Solid Freeform Fabrication
An Advanced Manufacturing Approach

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Introduction.

Solid freeform fabrication (SFF) is the production of freeform solid objects directly from a computer model without part-specific tooling or human intervention. SFF has been realized in the last ten years through the merging of several previously distinct technologies: computer science, mechanical design, controls, high-energy beam technology and materials science and engineering. Their combination has produced over a relatively short time-frame numerous SFF methods. The value of SFF to the commercial sector is usually articulated in terms of reduced time to market (prototyping), low production "one-of-a-kind" parts and patterns for casting. The purpose of this introductory paper is to describe briefly some of the approaches to SFF as a background for the articles included in this proceedings.

Solid Freeform Fabrication Techniques.

A number of SFF techniques have been developed in the last decade. To date, only one has made a major entry into the commercial sector, the 3D Systems Laser Stereolithography Apparatus (SLA). Illustrated in Figure 1, a UV light source scans a photosensitive polymer which partially cures under the energetic light source. After each layer is formed, the elevator is lowered to allow uncured liquid to flow over the top of the part, in preparation for scanning the next layer features. Post curing following laser scanning of the entire part completes the production cycle. Four other concepts using photosensitive polymers have been developed.

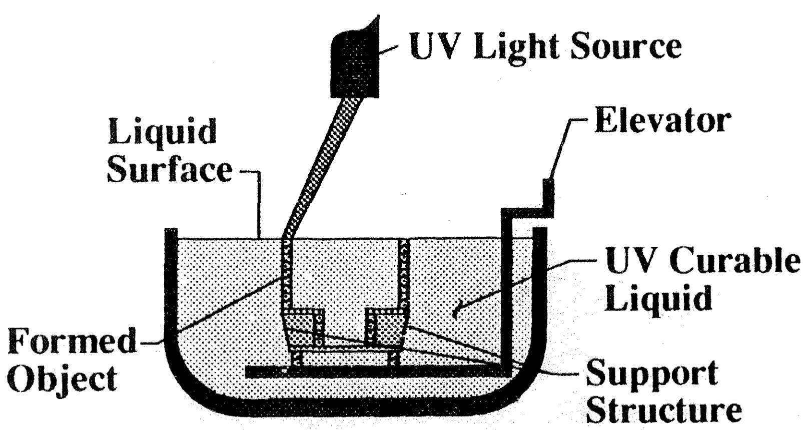

Figure 1: Stereolithography Apparatus (SLA)

Figure 2 shows a schematic of the Formigraphics Engine Company Photochemical Machining (PCM) apparatus. In this truly three dimensional approach, crossed lasers sum at the point of intersection to partially cure the polymer. No layering of the part is necessary with this technique, but the lasers must be accurately controlled to locate the curing voxel precisely.

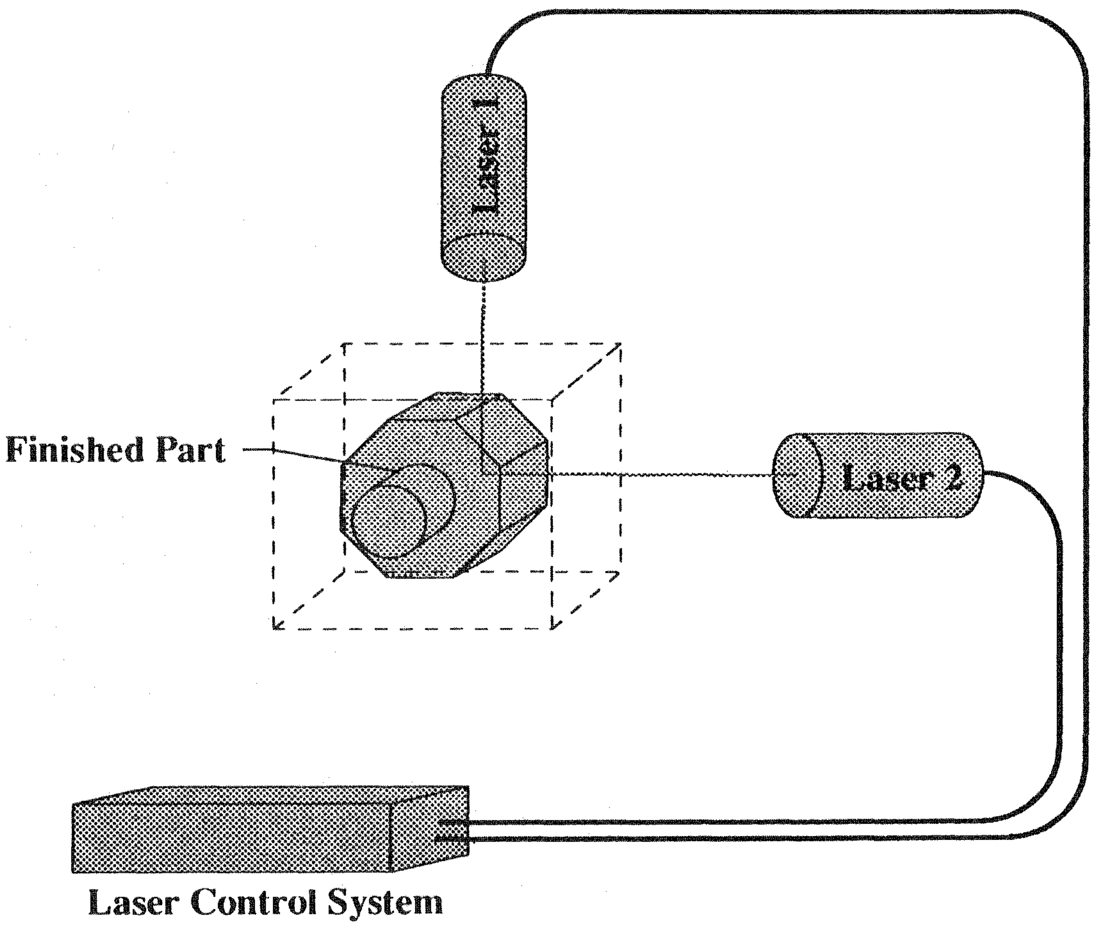

Figure 2: Photochemical Machining Apparatus (PCM)

The Cubital Instant Slice Curing Solider System is described in Figure 3. In Steps 1 and 2 the photosensitive polymer is carefully levelled on a base. In Step 3 a bath of light is beamed across a previously prepared mask, partially exposing the layer and curing the polymer. The uncured polymer is wiped away in Step 4 and a non-reacting material (wax) is spread over the surface to fill in the detents (Step 5). The layer is finished by milling to generate a new flat surface. This six step process is then repeated to build up a complete part. The wax is removed as the last step, revealing the photopolymer part.

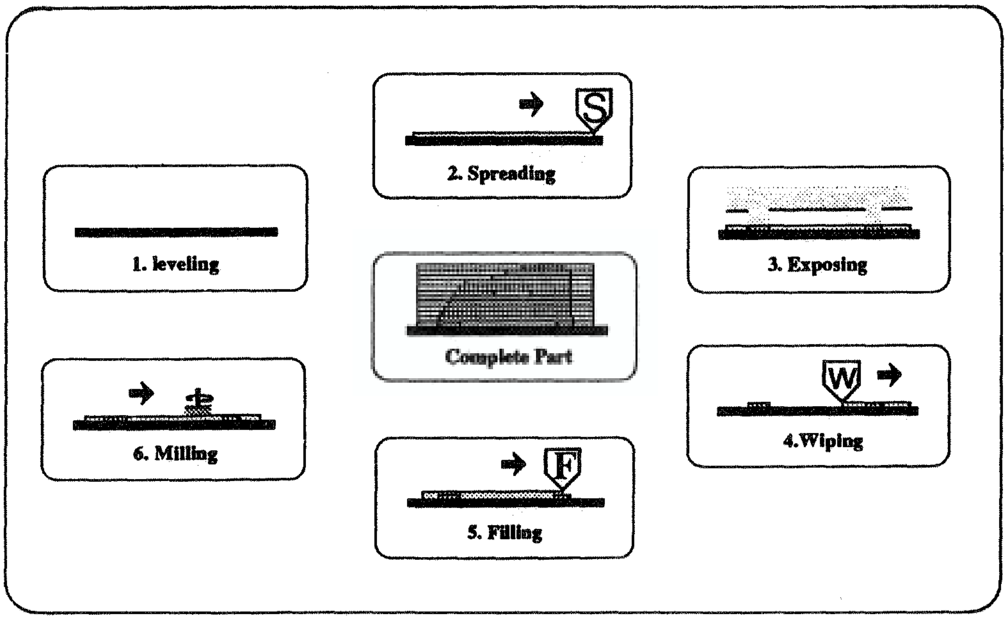

Figure 3: Cubital Instant Slice Curing Solider System

A variant of the Solider System and a predecessor to the 3D Systems SLA unit is light sculpting, Figure 4. Here, a polymer bath-elevator system is employed to support layered partial curing. Instead of a laser beam, a mask is produced from continuously fed stock which sweeps in stepwise fashion passed a blanketing light source.

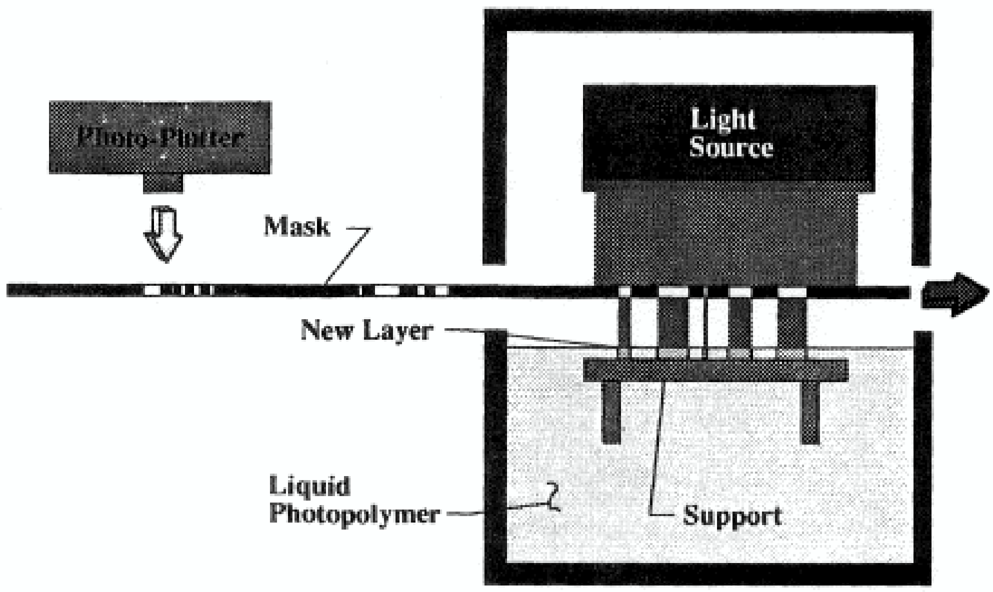

Figure 4: Light Sculpting Apparatus

The use of a computer-controlled, high-power laser to melt or sinter powder together is the basis for University of Texas developed DTM Corporation's Selective Laser Sintering (SLS) system, Figure 5. A thin layer of powder is spread over a base and a laser selectively scans the powder bed, sintering or melting the material together. The base is lowered slightly, a new layer of powder is spread over the selectively sintered layer, and the laser scans again, this time selectively sintering or melting powder together and into the preceding layer. The process is continued to generate a complete part.

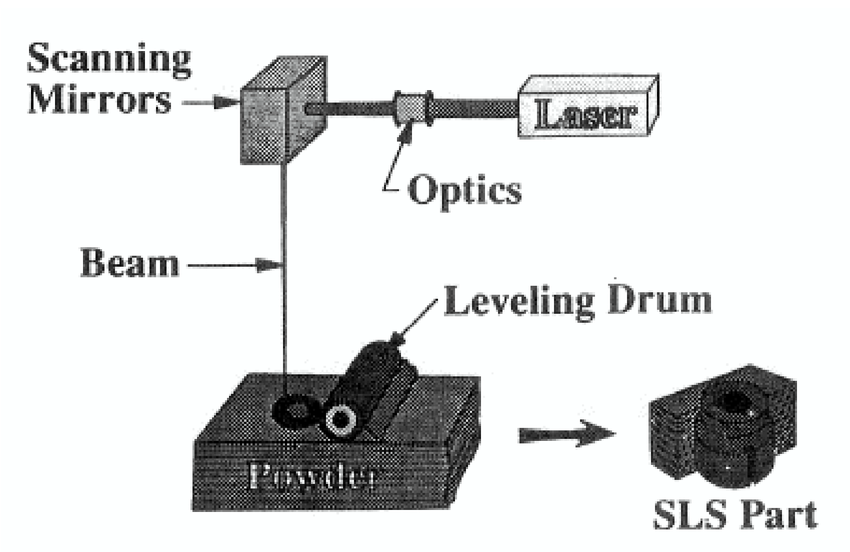

Figure 5: Selective Laser Sintering (SLS)

By replacing each powder layer with a thin strip of metal, and using the laser to "cookie-cut" a cross section, the Hydronetics Laminated Object Manufacturing (LOM) process for sheet is obtained, Figure 6. After each sheet is cut, it is ground flat and stacked on previously cut layers. The complete assemblage may be sintered or brazed to create a finished part.

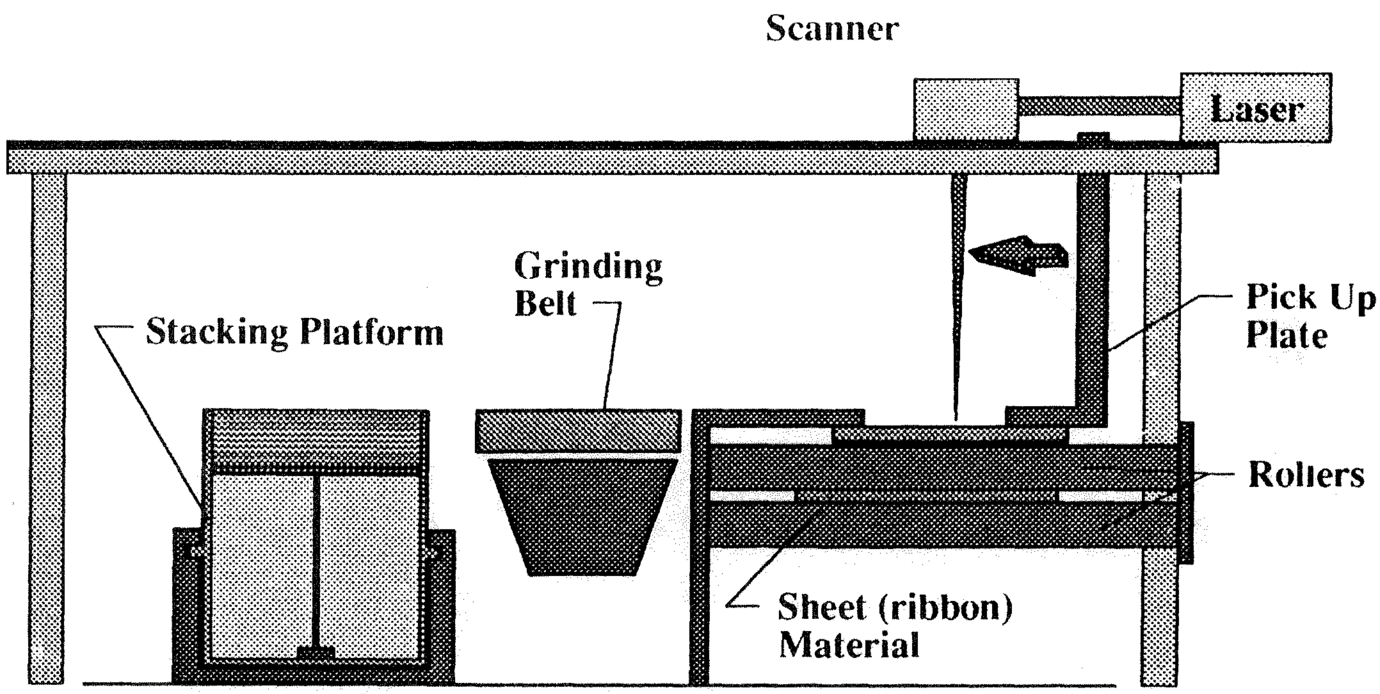

Figure 6: Laminated Object Manufacturing (LOM)

Another broad class of SFF techniques involves throwing material selectively onto a surface, which may be a substrate/mandrel or a stationary or translating table. Figure 7 shows the Automated Dynamics Corporation Ballistic Particle Manufacturing (BPM) unit. Raw material is fed into an injection system which creates a stationary particle beam. A table with x-y translation capability moves in a prescribed manner to generate the part.

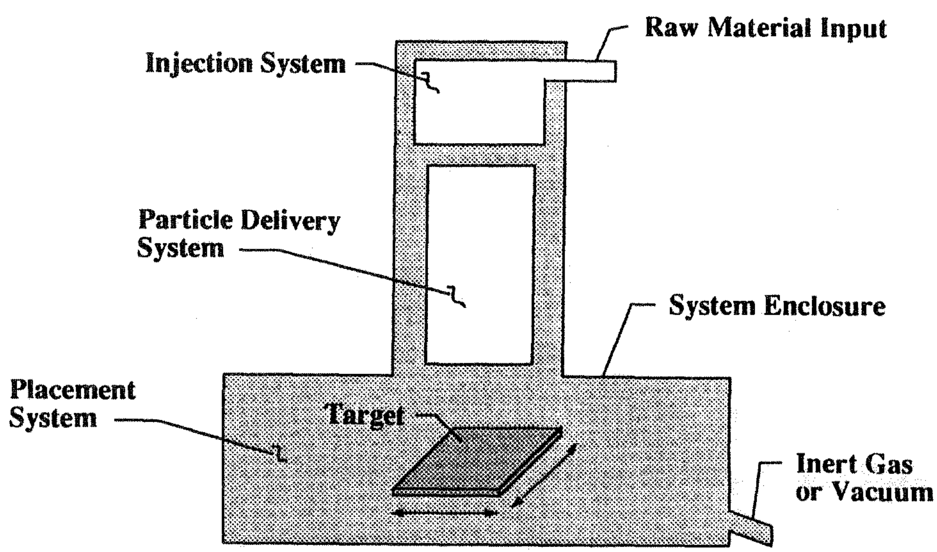

Figure 7: Ballistic Particle Manufacturing (BPM)

A process variant is being researched at MIT. In this process, a ceramic powder layer is selectively bound by an "ink-jet" of binder. To date, casting cores and shells have been produced using a multiple layer technology. One of the earliest predecessors to SFF followed a similar approach. Termed LAYERGLAZE™ and developed at United Technologies, the process involved laser melting powder distributed locally on the surface of a moving arbor, Figure 8. Final machining was necessary to maintain close tolerance.

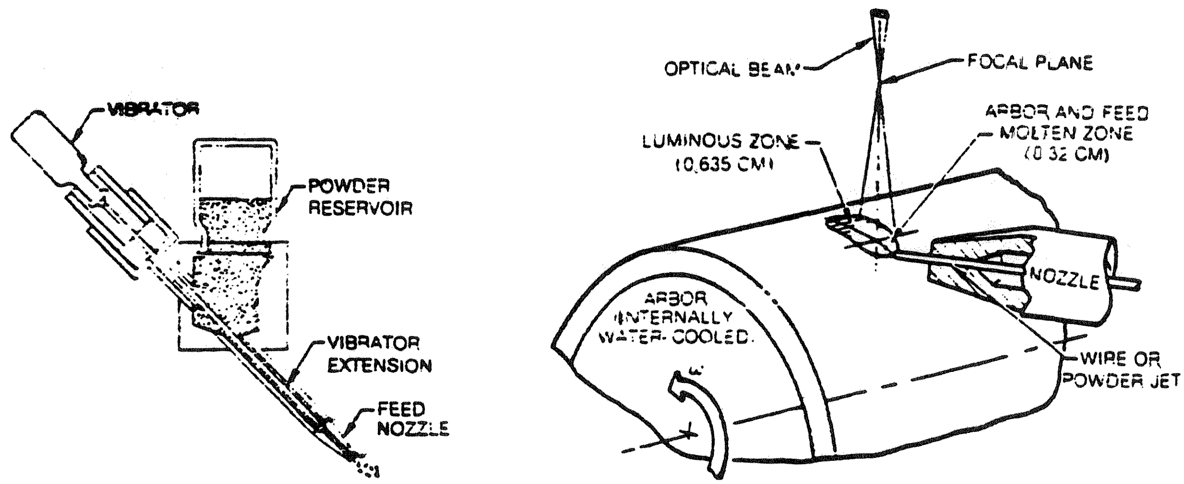

Figure 8: LAYERGLAZE™ Powder Method

Several techniques have been developed which convert a SFF part to a different material. For example, photopolymer or traditional polymer parts produced via any number of routes may be used to generate wax patterns for investment casting of metal parts. Researchers at Alcoa Laboratories and The Robotics Institute of Carnegie Mellon University have used a plasma spray approach to spray deposit steel onto a tooling shaped shell prepared using SFF. Selective lasering sintering may be used to produce directly a ceramic mold for casting (the "lost-lost-wax" technique).

The last SFF technique to be discussed is Gas Phase Deposition Selective Area Laser Deposition (SALD). Developed at The University of Texas at Austin, this technique uses both a laser and a translating table apparatus. Unlike the other SFF techniques, the gas is thermally or chemically decomposed from the atmosphere at the point of deposition defined by the computer-driven laser. This process might be considered to be a localized three-dimensional material deposition version of chemical/physical vapor deposition processes used extensively in microelectronics technology.

Solid Freeform Fabrication Symposium.

A three day symposium was held in Austin, Texas (August 6-8, 1990) to foster cross fertilization of the various SFF technologies, to share information between the research community and industrial users and to provide a forum where the various disciplines of SFF might be freely discussed. This proceedings is a compendium of papers presented at this meeting. Several papers deal with *computer issues*, such as computer generation of shapes (Drake [Alpha-1] and Gursoz,*et al.* [NOODLES]) and CAD formats (Darrah and Wielgus). *Physical modeling* of the photopolymerization process is discussed by Flach and Chartoff. Papers by Sun and Beaman, and Nelson and Barlow deal with physical modeling of selective laser sintering with special emphasis on polymer systems. Physical modeling of Gas Phase Deposition is treated by Jacquot, *et al.* Issues of control are addressed by Wu and Beaman. Papers are included which address specific SFF techniques: *stereolithography* (Baumgardner and Blake), *selective laser sintering* of polymers (Xue and Barlow, Balasubramanian and Barlow), metals (Manriguez and Bourell) and ceramics (Lakshminarayan *et al.*), *gas phase deposition* (Thissell, *et al.*, Zong, *et al.*), *metal spraying* (Fussell and Weiss) and *3D printing* of ceramic molds (Sachs and Cima).

It is the hope of the editors that this proceedings will serve as an initial source on SFF technology. Over the next decade advances in SFF will be the most exciting arena in total processing research and technology.

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