METAL ADDITIVE MANUFACTURING
ELECTRON BEAM PROCESS

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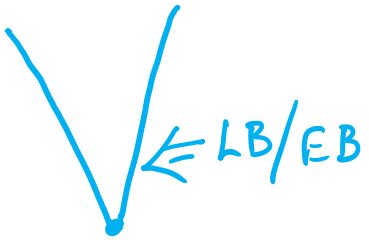
CONTENTS

- Basics of electron beam → EB (laser → photon, Electrons.)
- Electron beam powder bed fusion
- Electron beam mechanism

ELECTRON BEAM BASICS

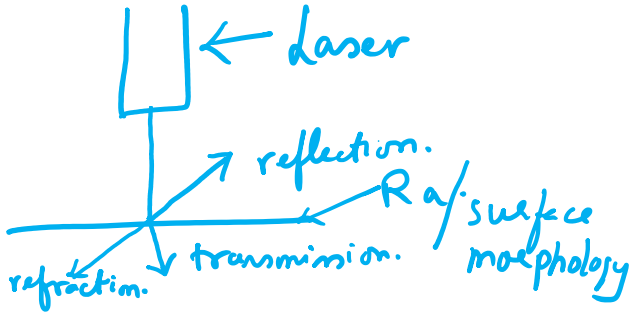
- In addition to the laser beam, the electron beam (EB or EBM) is a typical heat source for thermal metal powder bed additive manufacturing.
- EB, a collimated stream of free electrons, is a helpful heating and welding technique.
- EBs are used in micro- and nanoscopy, machining, and spectroscopy.
- With enough power, EB can be used for cutting, machining, and welding.

1. LASER VS ELECTRON BEAMS

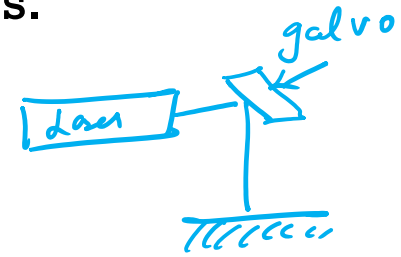


- EBs are very coherent and have low numerical intensity sources of high kinetic energy, while lasers have high numerical intensity sources of low energy photons.
- Both energy sources are collimated and can be concentrated on a tiny region while achieving great thermal intensity. These considerations make fine-featured items manufacturable.
- The difference between these energy sources is heat transfer to the powder bed.
- Lasers heat by absorbing atomic photons. Heat transfer depends on laser color spectrum and material electrical structure.

1. LASER VS ELECTRON BEAMS

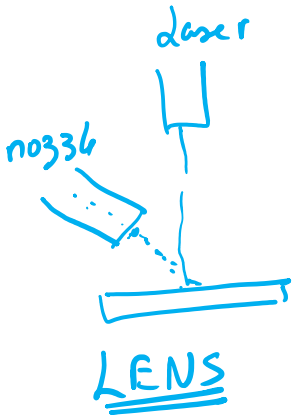


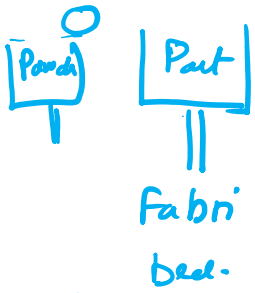
- Laser absorption depends on feed material finish and substrate finish since reflection limits available energy.
- EB transports heat by inelastic electron-substrate collisions. Electrons are accelerated to high kinetic energies to impact the substance and embed themselves, delaying the process.
- Material finish and electronic structure don't affect heat transfer efficiency, unlike laser beams.
- Magnetic fields can move EB at (>>1 km/s). The scanner's mechanical limits limit laser beam speed to 5–7 m/s.

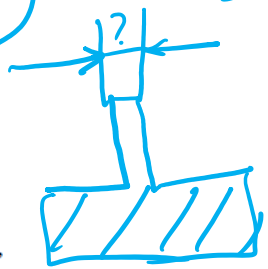


1. LASER VS ELECTRON BEAMS

Parameters	LPBF	EBM/EBPBF	LDED (LPF)
Energy source	Laser	Electron beam	Laser
Layer thickness (μm)	20–90	50	100–1000
Min wall thickness (mm)	~0.2	~0.6	~0.6
Accuracy (mm)	±0.1	±0.3	±0.4
Build rate (cm^3/h)	5–20	80–100	2–70
Surface roughness (μm)	5–15	15–20	15–40
Geometry limitations	Supports needed	Less supports needed	Same limitations as a typical 5 axes milling
Materials	Ferrous alloys, titanium, aluminum, nickel, ceramics, etc.	Just conductive materials (Ti alloys CrCo, Tool steel, Cu alloy, etc.)	Ferrous alloys Ti, Ni-base alloys, composites, ceramics, etc.
Productivity vs costs	Good (depends on applications)	Medium	Good
Residual stresses	Medium	Low	Medium
Part complexity	High	Medium	Low
Typical applications	Tooling, Implants, jet engines, prototypes	Near-net-shape manufacturing of Implants, turbine blades, prototypes	Repair of blades, vanes, shafts, coatings, etc.
Necessity of support structures	Medium	Low	Normally none



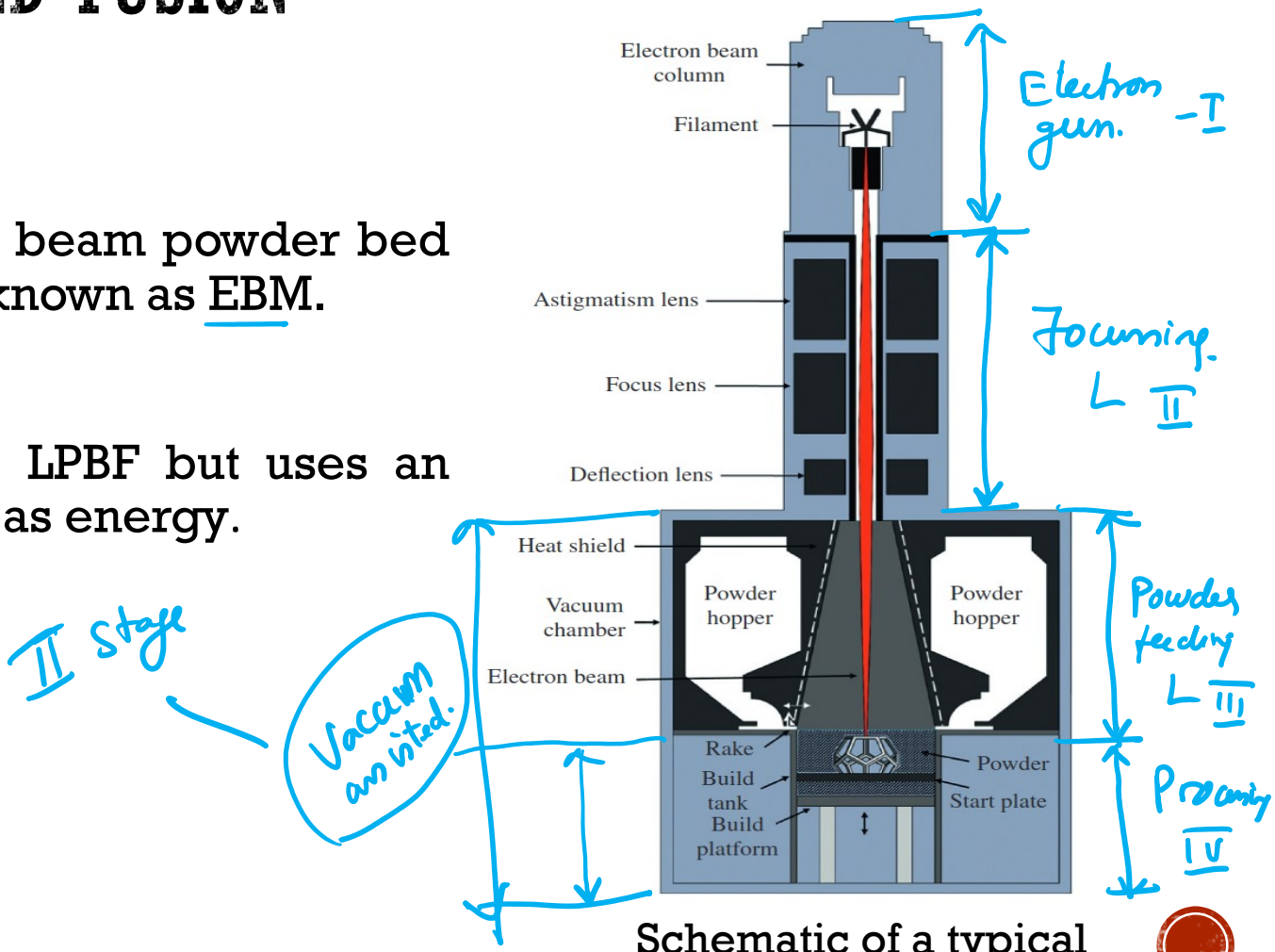




2. ELECTRON BEAM SETUP

POWDER BED FUSION

- EPBF (electron beam powder bed fusion) is also known as EBM.
- It is similar to LPBF but uses an electron beam as energy.



Schematic of a typical EBM apparatus.

"Arcam."[Online]. Available: http://www.arcam.com/technology/electron-beam-melting/hardware.

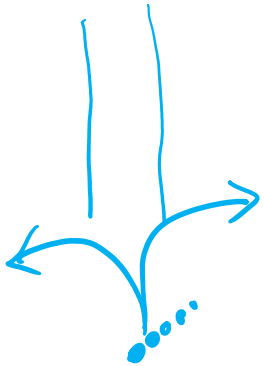
2. ELECTRON BEAM SETUP

POWDER BED FUSION

- EBM melts powder using a scanning high-energy electron beam cannon.
- EBM methods have greater resolution, surface roughness, and layer thickness than LPBF.
- Larger melt pools create a larger heat-affected zone. The kinetic energy of the beam electrons heats the metal powder, which accumulates a negative charge as it absorbs the incoming electrons.

2. ELECTRON BEAM SETUP

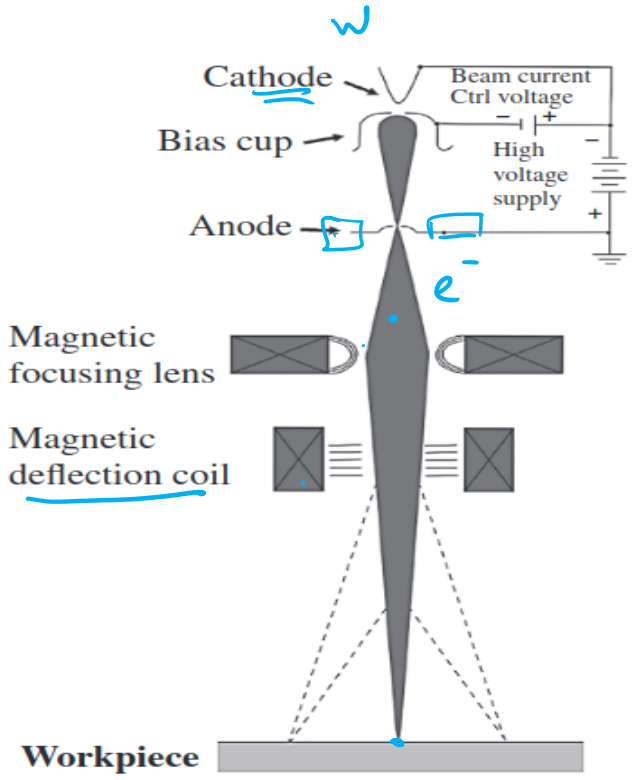
POWDER BED FUSION



- Because negatively charged particles repel one other, this may cause powder bed expulsion.
- This causes a powder cloud and/or a more diffuse beam, which increases the melt pool.
- Electron beam guns are more effective than lasers because the bulk of the electrical energy is converted into a beam, while the rest is dissipated as heat.

3. ELECTRON BEAM MECHANISM

- Under the influence of electric and magnetic fields, free electrons in a vacuum can be accelerated, creating high-energy, narrow electron beams.
- The conversion of this kinetic energy into thermal energy is the fundamental principle of an electron beam.

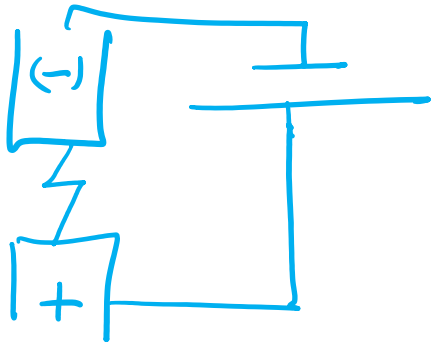


Electron beam formation schematic.

"World Scientific."[Online]. Available: http://www.worldscientific.com/worldscibooks/10.1142/7745

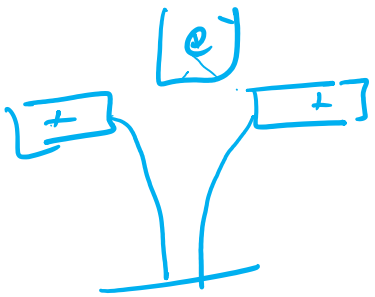
3. ELECTRON BEAM MECHANISM

- When electrons collide in a vacuum, their kinetic energy is converted to heat. When electron beams accelerate and collide with powerful electric fields and magnetic lenses, their power densities can reach up to 10^6 W/mm^2 and the localized temperatures can rise at a rate of up to 10^9 K/s.
- Basic required equipment to generate an electron beam
  - Power supply
  - Electron gun/source
  - An anode
  - Magnetic lenses
  - Electromagnetic lenses and deflection coils



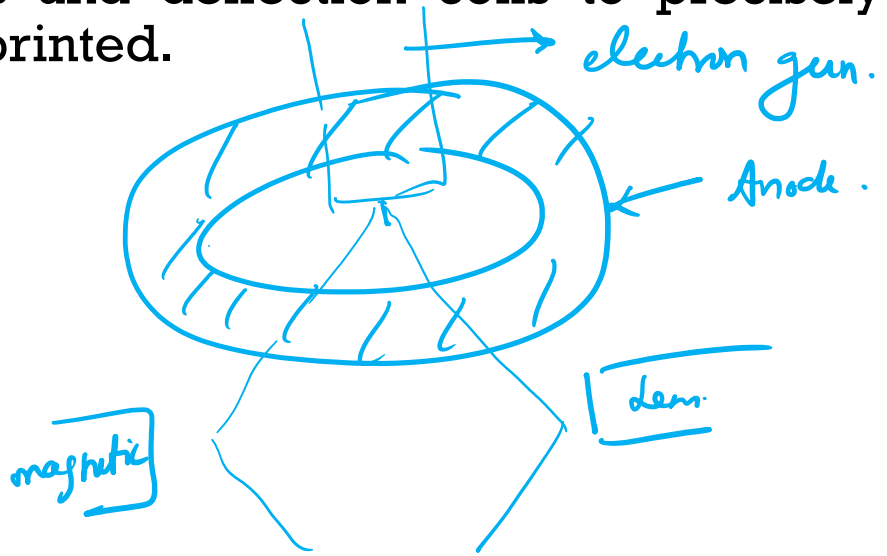
3. ELECTRON BEAM MECHANISM

- A power source is needed for an electron beam. Low- or high-voltage equipment from 5 to 30 to 70–150 kV is available depending on the process.
- The electron gun's cathode is heated by a low-voltage filament, evaporating electrons from it. As a cathode, tungsten is preferred.
- Evaporated electrons are accelerated toward the positively charged anode and placed after the electron gun.



3. ELECTRON BEAM MECHANISM

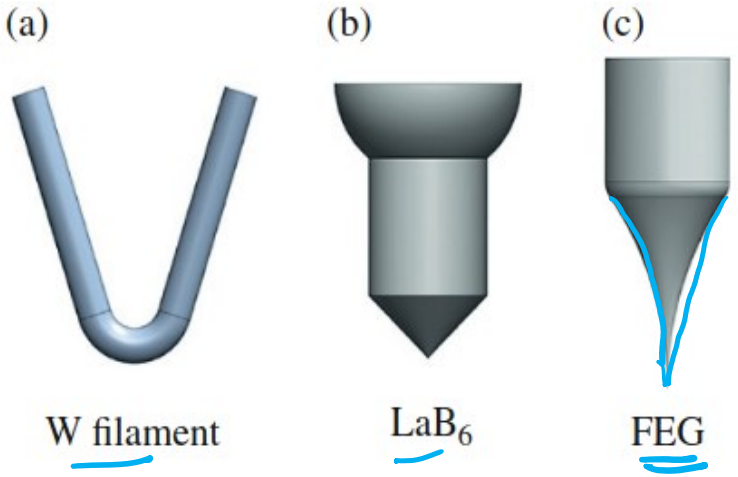
- An anode aperture creates an electron jet that moves toward magnetic lenses.
- These components block divergent electrons and provide a strong electron beam.
- The so-formed beam is focused and deflected by electromagnetic lenses and deflection coils to precisely position the part to be printed.



3. ELECTRON BEAM MECHANISM

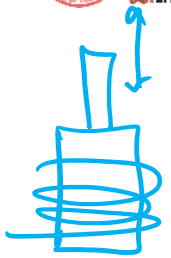
ELECTRON BEAM SOURCES:

- Gun electrode type was used for AM. Three types are common: Tungsten (W) filament, Lanthanum Hexaboride (LaB_6), and field-emission gun (FEG)



Gun electrode types: (a) Tungsten (W) filament, (b) Lanthanum Hexaboride (LaB_6), and (c) field-emission gun (FEG).

3. ELECTRON BEAM MECHANISM



ELECTRON BEAM OPTICS AND POSITIONING

- Electrons accelerated by beam power lack focus and control. Focusing, shaping, and positioning the beam provides the required control.

ELECTROMAGNETIC LENS

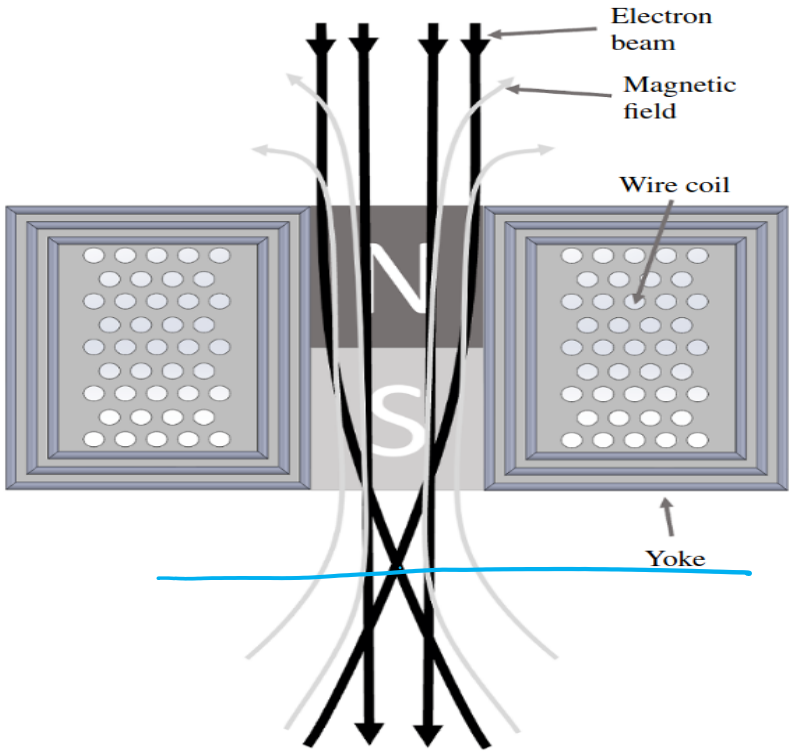
- EBs are focused using a lens, albeit an electromagnetic one made by magnetic fields, much like optical devices.
- The lens is constructed by winding wires around a coil, much like a solenoid. on the other hand, is wound across a very short length, making the magnetic field less dense towards the center of the lens than a solenoid, which generates a uniform magnetic field.

3. ELECTRON BEAM MECHANISM

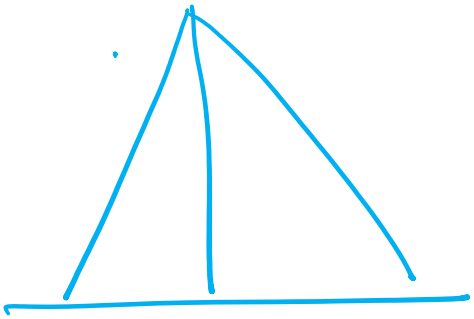
ELECTROMAGNETIC LENS

- An electron will initially encounter a clockwise force around the entrance as it travels through the lens. The force starts to point in the direction of the opening's center as soon as the electron gains some velocity in this direction.
- The windings and other components must be built with great radial symmetry to prevent defects in the lens's focusing abilities.
- An electromagnetic lens' generated picture is rotated and inverted by the force acting clockwise. Nevertheless, because the spot form is typically circular, this is not an issue for the majority of heating applications.

3. ELECTRON BEAM MECHANISM



Electromagnetic Lens



V. Adam, U. Clauß, D. Dobeneck, T. Krüssel, and T. Löwer, Electron beam welding –The fundamentals of a fascinating technology. pro-beam AG & Co. KGaA, 2011.

3. ELECTRON BEAM MECHANISM

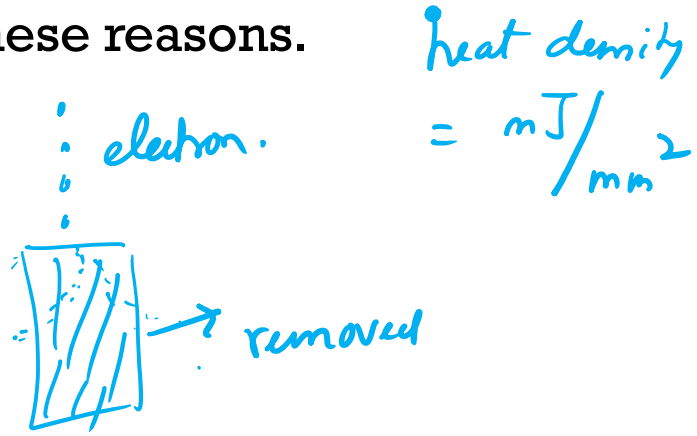
ELECTRON BEAM OPTICS AND POSITIONING

STIGMATORS

- Due to the electromagnetic lens's non-uniformity and the filament's geometry, the beam may initially be elliptical rather than circular. Astigmatism is the term for this condition, which stigmators can treat.
- Four solenoids with magnetic quadruple make up a stigmator, which is a device. According to which quadrant of the quadruple field an electron is in, it will either experience force toward or away from the center of the field.
- The beam can be made to be more or less elliptic by varying the strength of the current in the opposing pairs of solenoids.

4. VACUUM CHAMBERS

- A well-collimated EB that can focus down to tiny spots. Electrons scatter when they hit gas molecules in a fluid medium.
- This scattering reduces beam energy at the heating location and increases spot size, reducing beam intensity.
- EBs must operate in a vacuum for these reasons.



POINTS TO PONDER

- Basics of electron beam and its mechanism
- Similarities and differences between electron beam and laser beam

THANK YOU