SELECTIVE LASER SINTERING

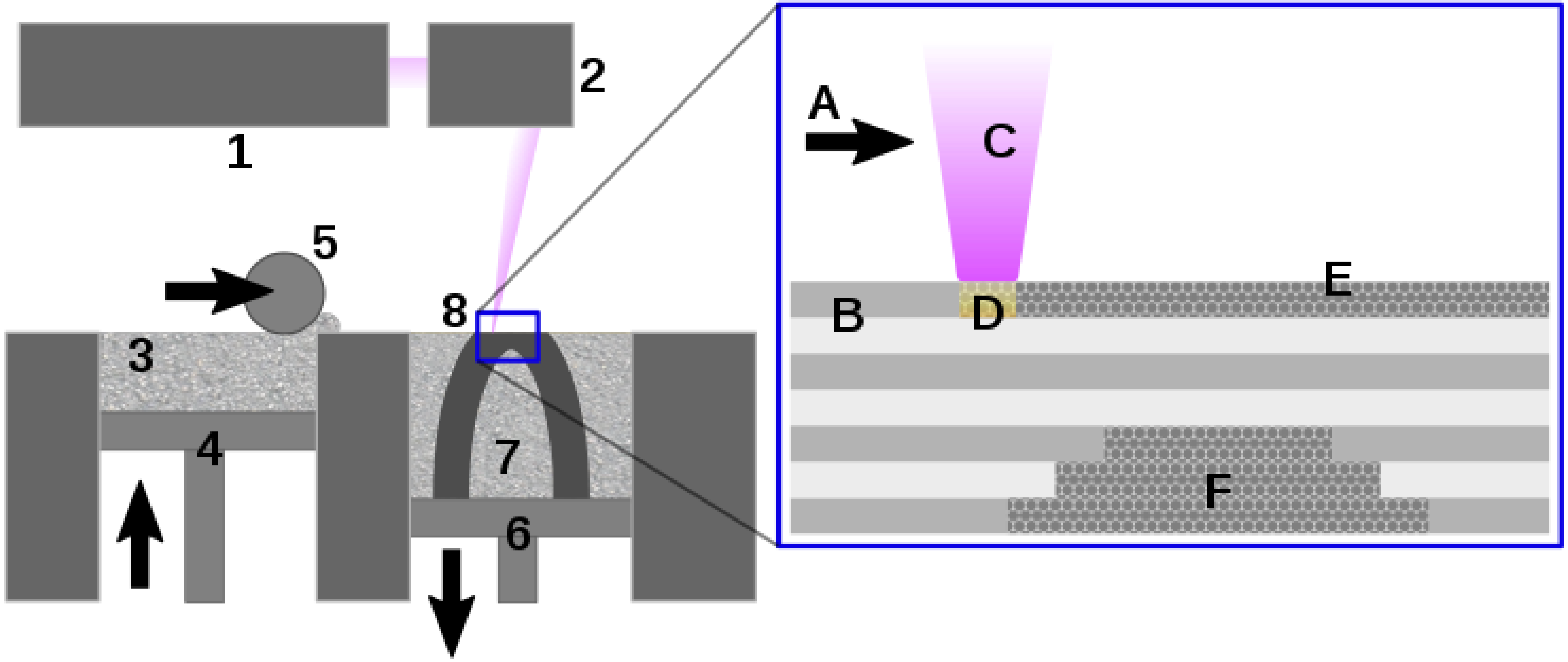
- Selective laser sintering (SLS) was developed and patented by Dr. Carl Deckard and academic adviser, Dr. Joe Beaman at the University of Texas at Austin in the mid-1980s, under sponsorship of DARPA

- Selective laser sintering (SLS) is an additive manufacturing (AM) technique that uses a laser as the power and heat source to sinter powdered material (typically nylon or polyamide), aiming the laser automatically at points in space defined by a 3D model, binding the material together to create a solid structure.

- Selective laser sintering (SLS) is a close cousin to direct metal laser sintering (DMLS), but builds parts made of plastic rather than metal. SLS uses a computer-controlled CO2 laser versus an ND: YAG fiber laser for DMLS, but both “draw” slices of a CAD model in a bed of material, fusing micron-sized particles of material one layer at a time.

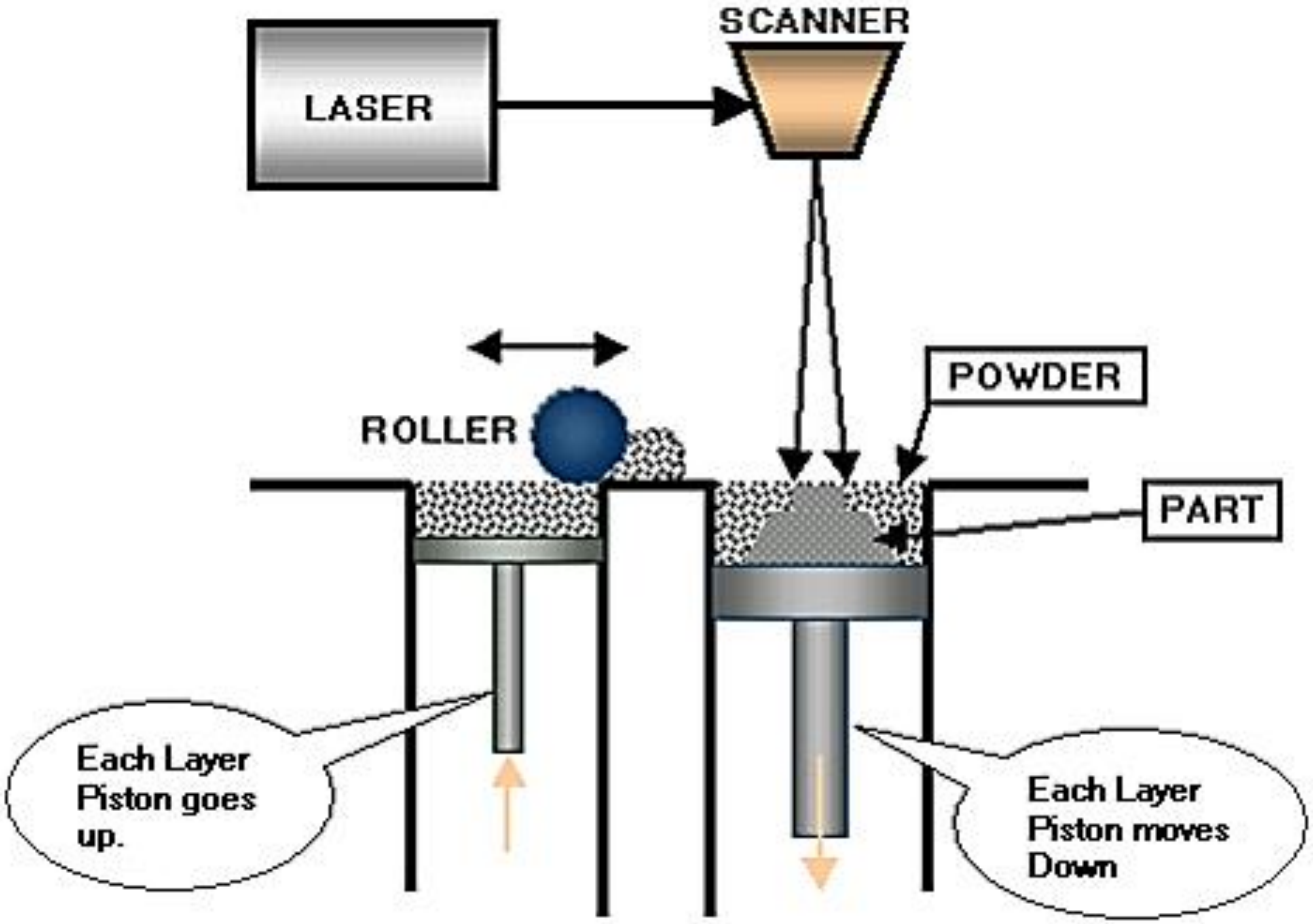
- An additive manufacturing layer technology, SLS involves the use of a high power laser (for example, a carbon dioxide laser) to fuse small particles of plastic, metal, ceramic, or glass powders into a mass that has a desired three-dimensional shape.

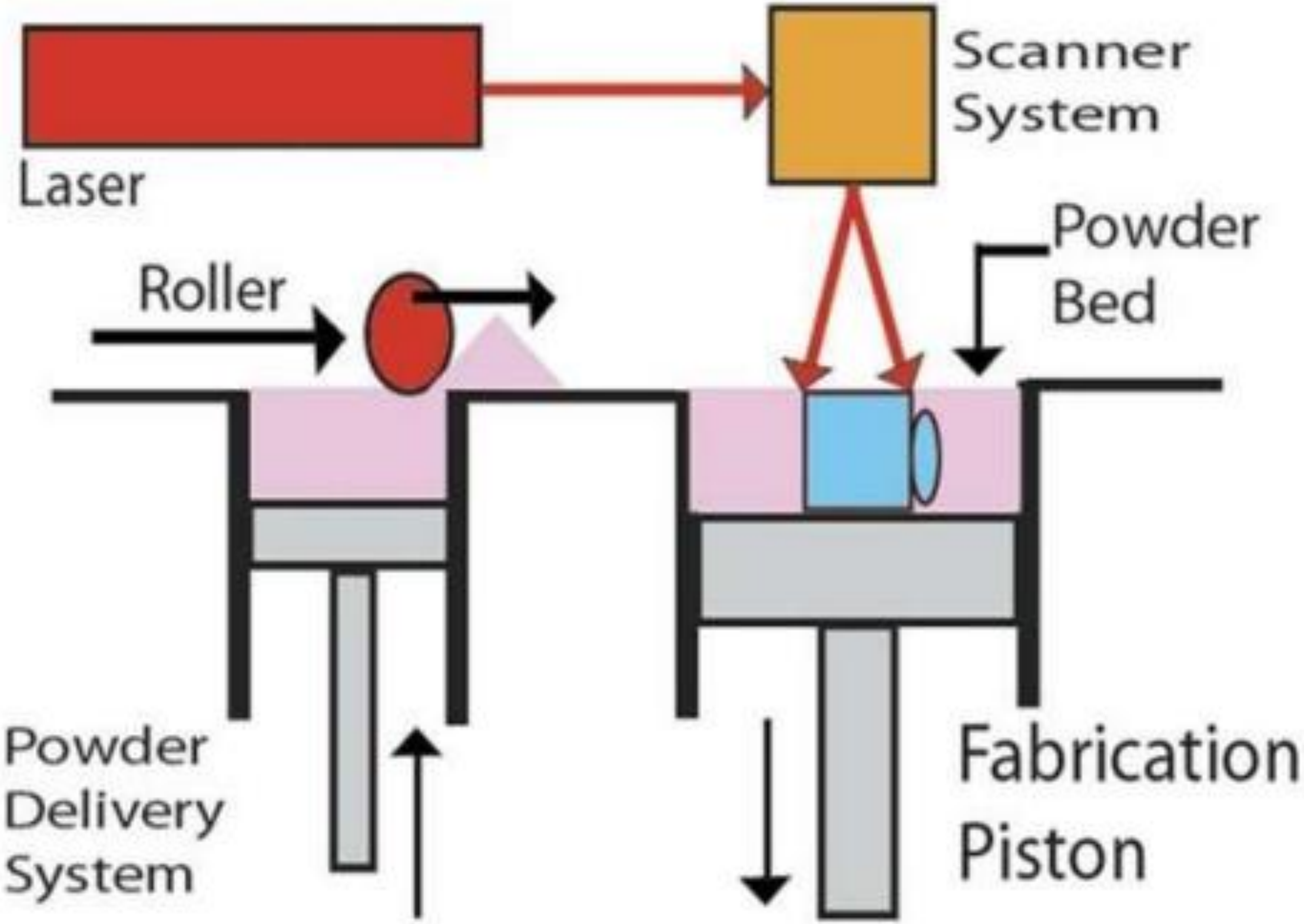
- The laser selectively fuses powdered material by scanning cross-sections generated from a 3-D digital description of the part (for example from a CAD file or scan data) on the surface of a powder bed. After each cross-section is scanned, the powder bed is lowered by one layer thickness, a new layer of material is applied on top, and the process is repeated until the part is completed

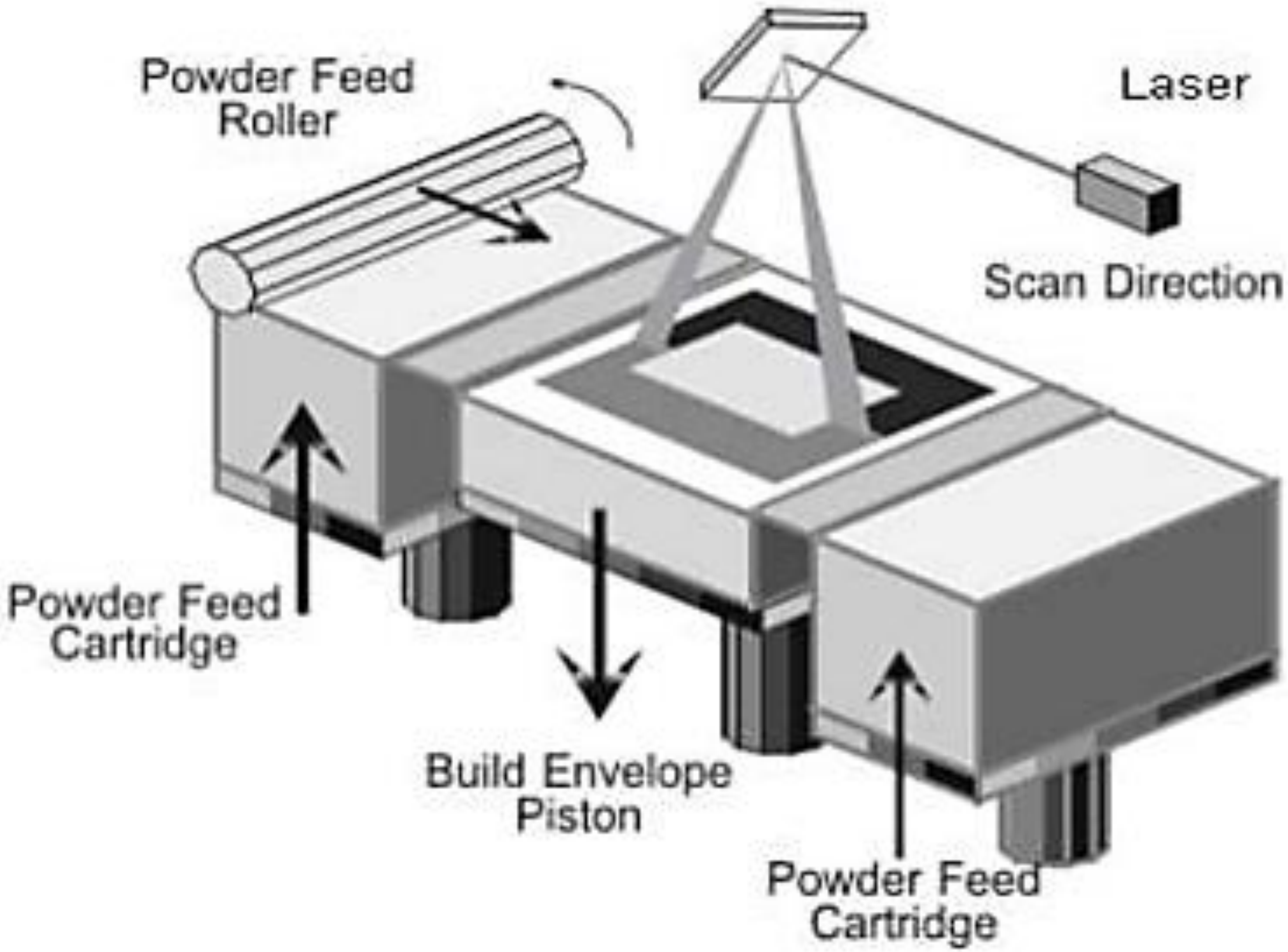


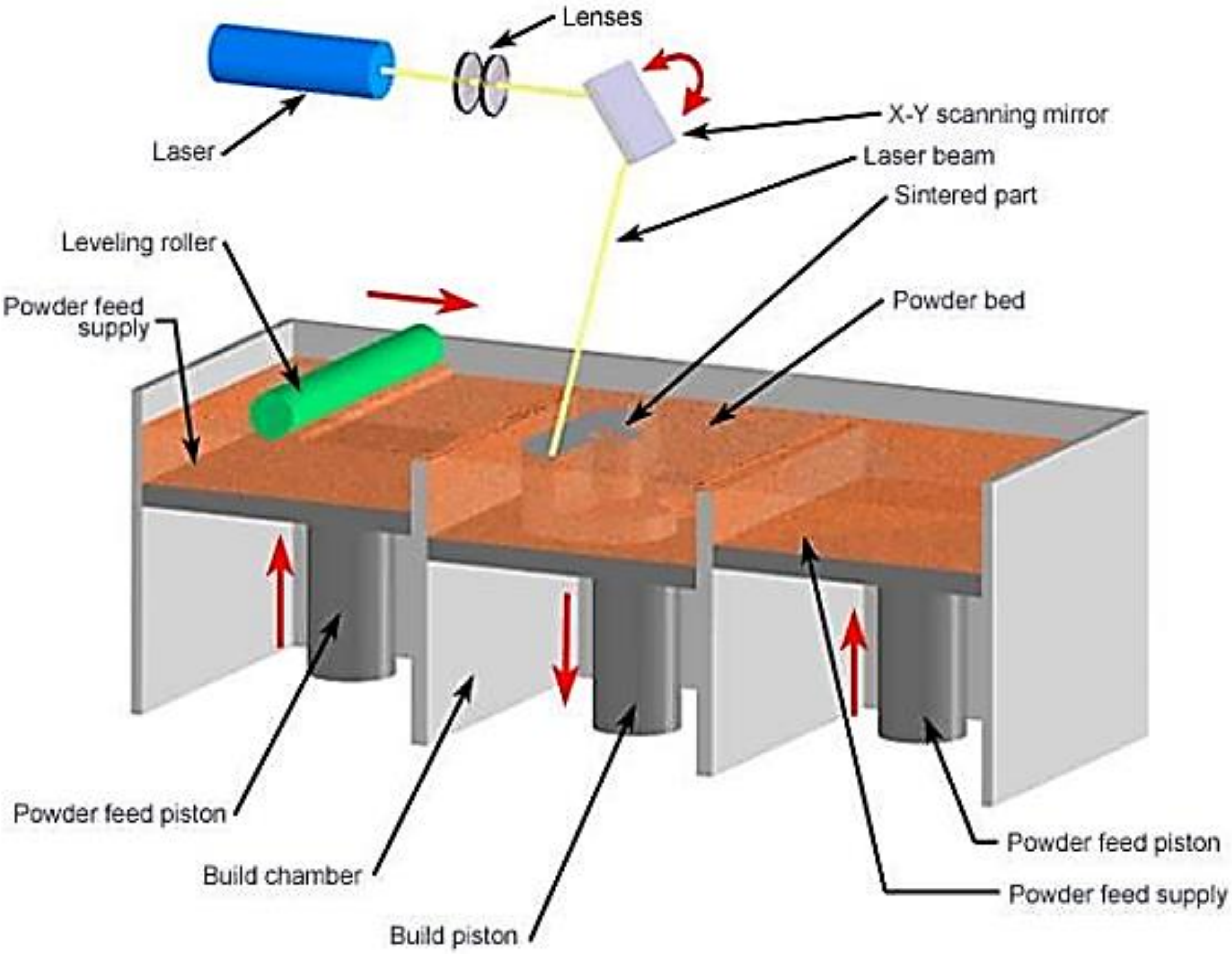
Selective laser sintering process
1 Laser **2** Scanner system **3** Powder delivery system **4** Powder delivery piston **5** Roller **6** Fabrication piston **7** Fabrication powder bed **8** Object being fabricated (see inset) **A** Laser scanning direction **B** Sintered powder particles (brown state) **C** Laser beam **D** Laser sintering **E** Pre-placed powder bed (green state) **F** Unsintered material in previous layers

- STL CAD file format. DTM view software uses the .STL files. This software do the required orientation and scaling of parts. This machine has auto nesting capabilities which will place multiple part optimally in the build chamber for best processing speed and results. Once the .STL file is placed and parameters are set the model is directly built from the sile.


LASER
SCANNER
POWDER
ROLLER
PART
Each Layer Piston goes up.
Each Layer Piston moves Down


Laser
Scanner System
Powder Bed
Roller
Powder Delivery System
Fabrication Piston


Powder Feed
Roller
Laser
Scan Direction
Powder Feed
Cartridge
Build Envelope
Piston
Powder Feed
Cartridge

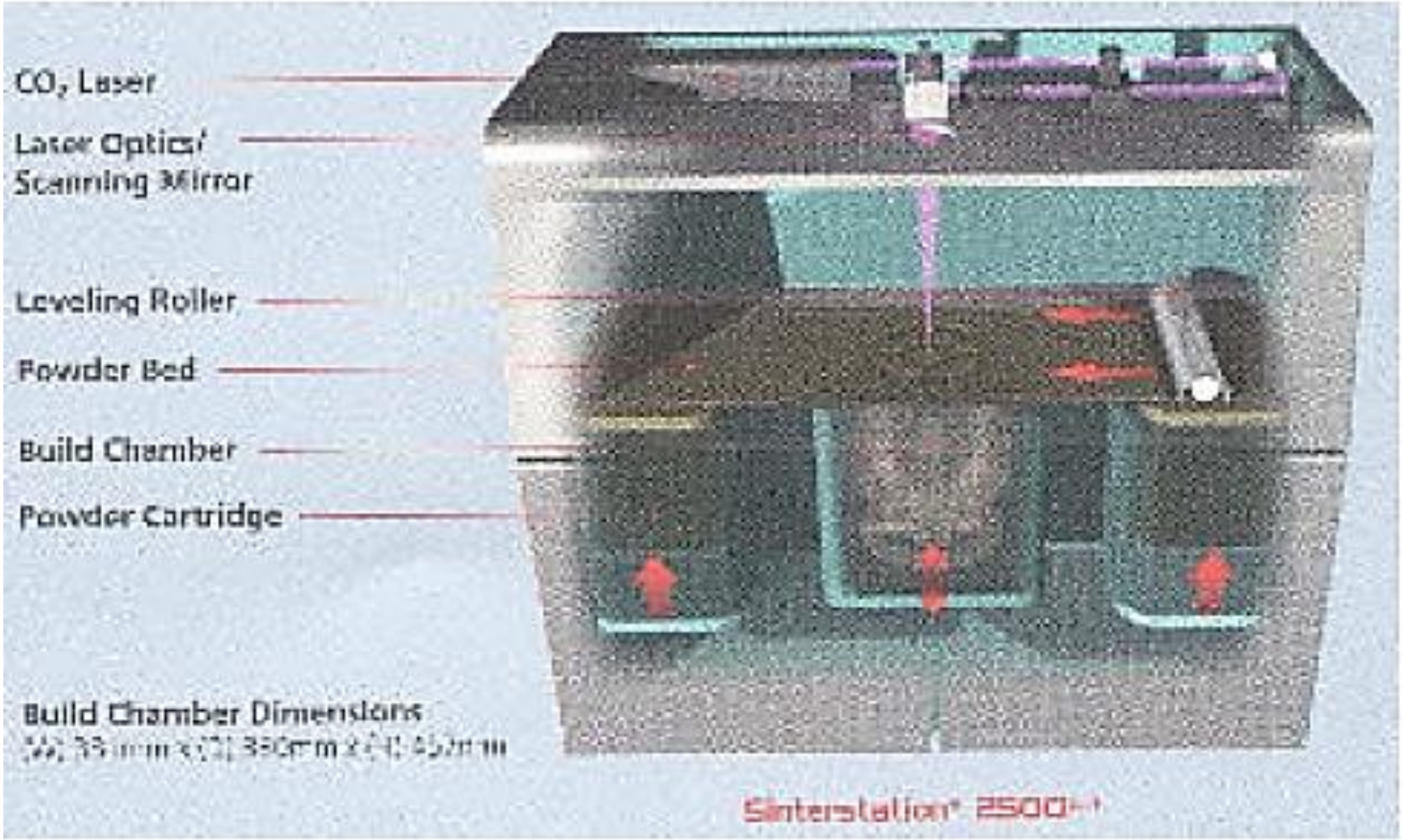


Lenses
Laser
X-Y scanning mirror
Laser beam
Sintered part
Leveling roller
Powder bed
Powder feed
supply
Powder feed piston
Build chamber
Build piston
Powder feed piston
Powder feed supply

PURPOSE OF SELECTIVE LASER SINTERING

- To avoid a prototyping tool.
- To decrease the time and cost of design to product cycle.
- It can use wide variety of materials to accommodate multiple application throughout the manufacturing process.

The Selective Laser Sintering process



- A thin layer of heat-fusible powder is deposited onto the part building chamber.
- The bottom-most cross-sectional slice of the CAD part under fabrication is selectively “drawn” (or scanned) on the layer of powder by a heat-generating CO2 laser. The interaction of the laser beam with the powder elevates the temperature to the point of melting, fusing the powder particles to form a solid mass.
- When the cross-section is completely drawn, an additional layer of powder is deposited via a roller mechanism on top of the previously scanned layer. This prepares the next layer for scanning.
- Steps 2 and 3 are repeated, with each layer fusing to the layer below it. Successive layers of powder are deposited and the process is repeated until the part is completed.

The SLS® system contains the following hardware components:

- Build chamber dimensions (381 × 330 × 457 mm)
- Process station (2100 × 1300 × 1900 mm)
- Computer cabinet (600 × 600 × 1828 mm)
- Chiller (500 × 800 × 900 mm)

APPLICATIONS

- As conceptual models - Physical representations of designs used to review design ideas, form and style.
- Functional models and working prototypes - Parts that can withstand limited functional testing, or fit and operate within an assembly.
- Polycarbonate patterns. Patterns produced using polycarbonate, then cast in the metal of choice through the standard investment casting process. These build faster than wax patterns and are ideally suited for designs with thin walls and fine features. These patterns are also durable and heat resistant.
- Metal tools - Direct rapid prototype of tools of molds for small or short production runs.

Advantages

- Good part stability
- Wide range of processing materials
- No part supports required
- Little post-processing required
- High throughput capabilities
- Self-supporting build envelop
- Parts are completed faster
- Damage is less
- Less wastage of material
- Advanced software support

DISADVANTAGES

- Initial cost of system is high
- High operational and maintenance cost
- Peripheral and facility requirement
- Large physical size of the unit
- Higher power consumption
- Poor surface finish

Materials

- Polyamide.
- Thermoplastic elastomer.
- Polycarbonate.
- Nylon.
- Metal.
- Ceramics.

Examples

- Boeing Uses Prototyping to Maximize Return on Investment - Boeing used the Sinterstation to prototyped visualization and technical review models, reproduce existing parts, and produced scaled models for laboratory testing.

RP part for aerospace and defense industry
(Coutesy 3D Systems)

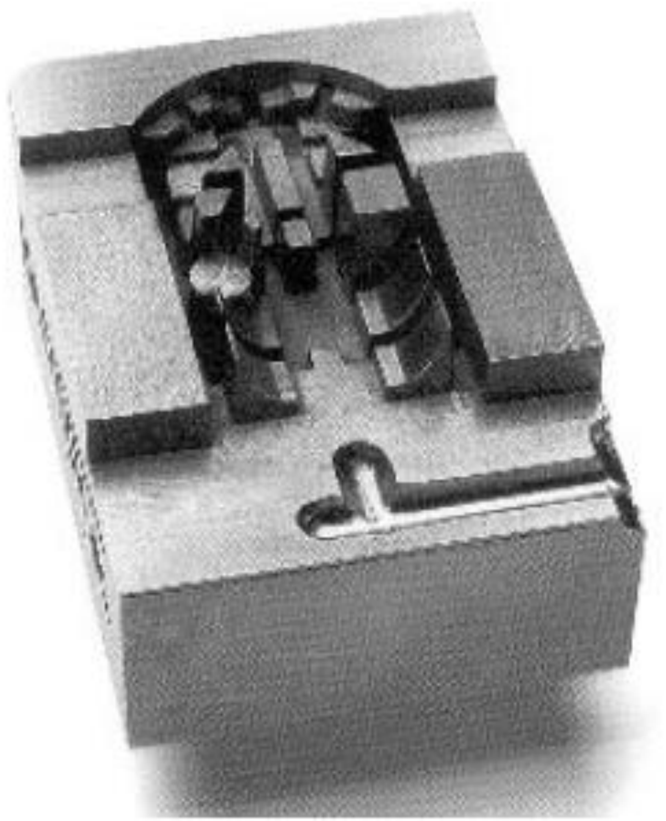
Examples

- Reebok Uses SLS Process for Developing Sports Shoes - Traditional prototyping methods would have taken 30 to 60 days and the company decided to use the SLS system and this took only seven hours and about US$250 worth of materials.

Prototypes for Reebok golf shoe soles produced by SLS®
(Courtesy 3D Systems)

Examples

- Rover Applies SLS Process in Tooling for Injection Molding -

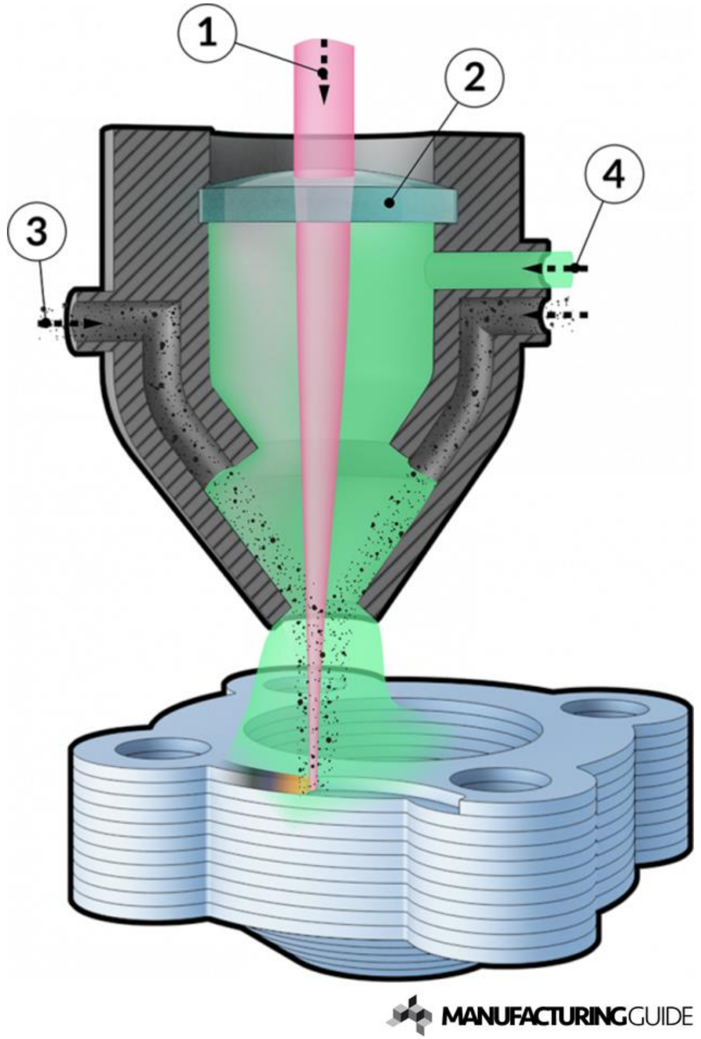


Metal injection molding tools produced by SLS®
(Courtesy 3D Systems)

LASER ENGINEERED NET SHAPING (LENS)

THE PROCESS

- A laser beam [1] created by a laser generator is focused through a lens [2] onto the workpiece. Metal powder [3], or metal wire, is introduced at the focus of the laser beam, where the metal powder and workpiece melt and thus building on the surface. An inert gas [4] is supplied to protect both the laser and the melt from contamination during the welding process.



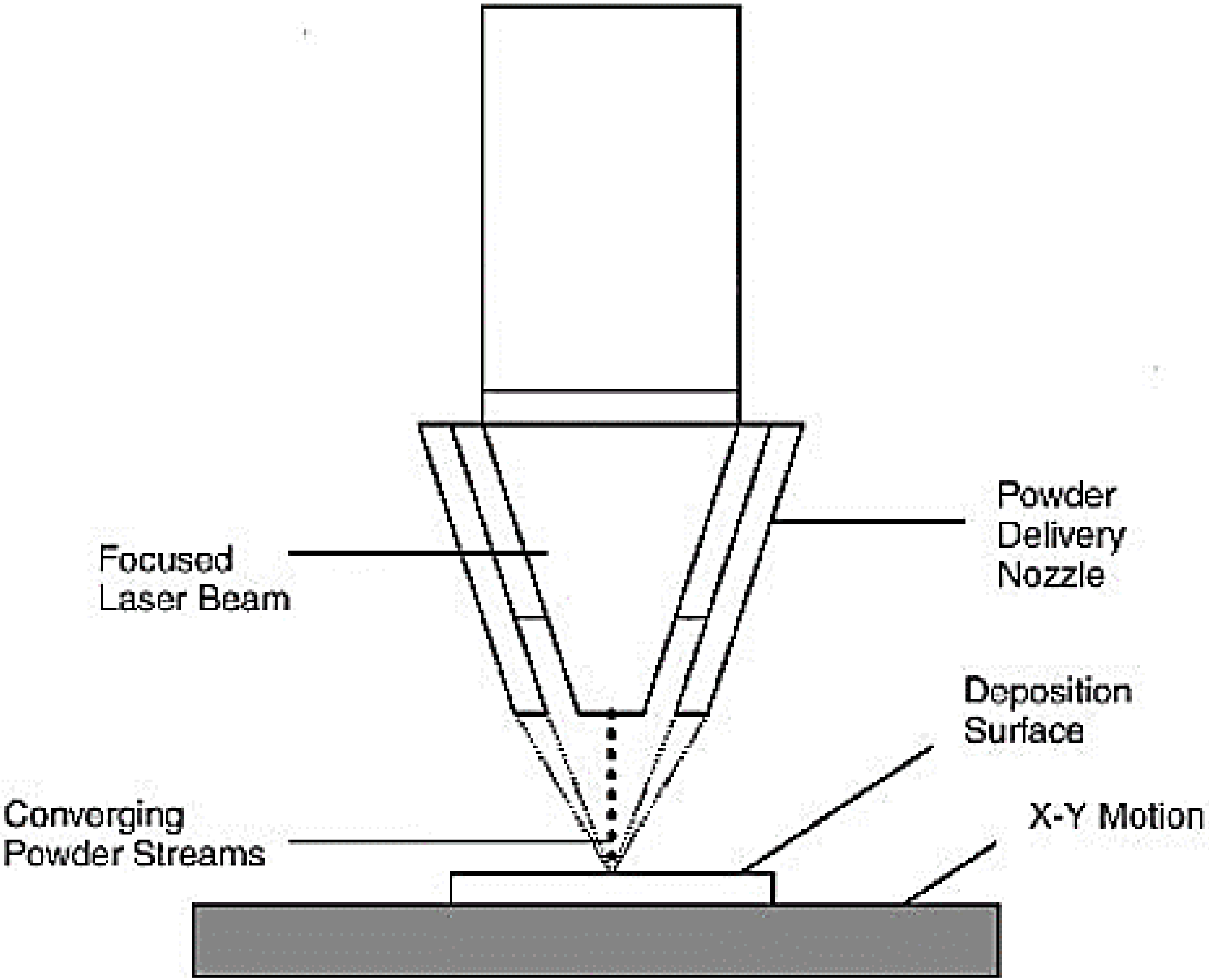
- Laser powder forming, also known by the proprietary name (laser engineered net shaping) is an additive manufacturing technology developed for fabricating metal parts directly from a computer-aided design (CAD) solid model by using a metal powder injected into a molten pool created by a focused, high-powered laser beam.

- A high power laser is used to melt metal powder supplied coaxially to the focus of the laser beam through a deposition head. The laser beam typically travels through the center of the head and is focused to a small spot by one or more lenses. The X-Y table is moved in raster fashion to fabricate each layer of the object. The head is moved up vertically after each layer is completed.

- Metal powders are delivered and distributed around the circumference of the head either by gravity, or by using a pressurized carrier gas. An inert shroud gas is often used to shield the melt pool from atmospheric oxygen for better control of properties, and to promote layer to layer adhesion by providing better surface wetting.

Process

- A deposition head supplies metal powder to the focus of a high powered Nd:YAG laser beam to be melted. This laser is typically directed by fiber optics or precision angled mirrors.
- The laser is focused on a particular spot by a series of lenses, and a motion system underneath the platform moves horizontally and laterally as the laser beam traces the cross-section of the part being produced. The fabrication process takes place in a low-pressure argon chamber for oxygen-free operation in the melting zone, ensuring that good adhesion is accomplished.
- When a layer is completed, the deposition head moves up and continues with the next layer. The process is repeated layer by layer until the part is completed. The entire process is usually enclosed to isolate the process from the atmosphere. Generally the prototypes need additional finishing, but are fully dense products with good grain formation.


Powder
Delivery
Nozzle
Focused
Laser Beam
Deposition
Surface
X-Y Motion
Converging
Powder Streams

Principle

- A high powered Nd:YAG laser focused onto a metal substrate creates a molten puddle on the substrate surface. Powder is then injected into the molten puddle to increase material volume.
- A “printing” motion system moves a platform horizontally and laterally as the laser beam traces the cross-section of the part being produced. After formation of a layer of the part, the machine’s powder delivery nozzle moves upwards prior to building next layer.

neodymium-doped yttrium aluminium garnet

Applications

- The LENS technology can be used in the following areas:
- (1) Build mold and die inserts
- (2) Producing titanium parts in racing industry
- (3) Fabricate titanium components for biological implants
- (4) Produce functionally gradient structures

Medical LENS produced metal part
(Courtesy of Optomec Inc.)

Advantages

- Superior material properties.
- Complex parts.
- Reduced post-processing requirements.

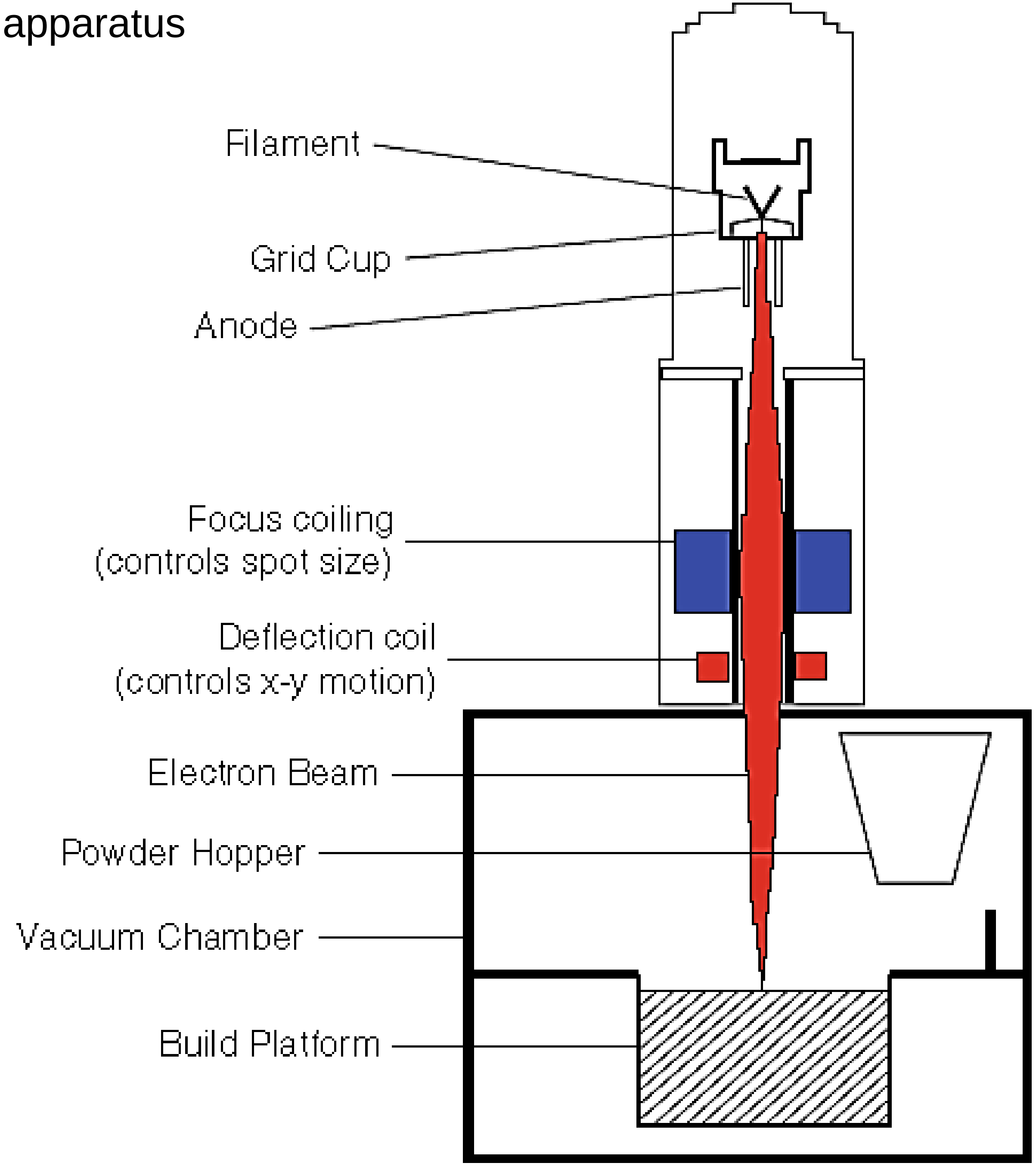
Disadvantages

- Limited materials.
- Large physical unit size.
- High power consumption.

Electron Beam Melting (EBM)

- Electron beam melting (EBM), also known as selective electron beam melting (SEBM)
- Uses a high-energy electron beam as a thermal energy source to fuse the powder.
- It is fairly comparable to SLM in its working principle, but it does have its specifics, with the heat source being a major difference.

Schematic of an EBM apparatus



- The electron beam in an EBM process is basically generated by a so-called electron gun. Under vacuum conditions, the electron gun extracts electrons from a filament (usually made of tungsten) with a voltage range of 30-60 kV and discharges them at approximately half the speed of light towards a layer of metal powder that has been predeposited on the build plate.

- The electron beam is directed with the help of two magnetic fields: one acting as a magnetic lens to narrow down the beam’s diameter and the other to deflect the beam towards the desired target points on the powder bed.

- The electron bombardment instantly converts the electrons’ high kinetic energy into thermal energy, which raises the powder’s temperature beyond its melting point and enables the selective fusion of particles in the powder bed.
- This continues until the part is constructed in a layer-by-layer fashion (similar to SLM). Here, high-vacuum conditions are crucial to circumvent issues like oxidation, contamination, and atmospheric interference.

- EBM is capable of processing highly reactive metals and high-melting-point metals and can provide exotic mechanical properties as a result.
- The most commonly used materials in EBM are titanium and chromium-cobalt alloys.
- Titanium alloys, for example, are of particular interest due to their biocompatibility, lightweight, and high mechanical strength.
- That is why it is ideal for applications that include spacecraft and biomedical implants.
- Turbine blades and engine parts are some of EBM’s most common applications.
- EBM has proven to have a much higher manufacturing speed than SLM but tends to have lower accuracy and finish quality.

Process

- The part to be produced is first designed in a 3D CAD program. The model is then sliced into thin layers, approximately a tenth of a millimeter thick.
- An equally thin layer of powder is scraped onto a vertically adjustable surface. The first layer's geometry is then created through the layer of powder melting together at those points directed from the CAD file with a computer-controlled electron beam.
- Thereafter, the building surface is lowered and the next layer of powder is placed on top of the previous layer. The procedure is then repeated so that the object from the CAD model is shaped layer by layer until a finished metal part is completed.

Principle

- Parts are built up when an electron beam is fired at the metal powder. The computer controlled electron beam in vacuum melts the layer of powder precisely as indicated by the CAD model with the gain of the electrons' kinetic energy.
- The building of the part is accomplished layer by layer. A layer is added once the previous layer has melted. In this way, the solid details are built up of thin metal slices melted together.

Applications

- The EBM process is used to manufacture H13 tool steel injection and compression molding tools, functional prototypes and components in small batches.

Differences between EBM and SLM

Characteristic	Electron beam melting	Selective laser melting
Thermal source	Electron beam	Laser
Atmosphere	Vacuum	Inert gas
Scanning	Deflection coils	Galvanometers
Energy absorption	Conductivity-limited	Absorptivity-limited
Powder pre-heating	Use electron beam	Use infrared heaters
Scan speeds	Very fast, magnetically-driven	Limited by galvanometer inertia
Energy costs	Moderate	High
Surface finish	Moderate to poor	Excellent to moderate
Feature resolution	Moderate	Excellent
Materials	Metals (conductors)	Polymers, metals and ceramics

	Selective Laser Sintering	Selective Laser Melting	Electron Beam Melting
Melting Point	below the melting point	above the melting point	above the melting point
Materials	all materials	all materials	all materials, especially titanium alloys
Type of Beam	laser beam	laser beam	electron beam
Energy Saving	++	+	+++
Melting Ratio	partial	fully	fully

BF Process		SLS	SLM	EBM
Fusion source		Laser	Laser	Electron beam
Compatible Materials		Polymers, metals	Metals	Metals (limited)
Printing resolution		20-150 µm	20-200 µm	50-150 µm
Pros		No need for support structures	No need for support structures	No need for support structures
		High speed	High accuracy	High speed
		Excellent layer adhesion	Good functionality	No oxidation and no residual stress
		Great for post-printing	Doesn't need a lot of post-processing	Preheating limits deformations
		Recyclability of unused powder (recommended amount: 50% recycled powder)	Recyclability of unused powder (recommended amount: 50% recycled powder)	Minimum material waste
Cons		Poor structural integrity (brittle and porous material)	High surface roughness and residual stress	Relatively low resolution
		Prone to shrinkage and warping	Anisotropic properties	Limited commercial options
		Requires a lot of post-process cleaning	Requires a supply of inert gas	Highly energy-intensive
		Produces relatively a lot of waste	Accuracy requires a longer process time	Relatively small size of manufactured part
		Expensive	Expensive	Highly expensive

- As powder particles absorb electrons they gain an increasingly negative charge. This has two potentially detrimental effects:

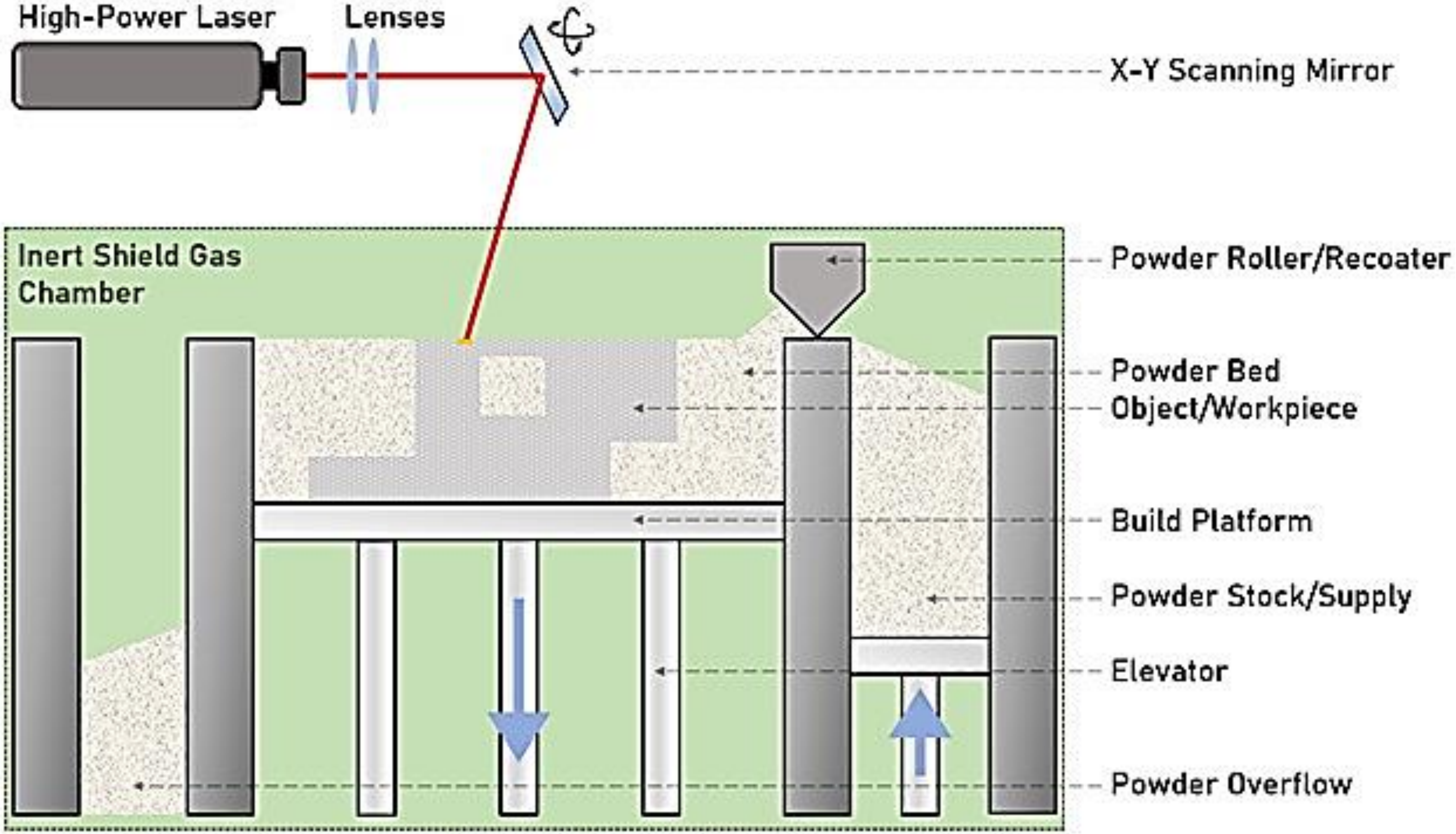
1. if the repulsive force of neighboring negatively charged particles overcomes the gravitational and frictional forces holding them in place, there will be a rapid expulsion of powder particles from the powder bed, creating a powder cloud; and
2. Increasing negative charges in the powder particles will tend to repel the incoming negatively charged electrons, thus creating a more diffuse beam.

<u>THERE ARE NO SUCH COMPLIMENTARY PHENOMENA WITH PHOTONS</u>

- EBM the powder bed must be conductive. Thus, EBM can only be used to process conductive materials (e.g., metals) whereas, lasers can be used with any material that absorbs energy at the laser wavelength (e.g., metals, polymers and ceramics).

LASER POWDER BED FUSION aka SLM

- In SLM, a high-powered laser selectively melts metal powder into a part in a layer-by-layer process. SLM is distinct from similar powder bed fusion techniques such as selective laser sintering (SLS) and direct metal laser sintering (DMLS) in that it fully melts metal, instead of sintering it (fusing it without reaching a liquid state).


High-Power Laser
Lenses
X-Y Scanning Mirror
Inert Shield Gas Chamber
Powder Roller/Recoater
Powder Bed
Object/Workpiece
Build Platform
Powder Stock/Supply
Elevator
Powder Overflow

ADVANTAGES

- SLM creates fully metal, high-performance parts that are highly accurate and detailed
- The range of materials in SLM is large, encompassing high-strength and specialty metals
- SLM can reduce part numbers by printing whole assemblies, and can create highly complex geometries
- SLM speeds up metal manufacturing techniques, reducing delays in repairs and increasing the pace of production
- SLM reduces material usage and waste, especially when compared to traditional manufacturing methods

DISADVANTAGES

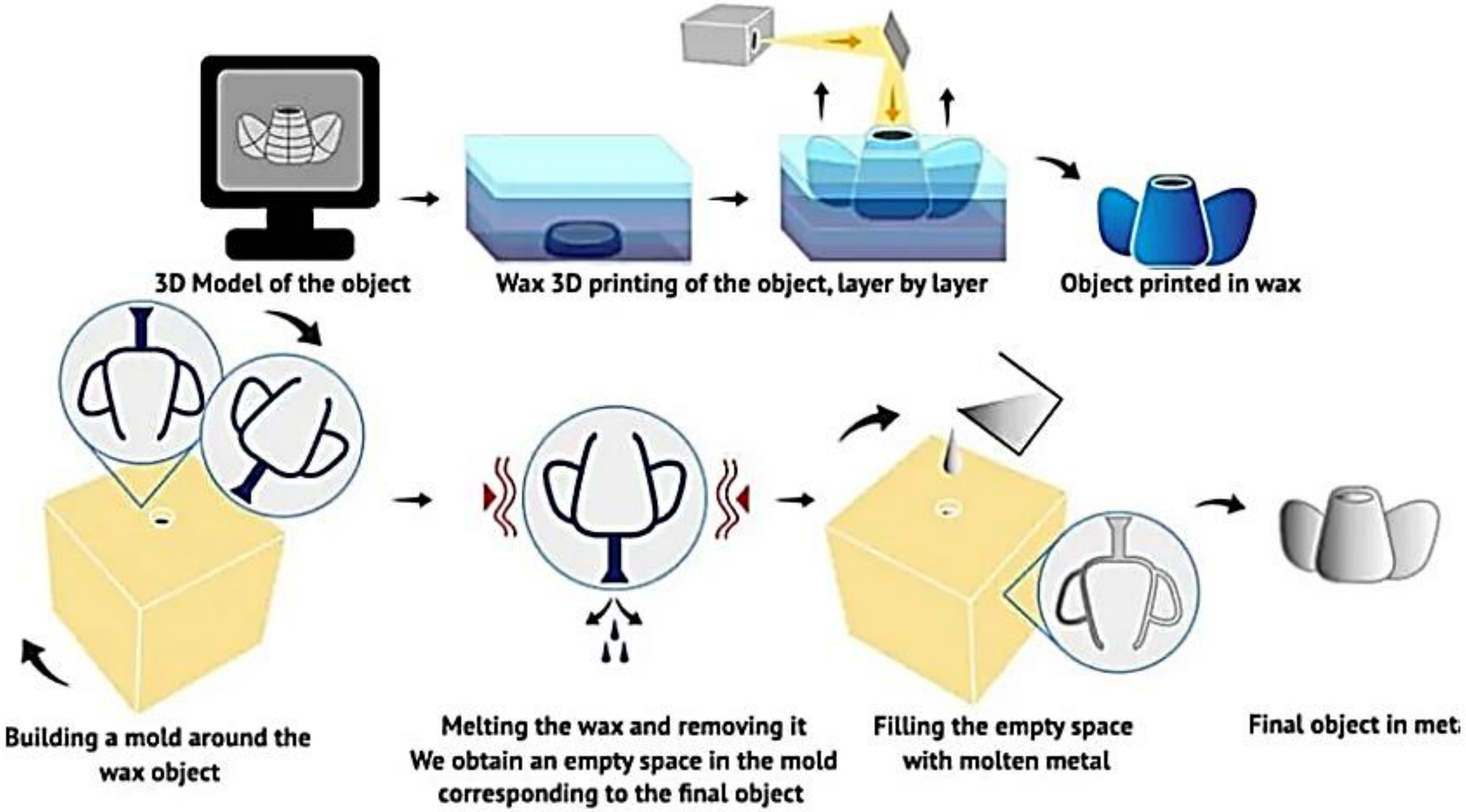
- Only single-component metals and specified materials with good flow characteristics are acceptable in SLM
- SLM is a high-energy process, leading to temperature gradients that can stress/dislocate parts and compromise their structural integrity
- SLM parts need extensive support structures and SLM requires a source of inert gas
- SLM parts have a rough surface finish out of print and require a lot of post-processing to take place
- SLM has a size restriction on parts and is very expensive, limited it to small-batch production runs

APPLICATIONS

- Aerospace industrial components
- Motor parts
- Dental and medical engineered equipment (implants, prosthetics, etc)
- High-pressure resistant components for mechanical/chemical engineering
- Bespoke parts for automotive applications
- Conformal cooling channels in production tool inserts

WAX PRINTING – Principle, Process, materials used and applications.

- Similar to investment casting



- Lost-wax casting – also called investment casting, precision casting, is the process by which a duplicate sculpture is cast from an original sculpture. Intricate works can be achieved by this method.

- In addition to the lost-wax casting process, it is possible to actually 3D print wax. The material often used to print wax is not real natural wax, but it is a wax-like material, the mechanical properties of this material are then similar to wax.

- Wax 3D printing and lost wax casting are used to build your design when using this material. The wax printing process is a type of stereolithography that uses a wax-like resin.
- Support structures are printed along with the model to make sure your model doesn’t fall apart. These support structures are automatically generated and manually removed after the printing process. After support structures are removed and your model is cleaned, the model can be prepared for casting.

- The plaster mold is then put in an oven and heated for several hours to a point where the wax is completely burned out.
- Then, the molten metal is poured in to fill the cavities left by the wax. Once the metal has cooled and solidified, the plaster mold is broken and the metal models are removed by hand. Finally, your model is filed and sanded to get rid of the sprues. It will be sanded, polished or sandblasted for the finish you desire.

Materials Used

- Gold
- Silver
- Bronze
- Brass
- Copper