Nano-Magnets and Additive Manufacturing for Electric Motors

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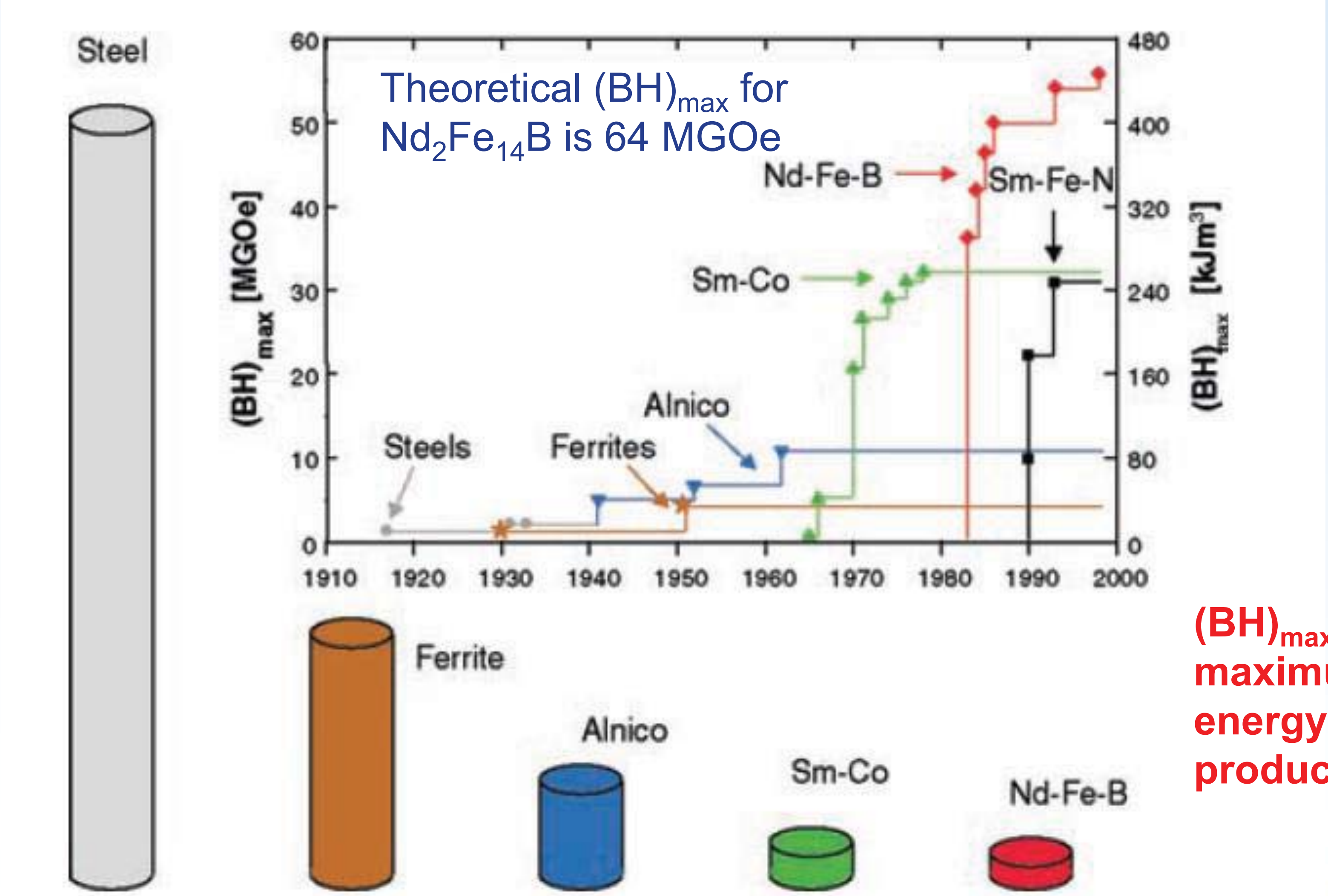
Enabling Technologies for High Power Density, High Performance Electric Motor

- Advanced electrical and magnetic materials
  - Magnets
  - Conductors
  - Insulation
- Thermal management
  - Thermal materials
  - Cooling technologies
- Power electronics
- Advanced topology
- Lightweight materials and structural concepts
- Advanced manufacturing processes

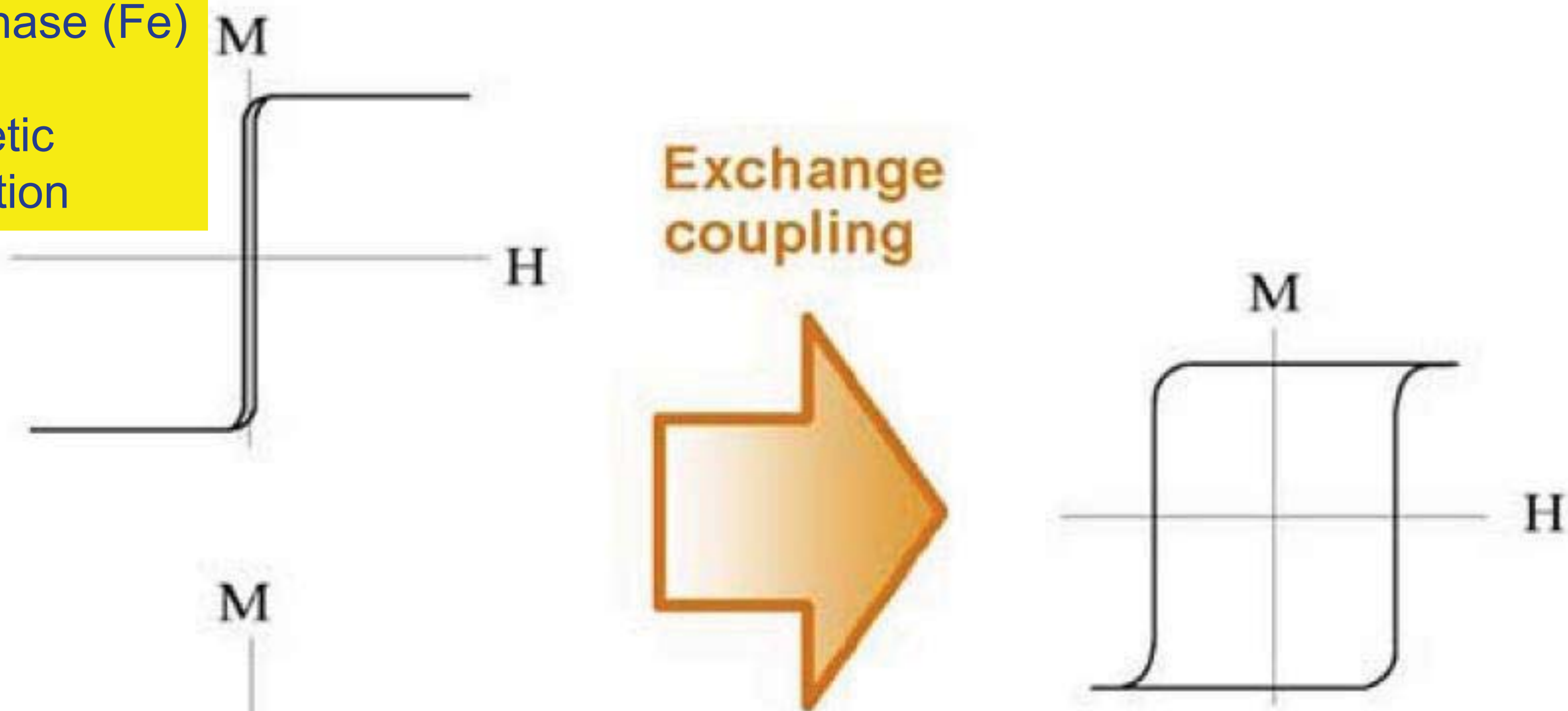
Advances in Permanent Magnets

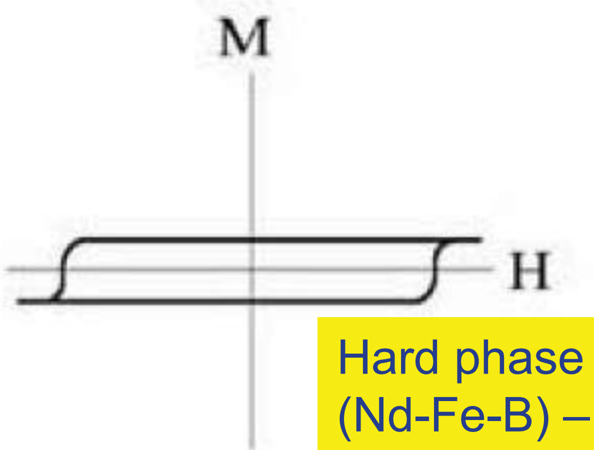


$(BH)_{max}$ = maximum energy product

Concept of Nanocomposite Magnet

Soft phase (Fe) – high magnetic saturation



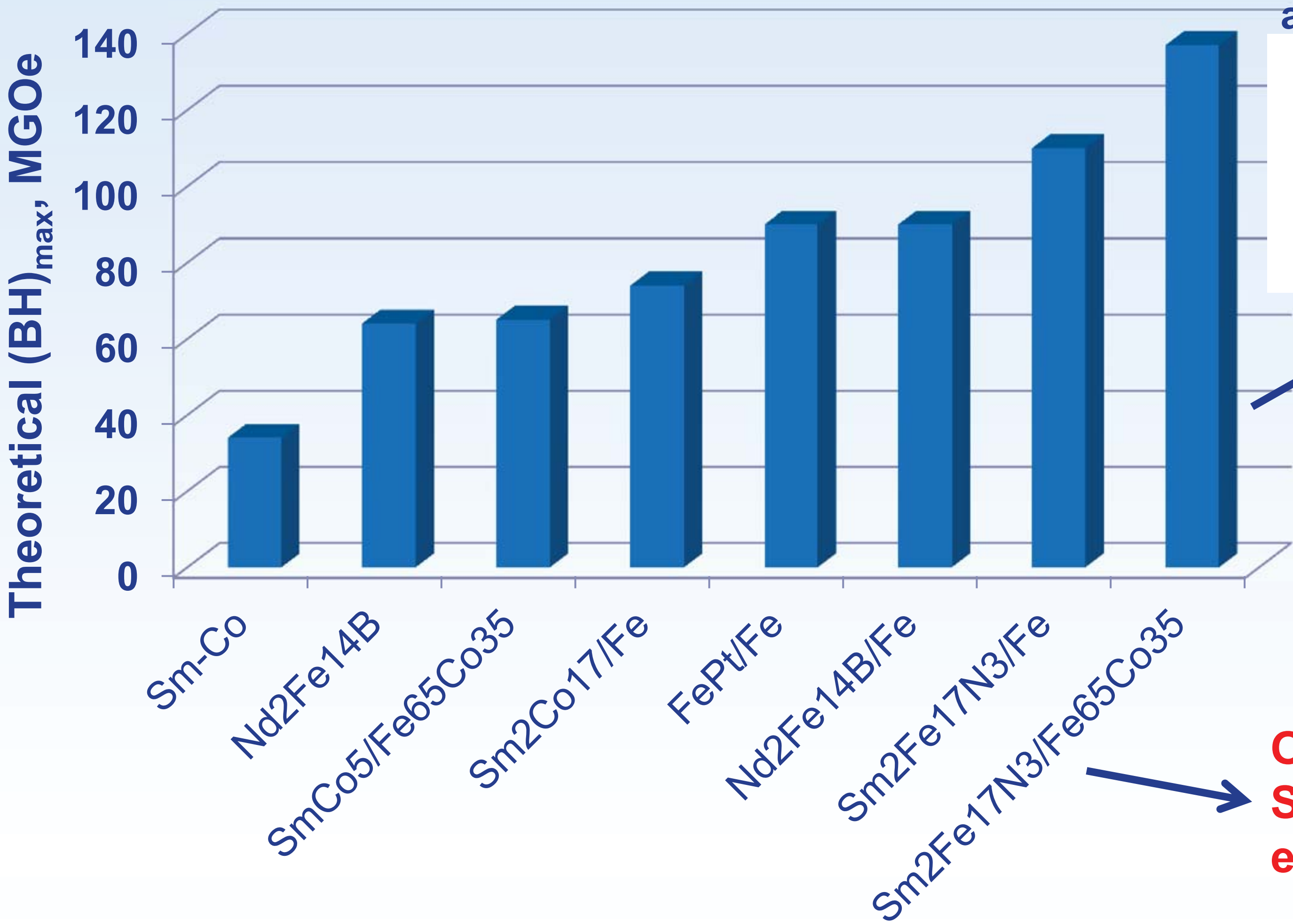


Hard phase (Nd-Fe-B) – high coercivity

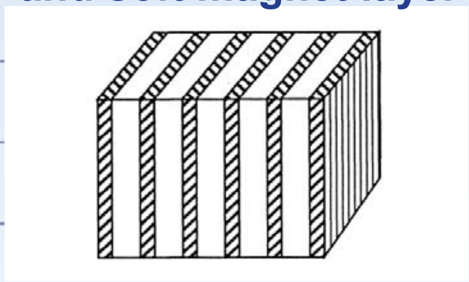
Requirements:

- Both phases in intimate contact with each other
- Size of individual phases < 10 nm
- Alignment of magnetic easy axis

Promise of Nanocomposite Magnets

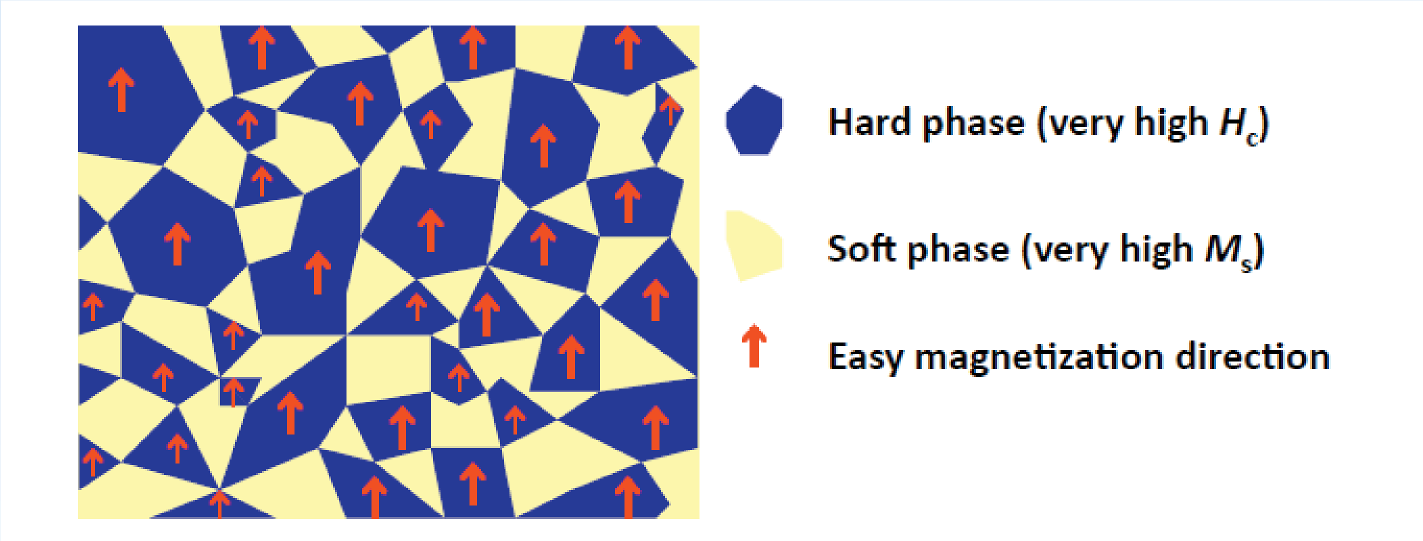


10nm alternate hard and soft magnet layer



Only 2 wt. % Samarium (rare earth element)

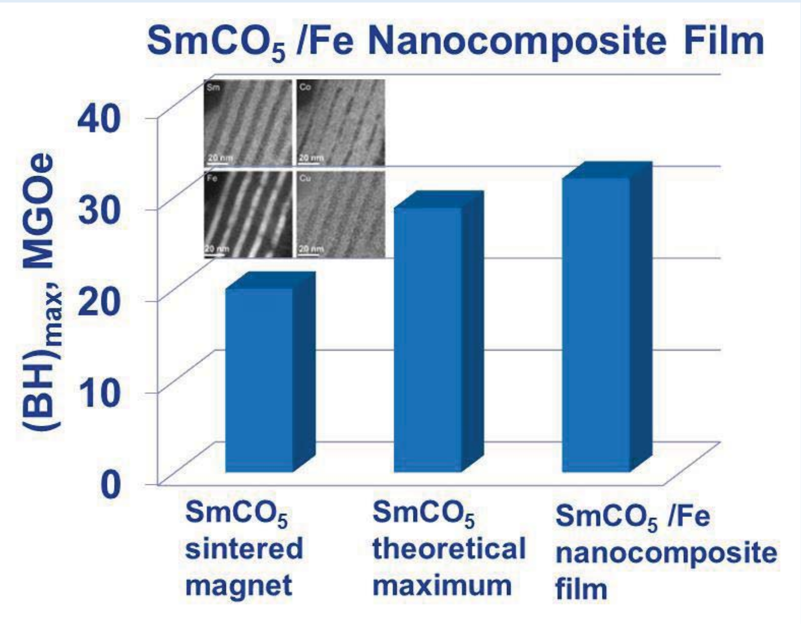
Challenges With Fabrication of Nanocomposite Magnets



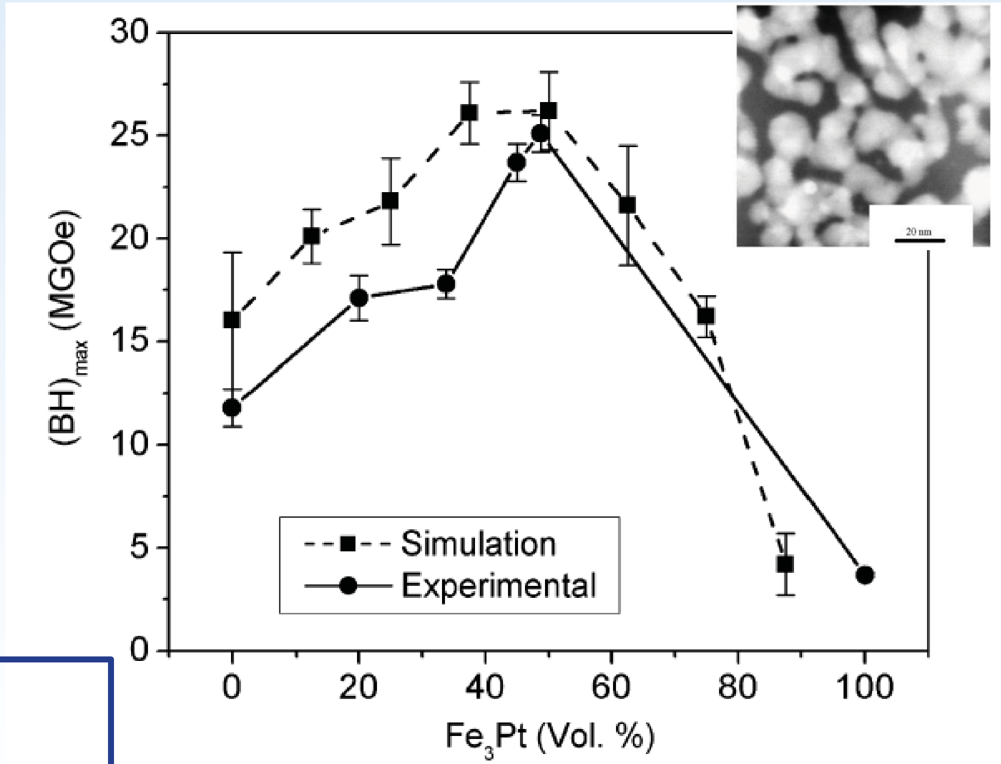
Challenges:

- Achieving a uniform mixture of hard and soft phases with a length scale on the order of 10 nm
- Arranging the nanostructure so that the coercivity of hard phase remains high as the percentage of soft phase is increased
- Aligning the easy anisotropy axes of the hard-phase
- Fabricating dense-packed bulk magnets for practical use

Nanocomposite Thin Film Magnets



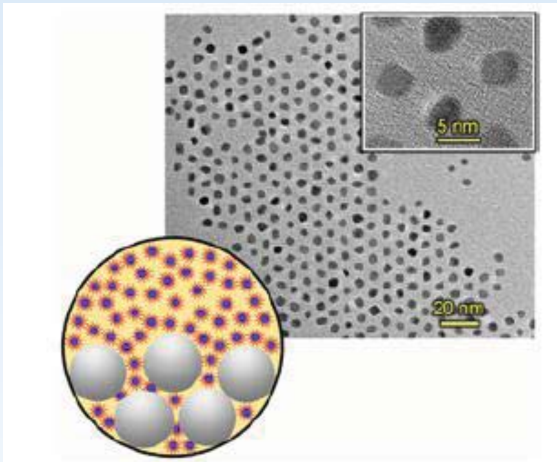
FePt/Fe_3Pt Nanocomposite Film



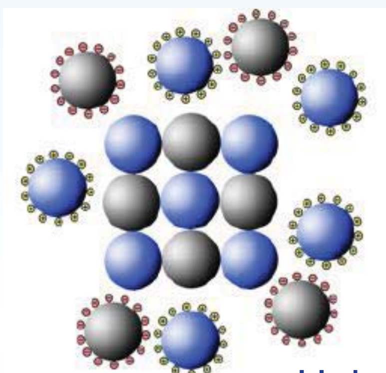
Best results so far for Fe-Pt nanocomposite film - 54 MGOe

Advanced Processing Techniques Critical for Achieving Desired Properties in Bulk Nanocomposite Magnets

Bottoms-Up Chemical Approach



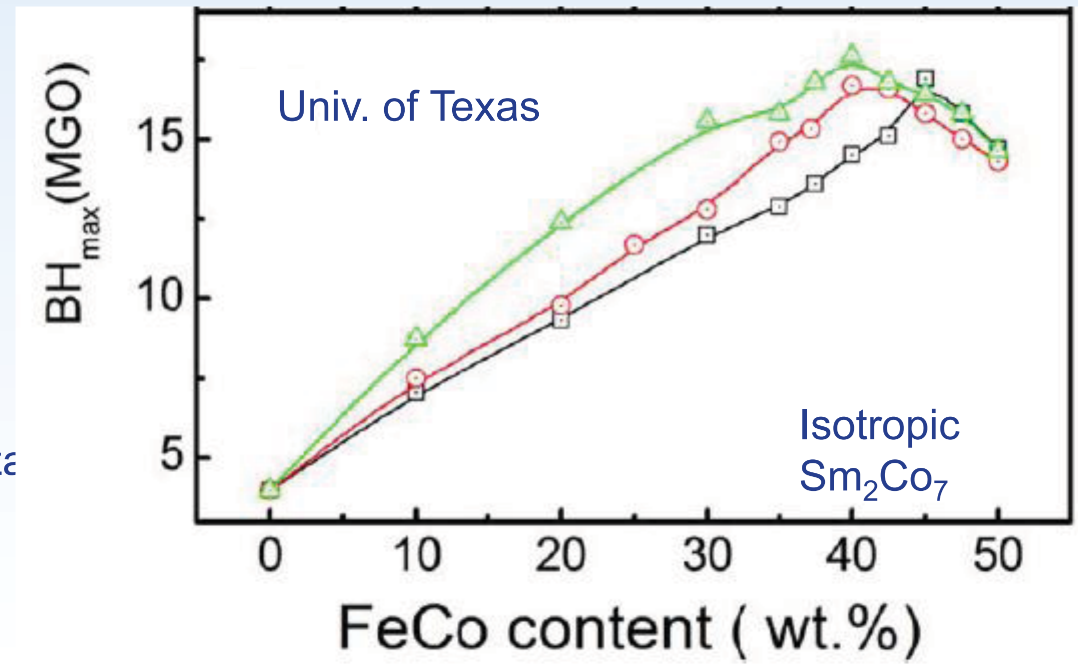
Surfactant-assisted high energy ball milling to produce nanoparticles



Functionaliza
on to align
particles

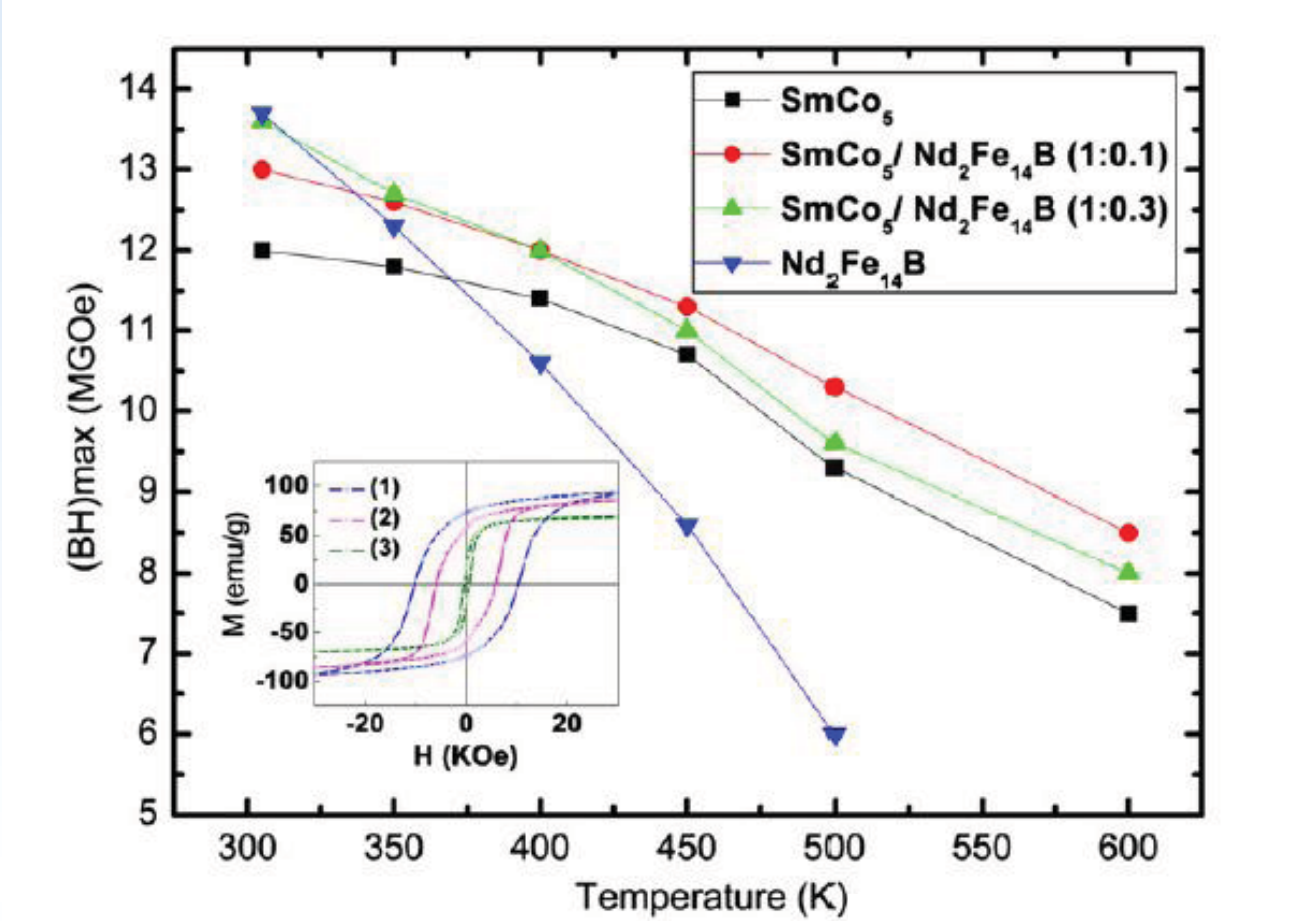
Univ. of Delaware

Sm_2Co_7/FeCO Nanocomposite Fabricated by High Energy Ball Milling Followed by Warm Compaction



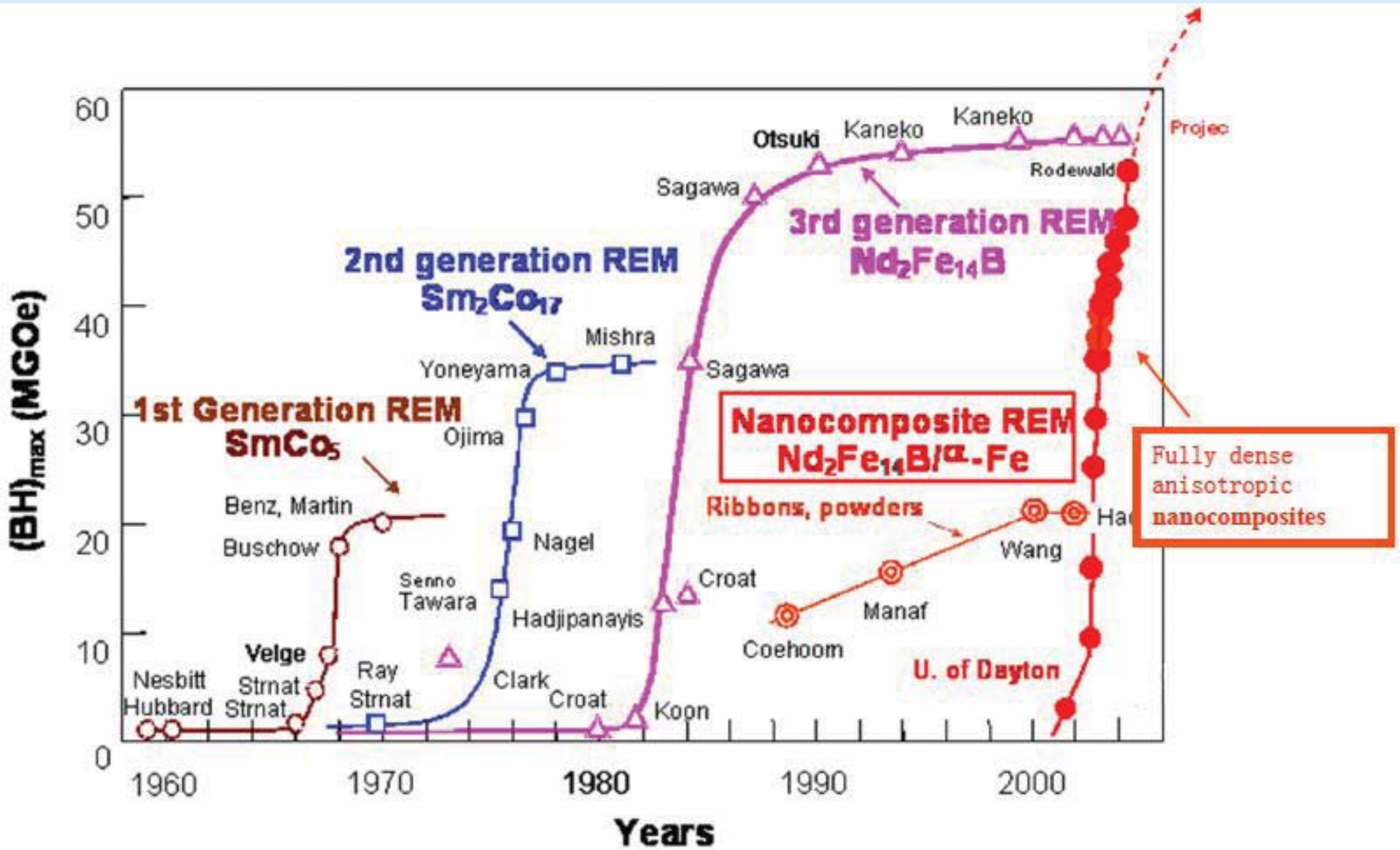
Nanocomposite High Temperature Magnets

SmCo/NdFeB Nanocomposite Magnet



Journal of Magnetism and Magnetic Materials 324 (2012) 2836–2839

Nanocomposite Magnets are Promising, But Significant Challenges Remain

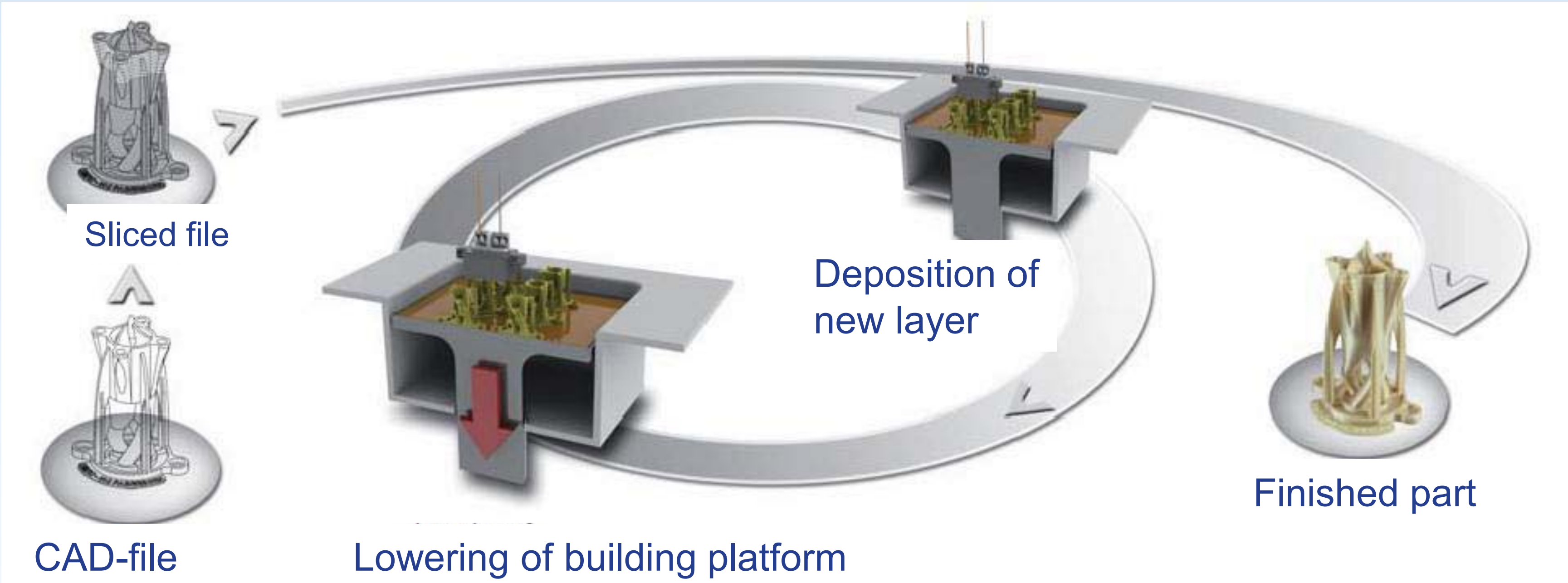


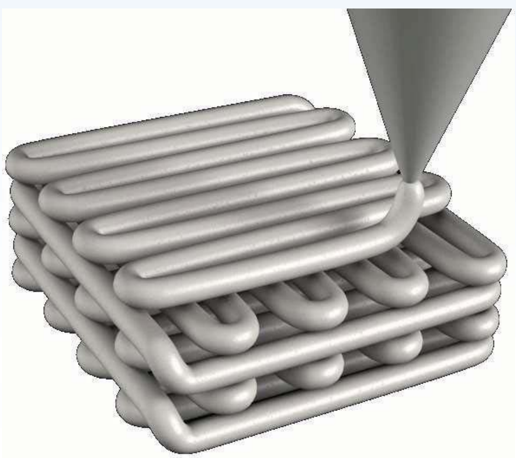
From University of Delaware presentation

President Obama's State-of-the-Union Speech, 2013

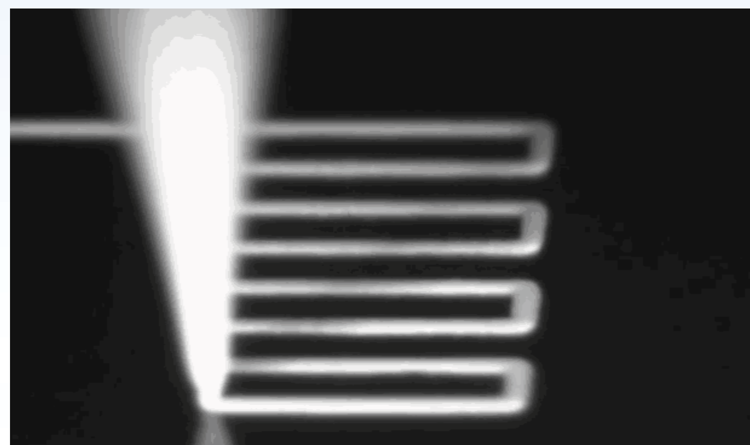
"3D printing that has the potential to revolutionize the way we make almost everything" President Obama

Principles of Additive Manufacturing

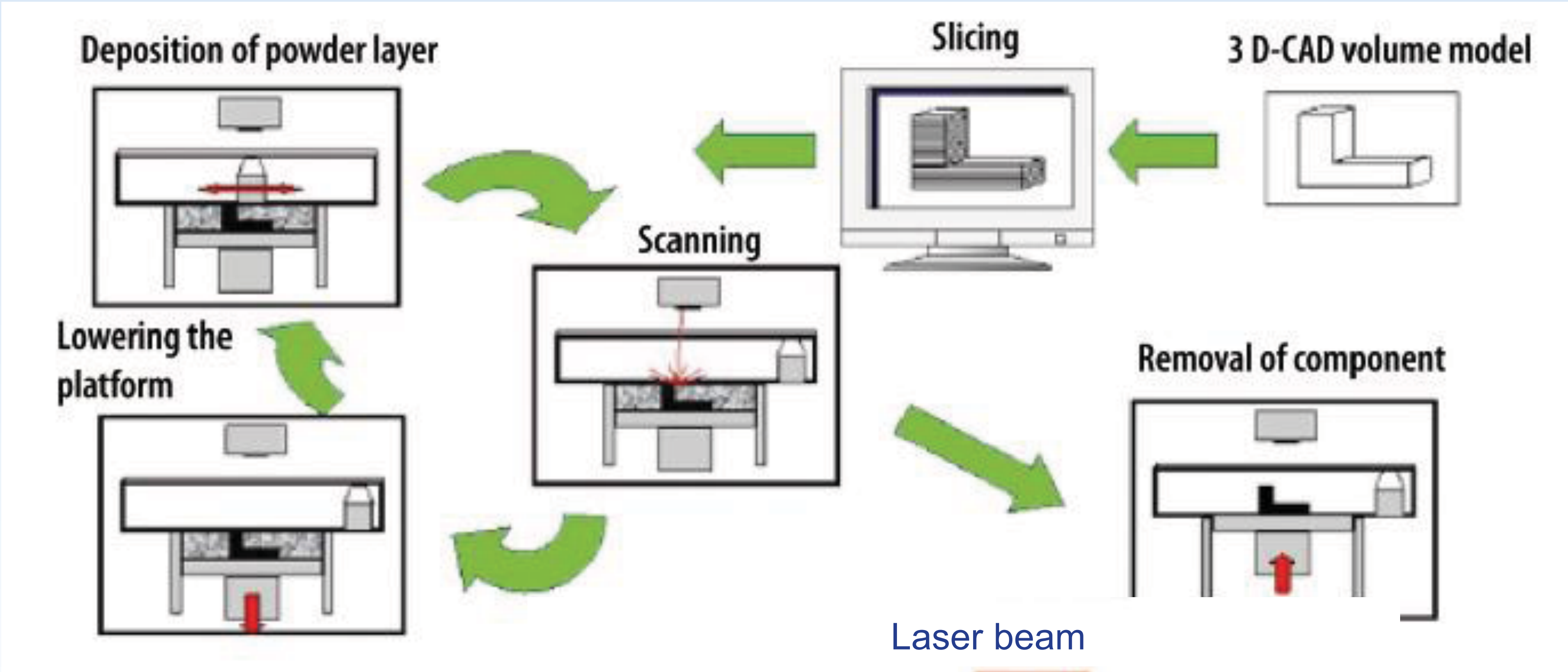




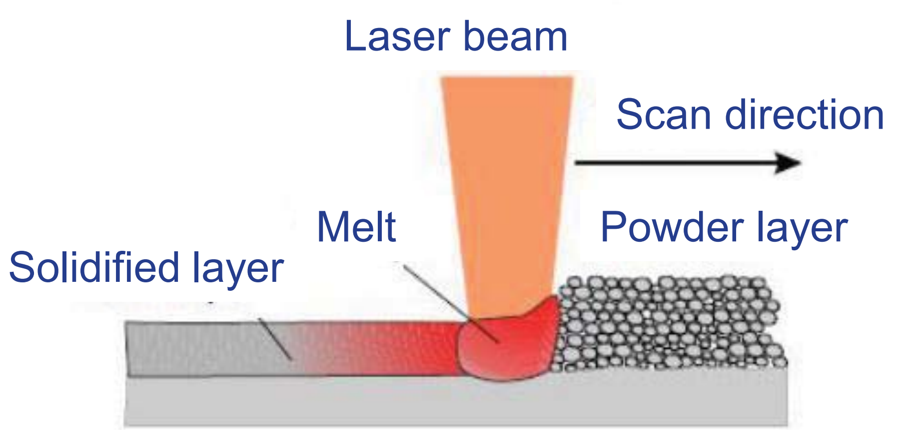
Fused deposition modeling (FDM) process



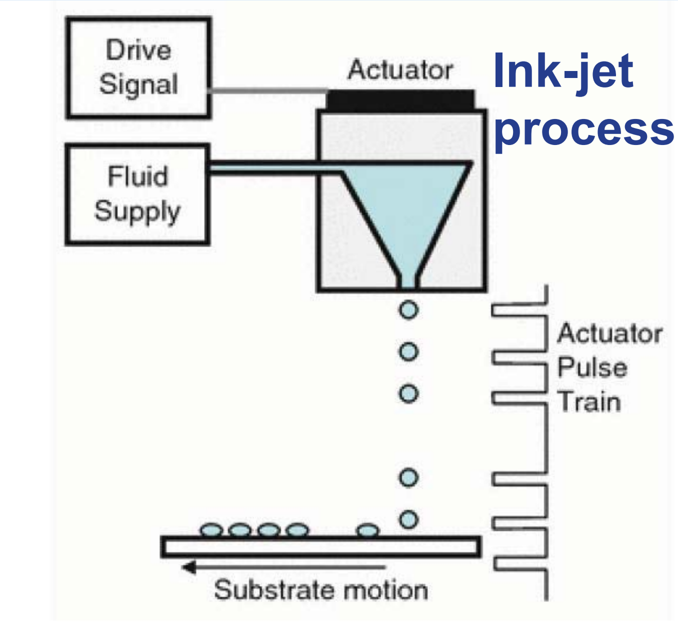
Additive Manufacturing Through Powder Bed Processes



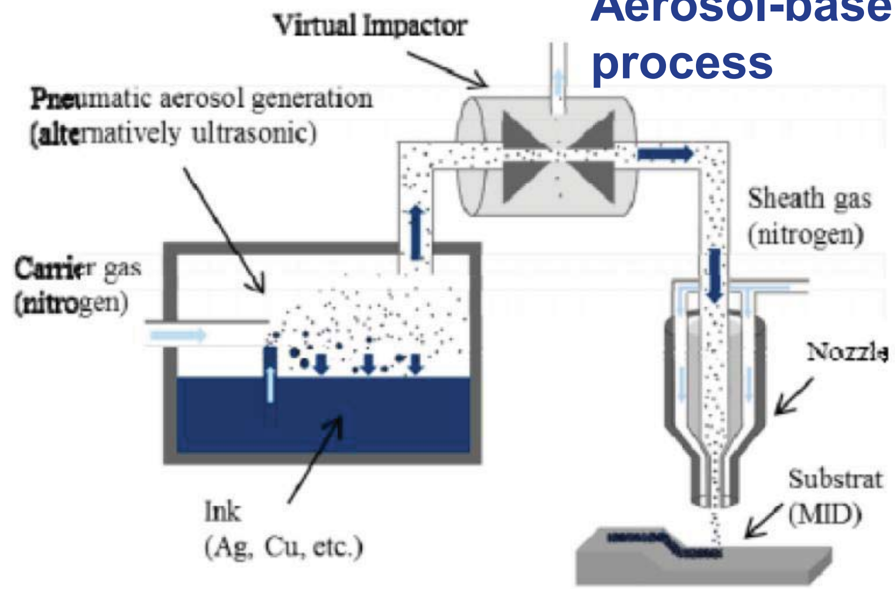
Laser sintering
Electron beam melting



Direct Writing Processes

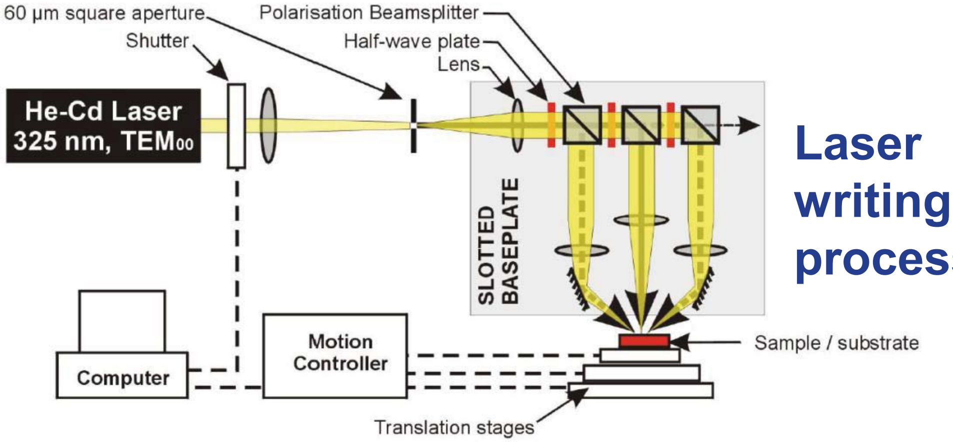


Ink-jet process



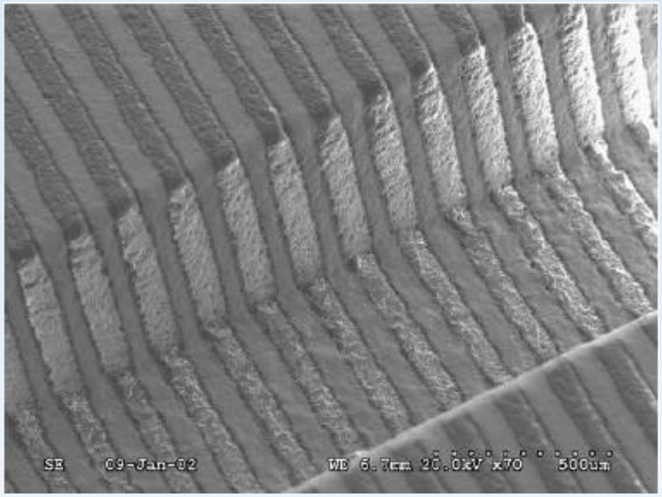
Aerosol-based process

Extrusion-based process

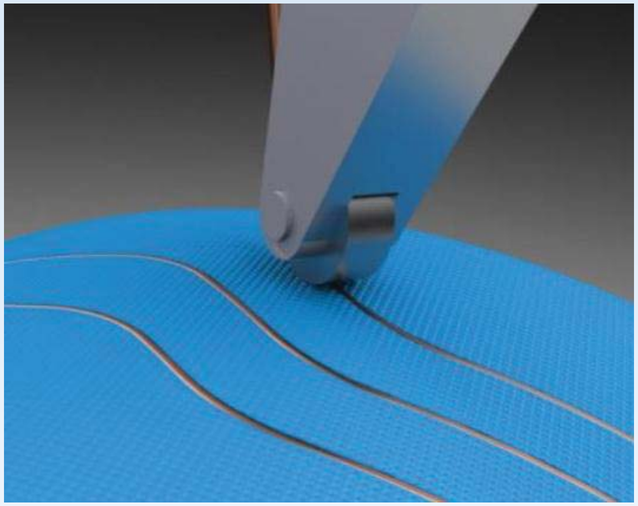


Laser writing process

Examples of Direct Writing Processes

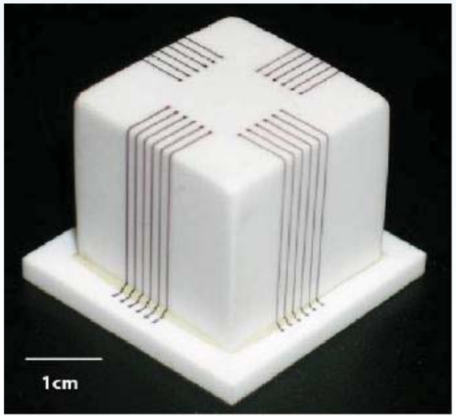


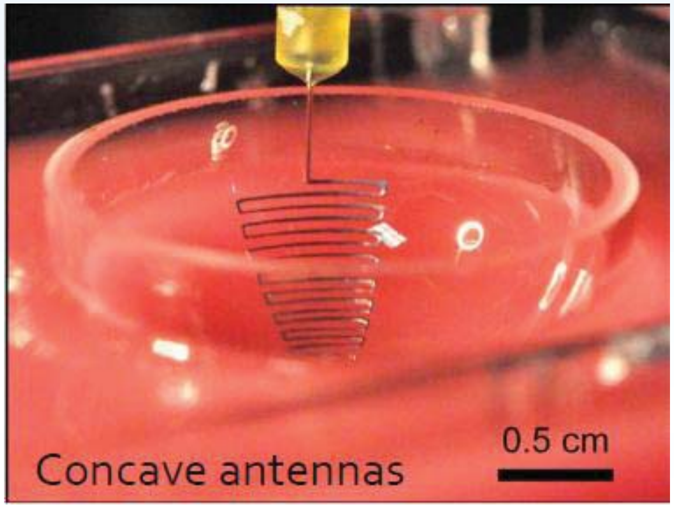
60 micron Ag lines written over a 500 micron trench



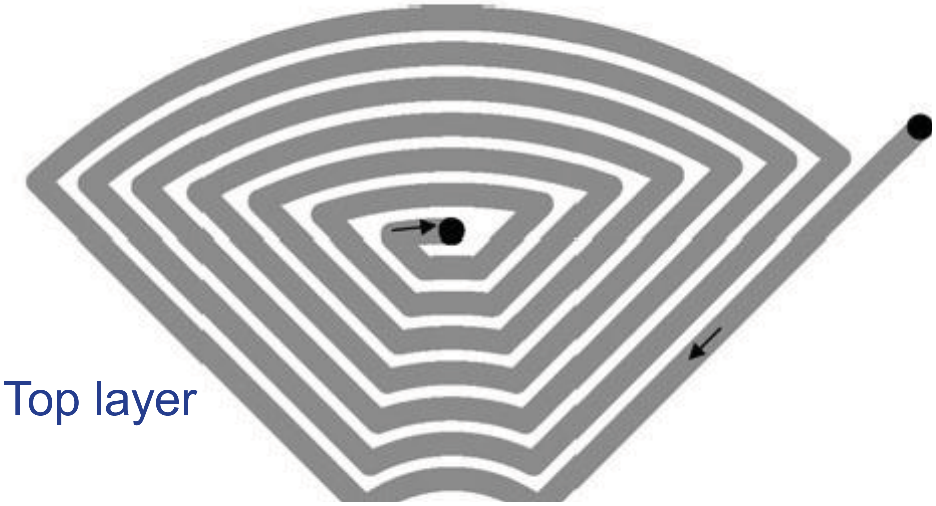
Printing of Cu interconnect

3D silver interconnects, 150 micron line width written over an alumina cube

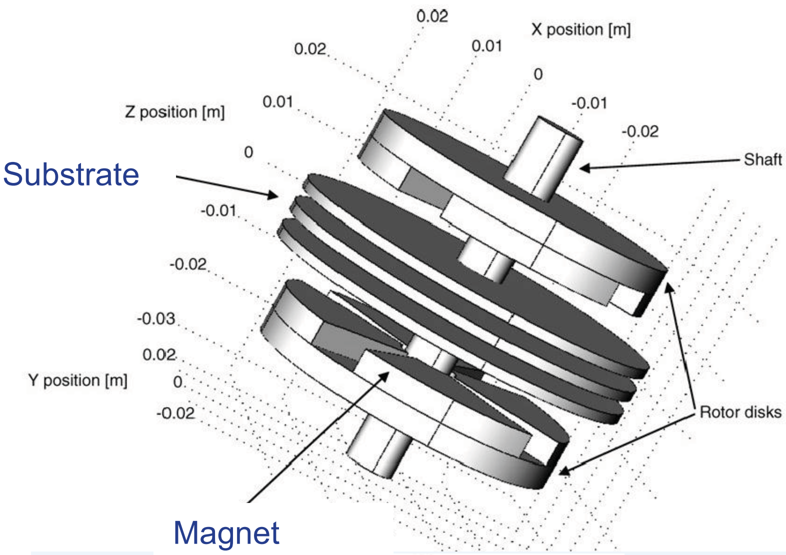


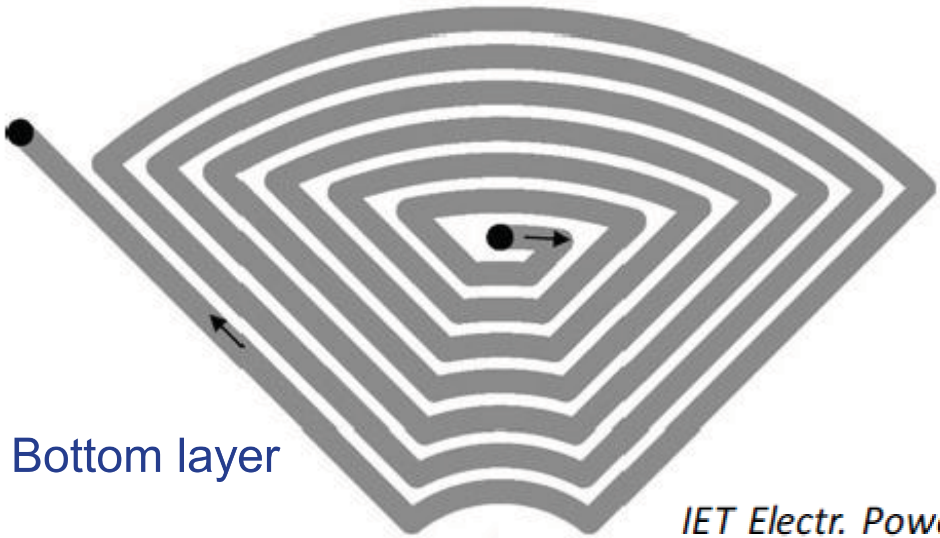


Application of Direct Write Process for Fabricating Printed Circuit Stators in Small Permanent Magnet Motors



Top layer

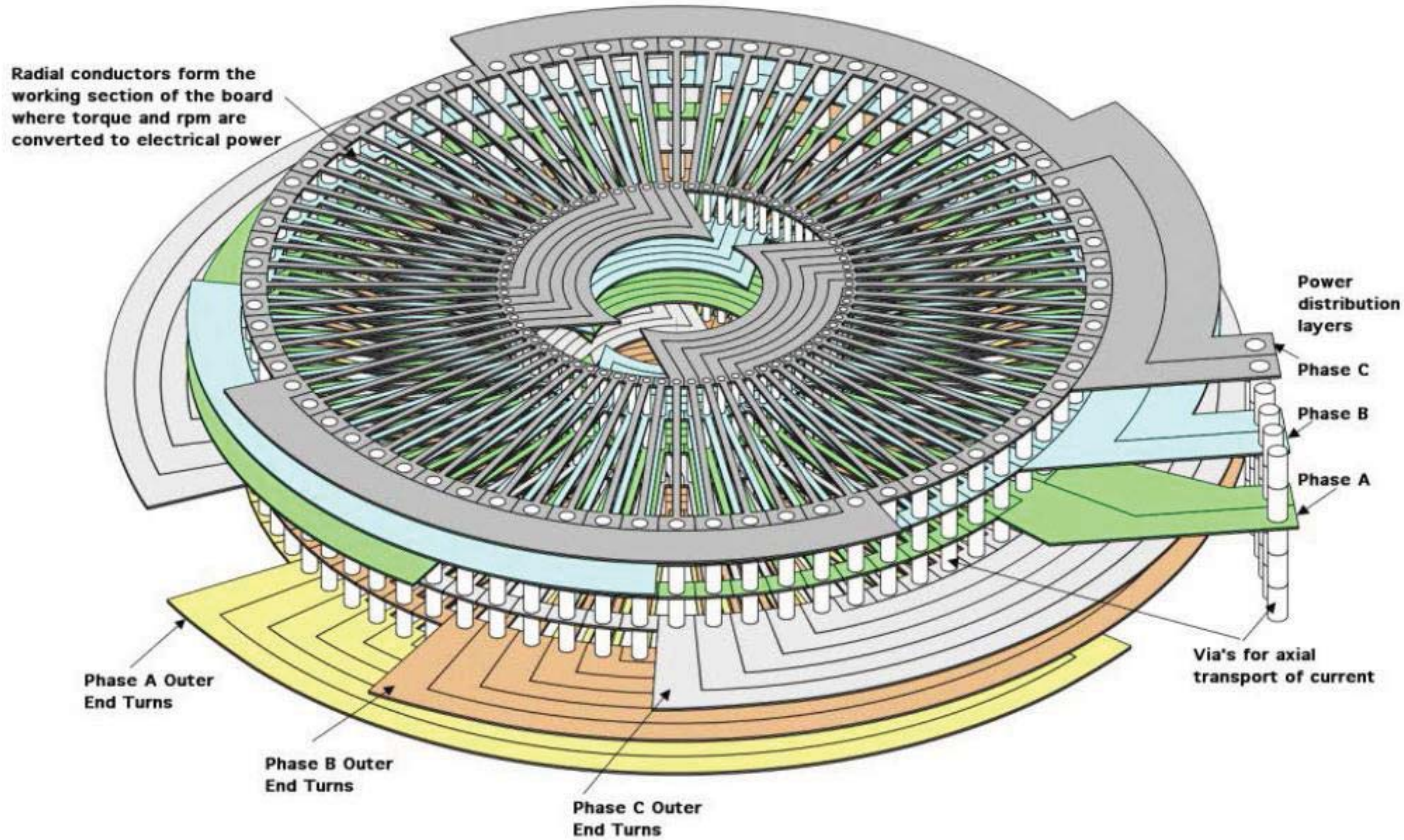




Bottom layer

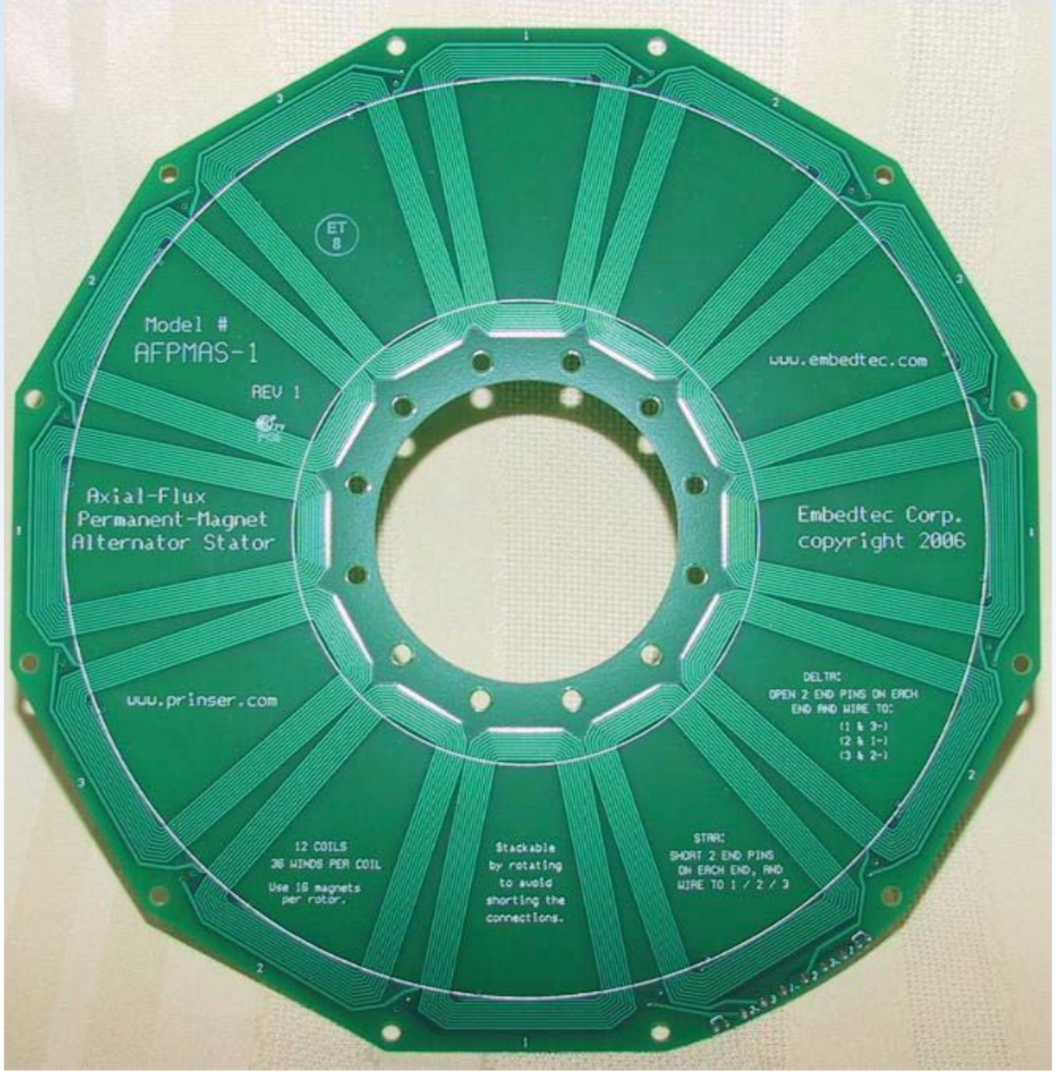
IET Electr. Power Appl., 2009, Vol. 3, Iss. 5, pp. 482–490

Application of Direct Printing Technology for Large Stators

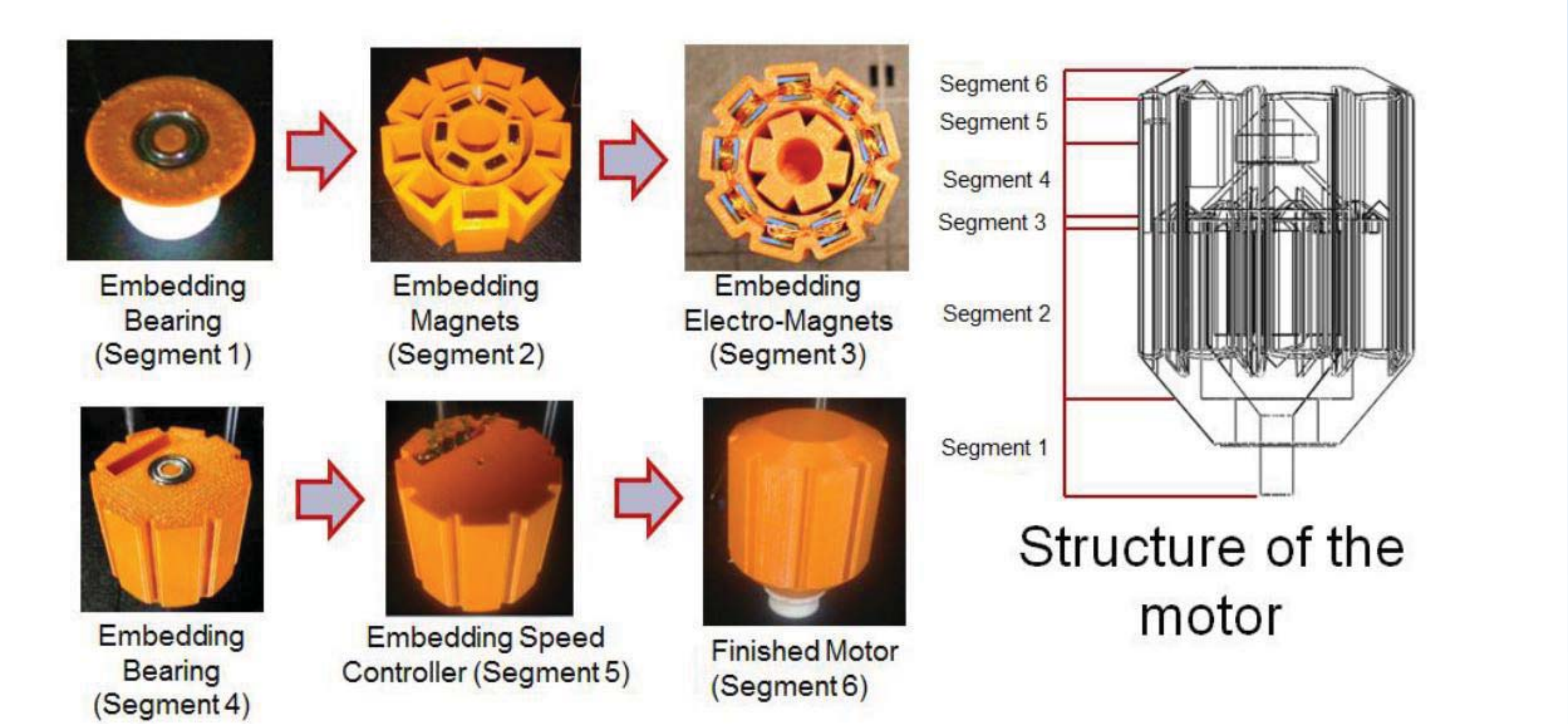


Printed circuit board stator by Boulder Wind Power using CORE (conductor optimized rotary energy) technology

Example of Direct Printed Stator



3D Printing of Electromechanical System



From the work of Aguilera et. al., University of Texas at El Paso

Additive Manufacturing of Electric Motors

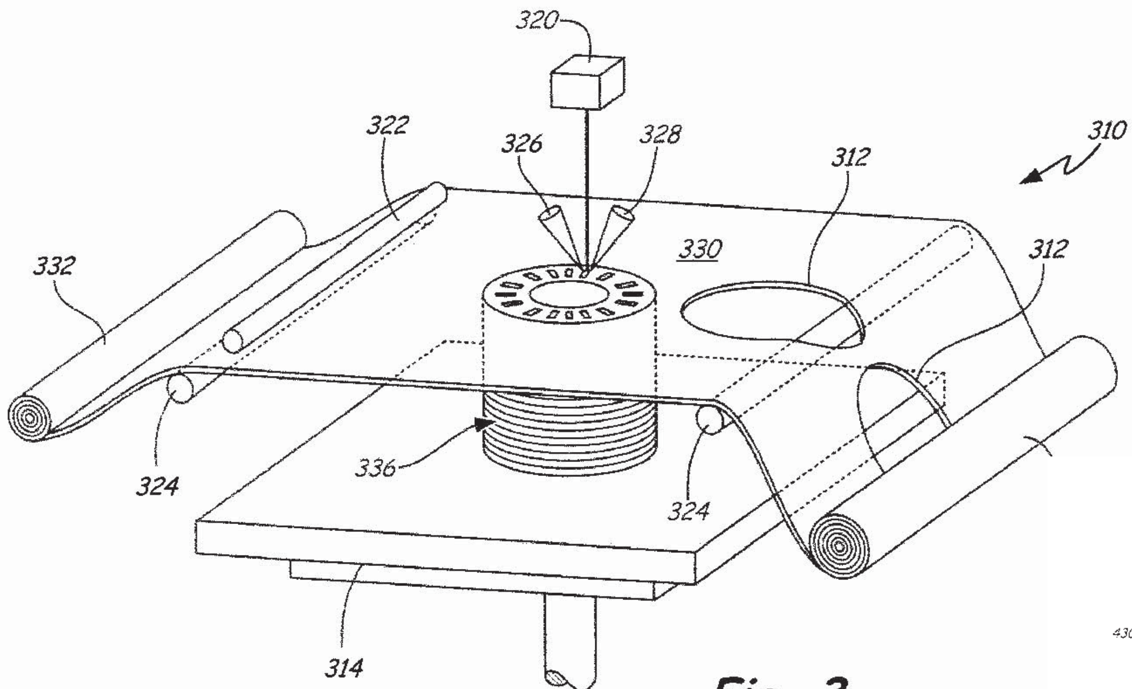


Fig. 3

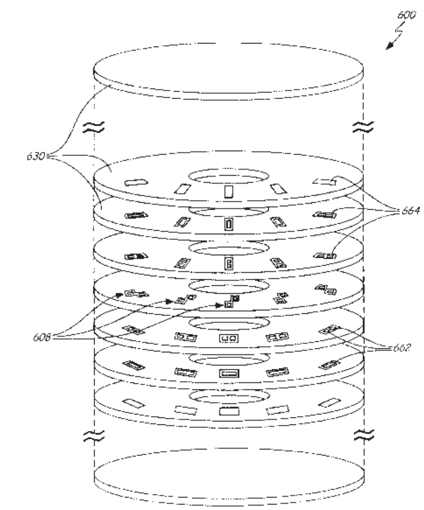


Fig. 6

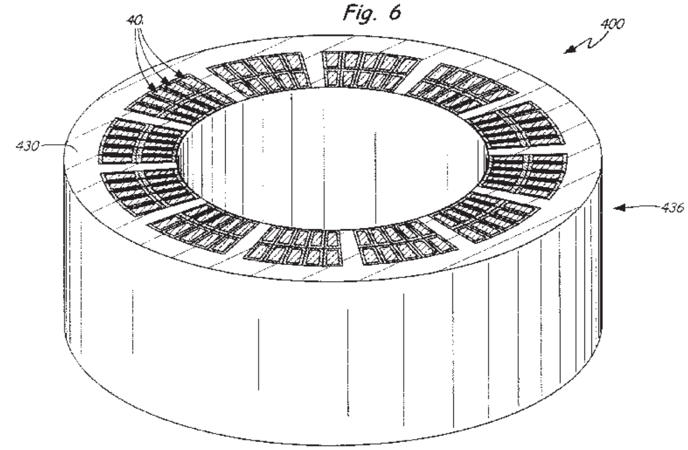


Fig. 4

US Patent 20140035423 A1 (2014)

Concluding Remarks

- Nanocomposite magnets offer significant potential to increase maximum energy product in magnets (and reduce size of magnets) for permanent magnet motors
  - Significant advances in fabrication technology required to produce bulk magnets

- Additive manufacturing is emerging as a promising technique for fabrication of electric motors and offers several potential advantages:
  - High power density and reduced volume
  - New electromagnetic design
  - Reduction of cost
  - Integration of electronics