIVE

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Fused deposition modeling (**FDM**) is an additive manufacturing technology commonly used for modeling, prototyping, and production applications.

FDM works on an "additive" principle by laying down material in layers; a plastic filament or metal wire is unwound from a coil and supplies material to produce a part.

The technology was developed by S. Scott Crump in the late 1980s and was commercialized in 1990.[1]

The term *fused deposition modeling* and its abbreviation to *FDM* are trademarked by Stratasys Inc. The exactly equivalent term, ***fused filament fabrication*** (***FFF***), was coined by the members of the RepRap project to give a phrase that would be legally unconstrained in its use. It is also sometimes called Plastic Jet Printing (PJP).

History

Fused deposition modeling (FDM) was developed by S. Scott Crump in the late 1980s and was commercialized in 1990 by Stratasys.[2] With the expiration of the patent on this technology there is now a large open-source development community, as well as commercial and DIY variants, which utilize this type of 3D printer. This has led to a two orders of magnitude price drop since this technology's creation.

Process

FDM begins with a software process which processes an STL file (stereolithography file format), mathematically slicing and orienting the model for the build process. If required, support structures may be generated. The machine may dispense multiple materials to achieve different goals: For example, one may use one material to build up the model and use another as a soluble support structure,[3] or one could use multiple colors of the same type of thermoplastic on the same model.

The model or part is produced by extruding small beads of thermoplastic material to form layers as the material hardens immediately after extrusion from the nozzle.

A plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off. There is typically a worm-drive that pushes the filament into the nozzle at a controlled rate.

The nozzle is heated to melt the material. The thermoplastics are heated past their glass transition temperature and are then deposited by an extrusion head.

The nozzle can be moved in both horizontal and vertical directions by a numerically controlled mechanism. The nozzle follows a tool-path controlled by a computer-aided manufacturing (CAM) software package, and the part is built from the bottom up, one layer at a time. Stepper motors or servo motors are typically employed to move the extrusion head. The mechanism used is often an X-Y-Z rectilinear design, although other mechanical designs such as deltabot have been employed.

Although as a printing technology FDM is very flexible, and it is capable of dealing with small overhangs by the support from lower layers, FDM generally has some restrictions on the slope of the overhang, and cannot produce unsupported stalactites.

Myriad materials are available, such as ABS, PLA, polycarbonate, polyamides, polystyrene, lignin, among many others, with different trade-offs between strength and temperature properties.

Commercial applications

FDM, a prominent form of rapid prototyping, is used for prototyping and rapid manufacturing. Rapid prototyping facilitates iterative testing, and for very short runs, rapid manufacturing can be a relatively inexpensive alternative.[4]

FDM uses the thermoplastics ABS, ABSi, polyphenylsulfone (PPSF), polycarbonate (PC), and Ultem 9085, among others. These materials are used for their heat resistance properties. Ultem 9085 also exhibits fire retardancy making it suitable for aerospace and aviation applications.

FDM is also used in prototyping scaffolds for medical tissue engineering applications.[5]

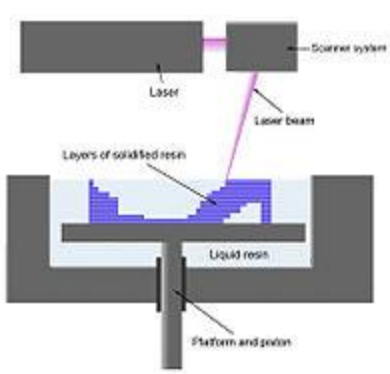
An SLA produced part

Stereolithography (**SLA** or **SL**; also known as **optical fabrication**, **photo-solidification**, **solid free-form fabrication** and **solid imaging**) is an additive manufacturing or 3D printing technology used for producing models, prototypes, patterns, and production parts up one layer at a time by curing a photo-reactive resin with a UV laser or another similar power source.[1]

History

The term "stereolithography" was coined in 1986 by Charles (Chuck) W. Hull,[2] who patented it as a method and apparatus for making solid objects by successively "printing" thin layers of an ultraviolet curable material one on top of the other. Hull's patent described a concentrated beam of ultraviolet light focused onto the surface of a vat filled with liquid photopolymer. The light beam draws the object onto the surface of the liquid layer by layer, and using polymerization or cross-linking to create a solid, a complex process which requires automation. In 1986, Hull founded the first company to generalize and commercialize this procedure, 3D Systems Inc,[3][4][5] which is currently based in Rock Hill, SC. More recently, attempts have been made to construct mathematical models of the stereolithography process and design algorithms to determine whether a proposed object may be constructed by the process[1]

Technology[



Stereolithography apparatus

Stereolithography is an additive manufacturing process which employs a vat of liquid ultraviolet curable photopolymer "resin" and an ultraviolet laser to build parts' layers one at a time. For each layer, the laser beam traces a cross-section of the part pattern on the surface of the liquid resin. Exposure to the ultraviolet laser light cures and solidifies the pattern traced on the resin and joins it to the layer below.

After the pattern has been traced, the SLA's elevator platform descends by a distance equal to the thickness of a single layer, typically 0.05 mm to 0.15 mm (0.002" to 0.006"). Then, a resin-filled blade sweeps across the cross section of the part, re-coating it with fresh material. On this new liquid surface, the subsequent layer pattern is traced, joining the previous layer. A complete 3-D part is formed by this process. After being built, parts are immersed in a chemical bath in order to be cleaned of excess resin and are subsequently cured in an ultraviolet oven.

Stereolithography requires the use of supporting structures which serve to attach the part to the elevator platform, prevent deflection due to gravity and hold the cross sections in place so that they resist lateral pressure from the re-coater blade. Supports are generated automatically during the preparation of 3D Computer Aided Design models for use on the stereolithography machine, although they may be manipulated manually. Supports must be removed from the finished product manually, unlike in other, less costly, rapid prototyping technologies.

Advantages and disadvantages

One of the advantages of stereolithography is its speed; functional parts can be manufactured within a day. The length of time it takes to produce one particular part depends on the size and complexity of the project and can last from a few hours to more than a day. Most stereolithography machines can produce parts with a maximum size of approximately 50×50×60 cm (20"×20"×24") and some, such as the Mammoth stereolithography machine (which has a build platform of 210×70×80 cm),[7] are capable of producing single parts of more than 2 m in length. Prototypes made by stereolithography are strong enough to be machined and can be used as master patterns for injection molding, thermoforming, blow molding, and various metal casting processes.

Although stereolithography can produce a wide variety of shapes, it has often been expensive; the cost of photo-curable resin has long ranged from $80 to $210 per liter, and the cost of stereolithography machines has ranged from $100,000 to more than $500,000.

Recently, renewed public interest in stereolithography has inspired the design of several consumer model printers with drastically reduced prices, such as the Ilios HD by OS-RC, the Form 1 by Formlabs, the Titan 1 by Kudo3D, the Pegasus Touch by FSL3D and the Nobel 1.0 by XYZPrinting. There has also been a drastic reduction in the cost of photo-curable resins, with USA based providers such as MakerJuice Labs offering materials as low as $40 per liter and European based providers such as spot-A Materials offering materials for €68 per liter.

Ion beam lithography is the practice of scanning a focused beam of ions in a patterned fashion across a surface in order to create very small structures such as integrated circuits or other nanostructures.[1]

Ion beam lithography has been found to be useful for transferring high-fidelity patterns on three-dimensional surfaces.[2]

Ion beam lithography offers higher resolution patterning than UV, X-ray, or electron beam lithography because these heavier particles have more momentum. This gives the ion beam a smaller wavelength than even an e-beam and therefore almost no diffraction. The momentum also reduces scattering in the target and in any residual gas. There is also a reduced potential radiation effect to sensitive underlying structures compared to x-ray and e-beam lithography.[3]

Ion beam lithography, or ion projection lithography, is similar to Electron beam lithography, but uses much heavier charged particles, ions. In addition to diffraction being negligible, ions move in straighter paths than electrons do both through vacuum and through matter, so there seems be a potential for very high resolution. Secondary particles (electrons and atoms) have very short range, because of the lower speed of the ions. On the other hand, intense sources are more difficult to make and higher acceleration voltages are needed for a given range. Due to the higher energy loss rate, higher particle energy for a given range and the absence of significant space charge effects, shot noise will tend to be greater.

Fast moving ions interact differently with matter than electrons do, and, due to their higher momentum, their optical properties are different. They have much shorter range in matter and move straighter through it. At low energies, at the end of the range, they lose more of their energy to the atomic nuclei, rather than to the atoms, so that atoms are dislocated rather than ionized. If the ions don't defuse out of the resist, they dope it. The energy loss in matter follows a Bragg curve and has a smaller statistical spread. They are "stiffer" optically, they require larger fields or distances to focus or bend. The higher momentum resists space charge effects.

Collider particle accelerators have shown that it is possible to focus and steer high momentum charged particles with very great precision.

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