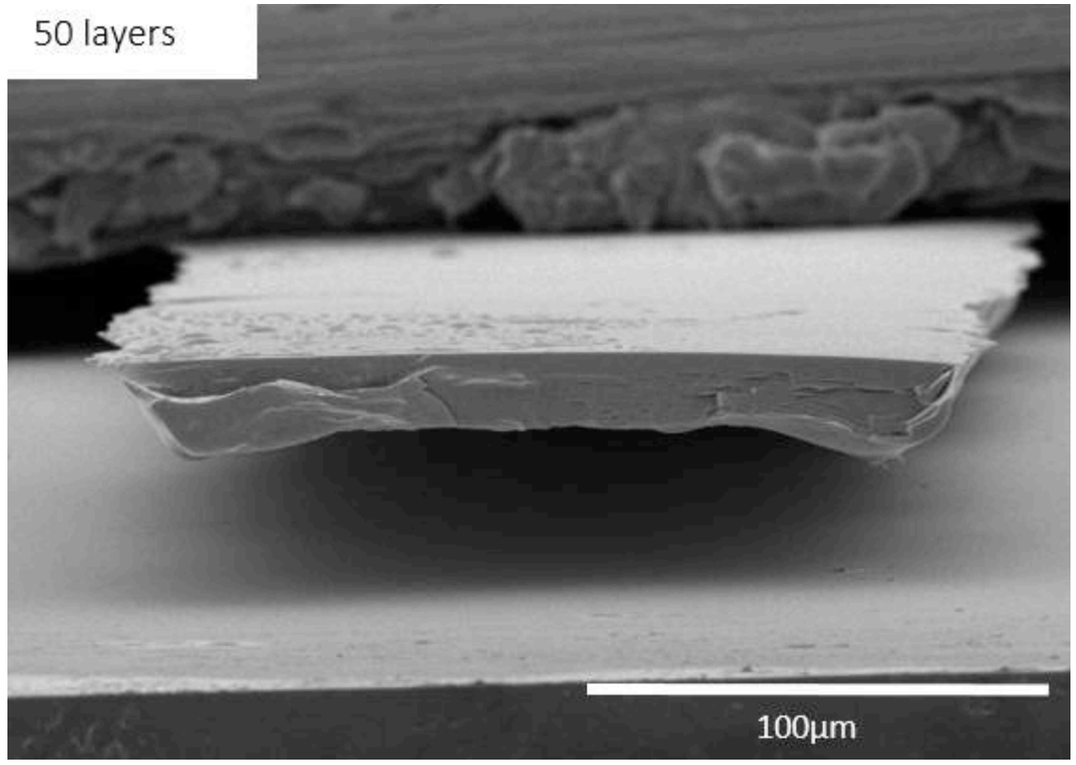
Dissolvable Metal Supports, Reactive Inks, Nano-inkjet Printing



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Summary

- Dissolvable Supports
  - easy support removal, reduced costs
  - remove supports from entire build platforms at once
  - improve surface finish for entire parts
  - supports only need to be fluid accessible
  - remove design constraints

- Reactive Inks
  - potentially space-compatible (no powders, small space requirements)
  - print metals, oxides, and polymers
  - print complete, functional devices

- Nano-inkjet printing
  - nano-scale resolution
  - print reactive inks
  - print complete devices with sub-micron resolution

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Why Dissolvable Supports?

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Problems Removing Metal Supports

Current Methods	Limitations	Impact to Mission Success
Manual Grinding (Dremel, chisel, hammers)	• slow (days to weeks) • inconsistent (user-to-user) • leaves behind a rough surface • difficult to reach internal supports	• miss mission-critical deadlines • consuming critical military personal time • difficult to qualify parts • poor mechanical performance • limits design options reduces warfighting capability
Machining (5-axis mill + trained machinists)	• extremely slow (weeks) • requires highly trained machinists • requires highly specialized, delicate equipment • difficult to reach internal supports	• miss mission-critical deadlines (lost agility) • few qualified personal with years of training & experience • 5-axis mills are difficult to maintain in the field • limits design options reduces warfighting capability

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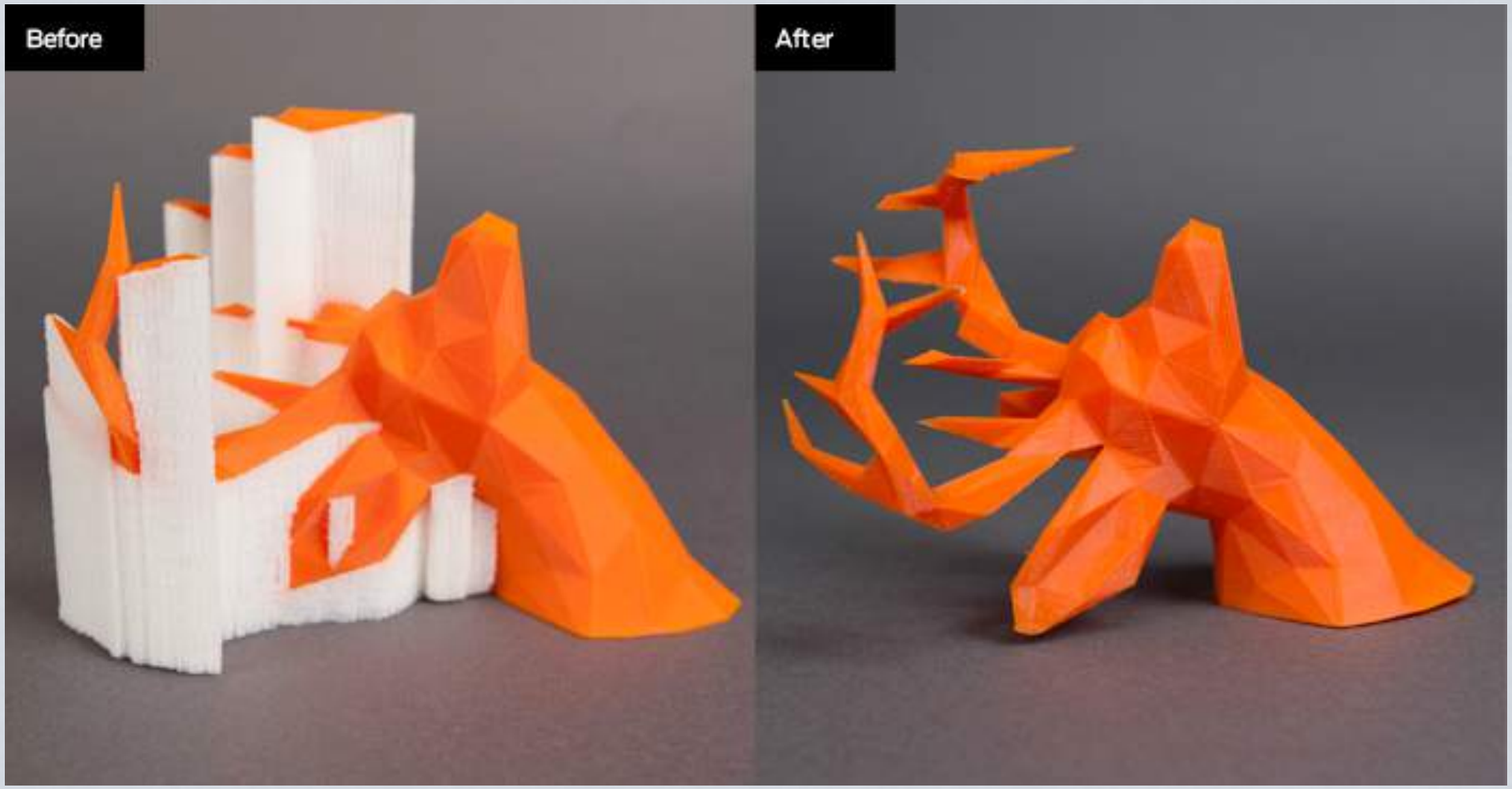
Polymer Dissolvable Supports

- Part: Acrylonitrile butadiene styrene (ABS)
- Support Poly-vinyl alcohol (PVA) or Polylactic acid (PLA) or
- Remove: Water or Isopropyl Alcohol (IPA) + KOH
- Commercial equipment and processes enables in-field fabrication + support dissolution



http://www.makerbot.com/blog/2013/12/09

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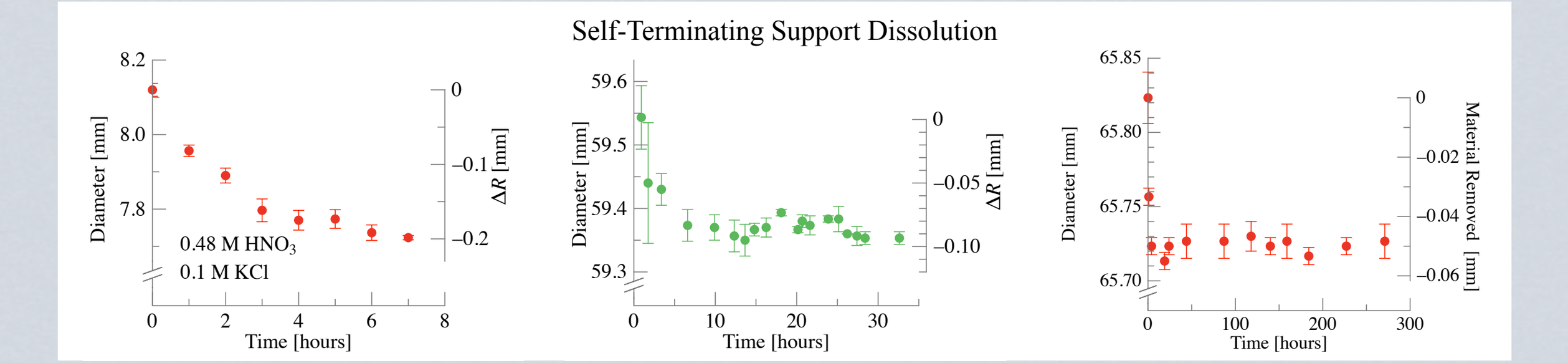
Dissolvable Supports for PBF



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PBF Process Results

a) Printed Part

b) After Sensitization

c) Etching; T = 7 hrs

d) Etching; T = 22 hrs

e) Separated; T = 32.5 hrs

f)

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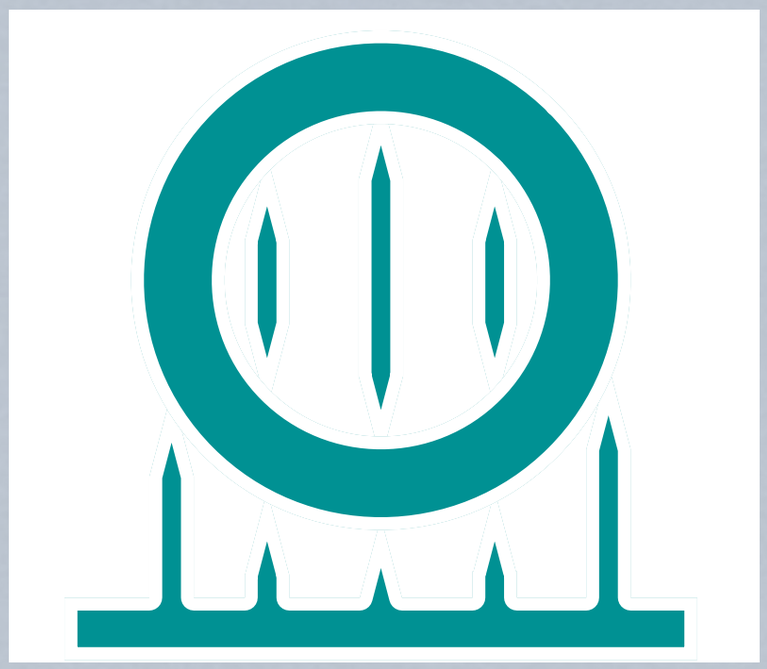
Powder Bed Fusion

- Highlights
  - self-terminating
  - no change in printing parameters
- Sensitize surface (50 - 100 µm)
  - supports are very thin, 80 - 150 µm
  - increase corrosion susceptibility
  - ingrate sensitization directly into post-process annealing step
- Proof-of-Concept
  - PH-17 Stainless steel
  - carburization at 800 ˚C for 6 hours
  - captures chromium in carbide precipitates
  - etch in HNO_3 and KCl under bias

Supports are thin/narrow

Only need to remove ~100 µm



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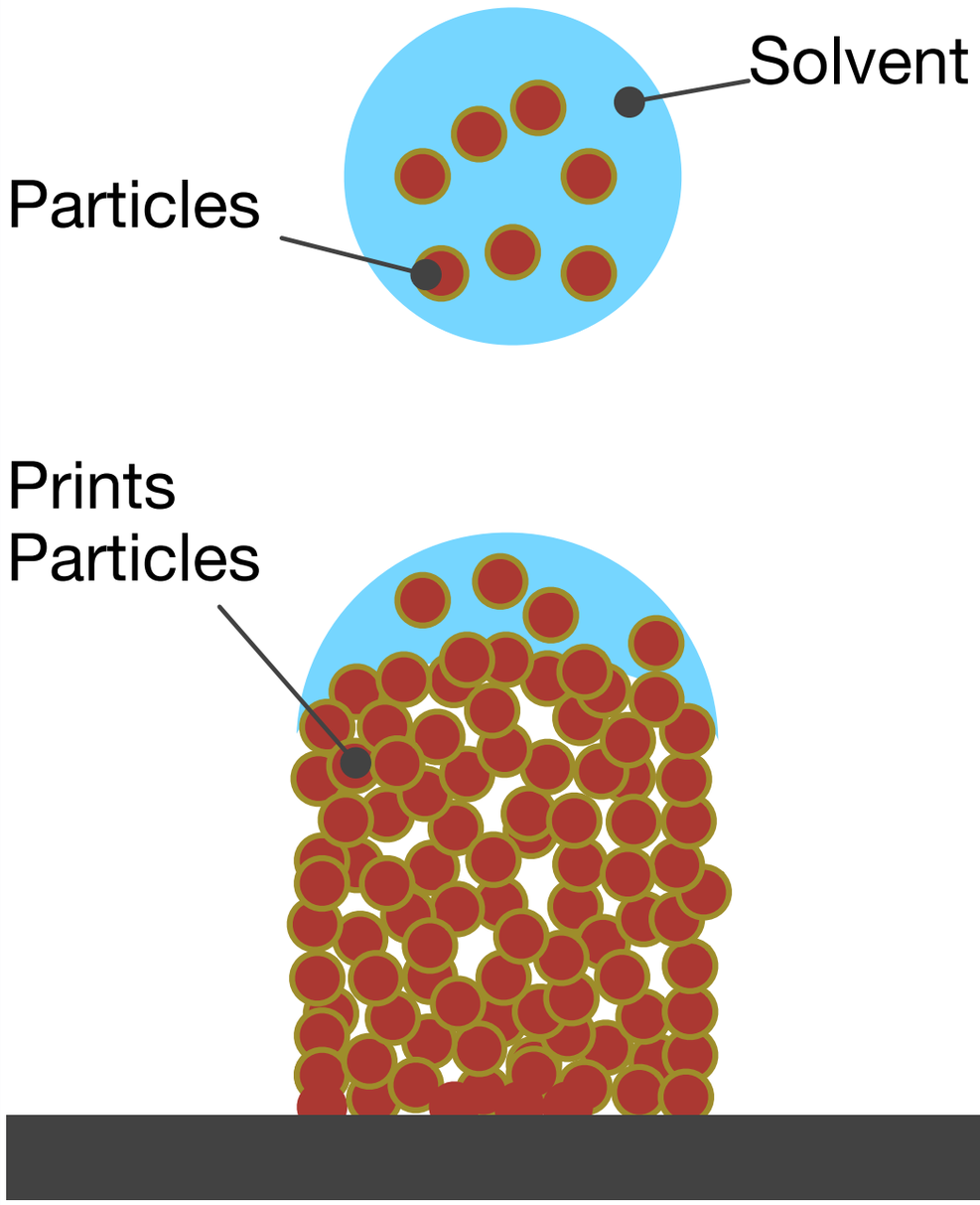
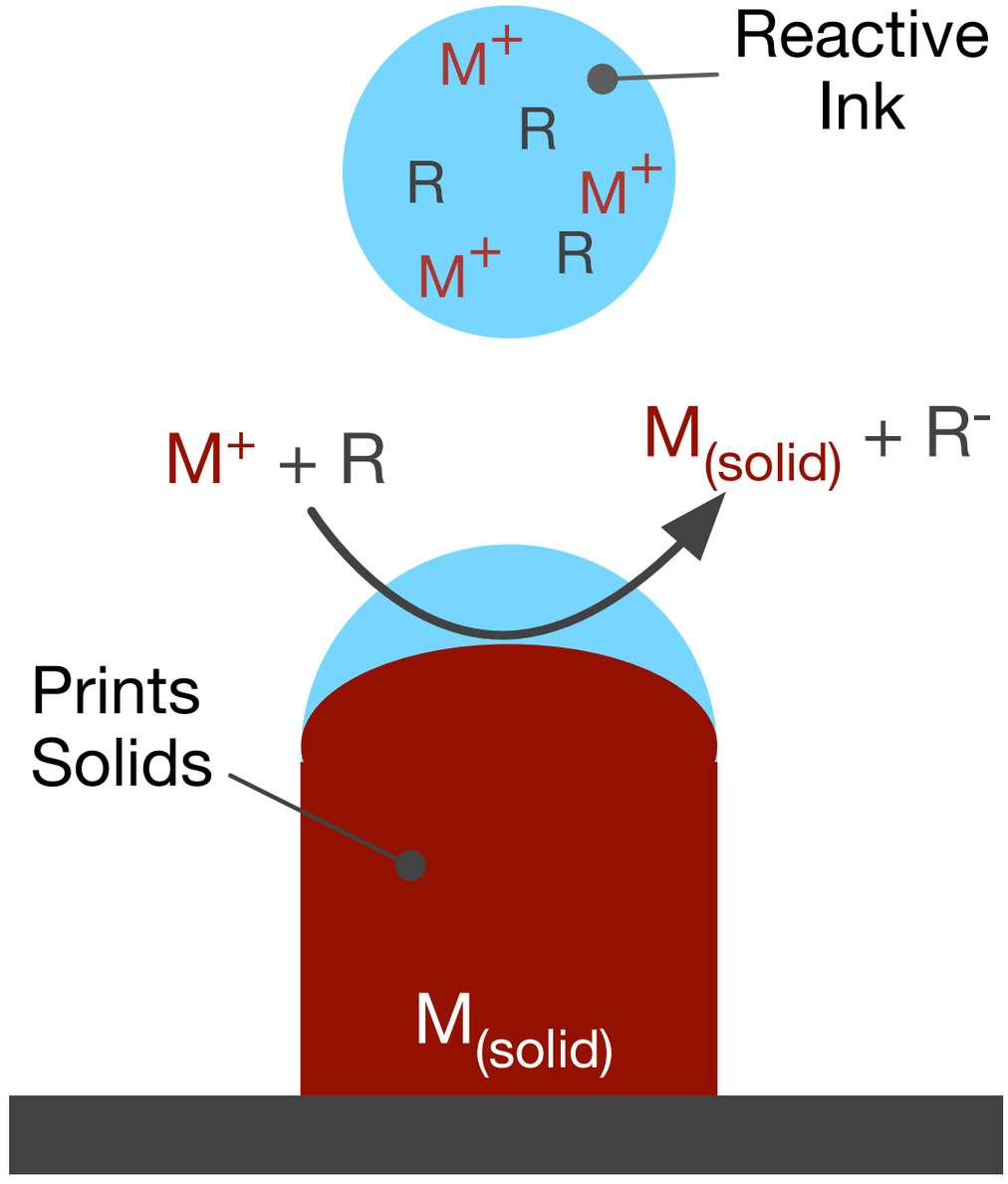
Reactive Inks: New Approach to Printing

a) Traditional Ink



Traditional inks
print particle clusters

b) Reactive ink



Reactive inks
print solid structures

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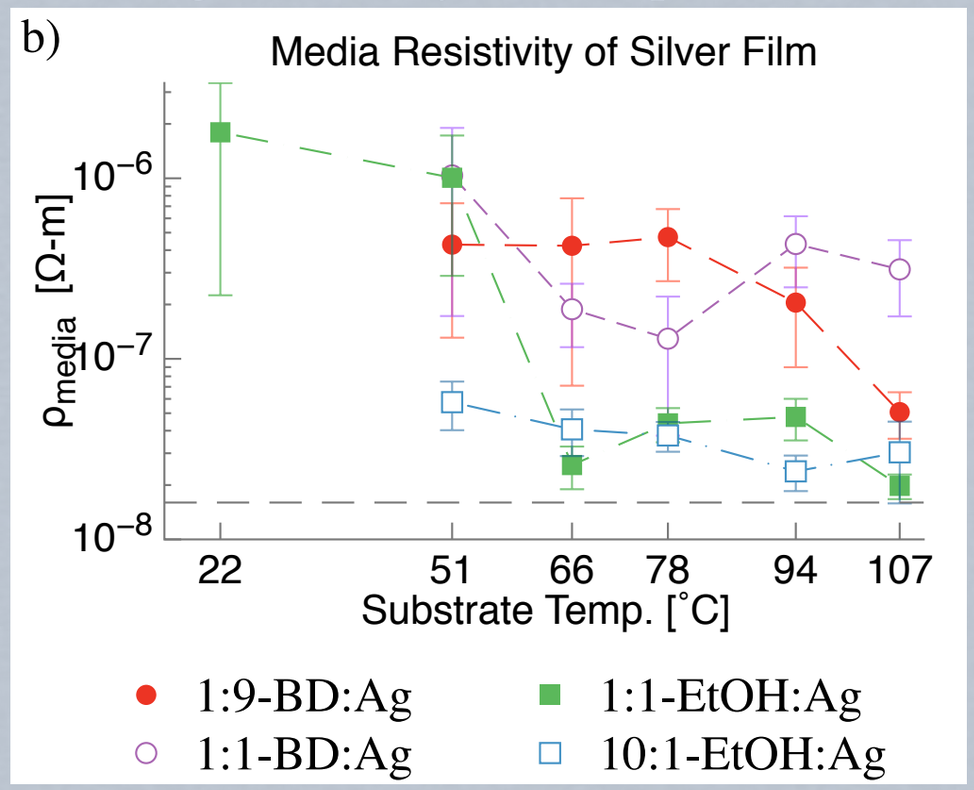
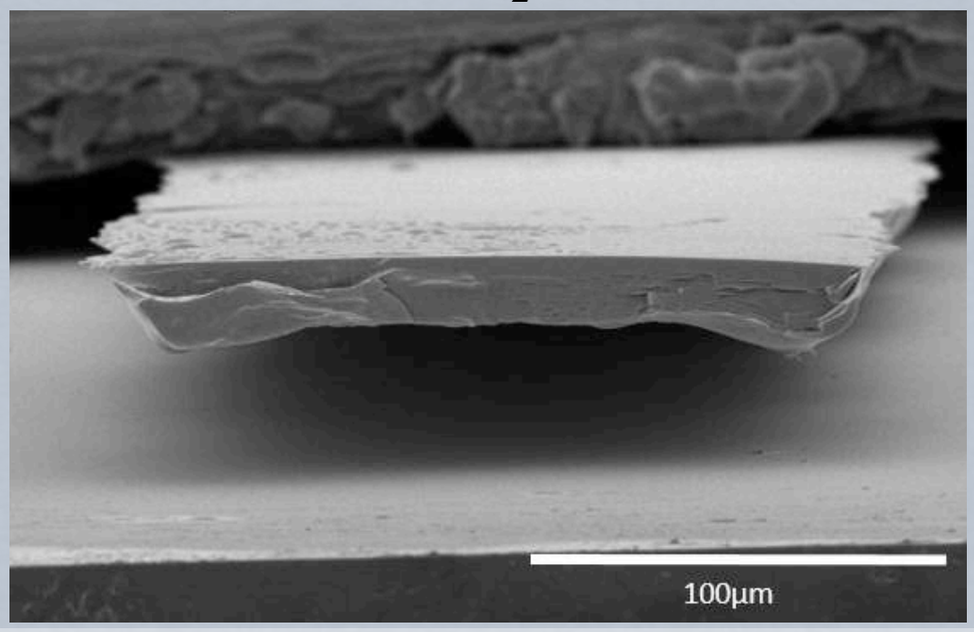
Reactive Inks

- Materials
  - Ag, Cu, Ni, SiO_2, PDMS
- Excellent material properties
  - printed Ag resistivity @ 1.8 μΩ-cm
  - bulk Ag is 1.6 μΩ-cm
- Extremely low temperature
  - Ag from 30 ˚C to 150 ˚C
  - SiO_2 from 80 ˚C
- Control morphology
  - porosity from <5% to 95%
- Print complete devices
  - microfluidic devices w/ integrated electronics
- Photovoltaics
  - reduce Ag usage by 90%
  - saves industry $12 billion/year

Ag Resistivity vs. Temperature



Printed SiO_2 at ˚85 C



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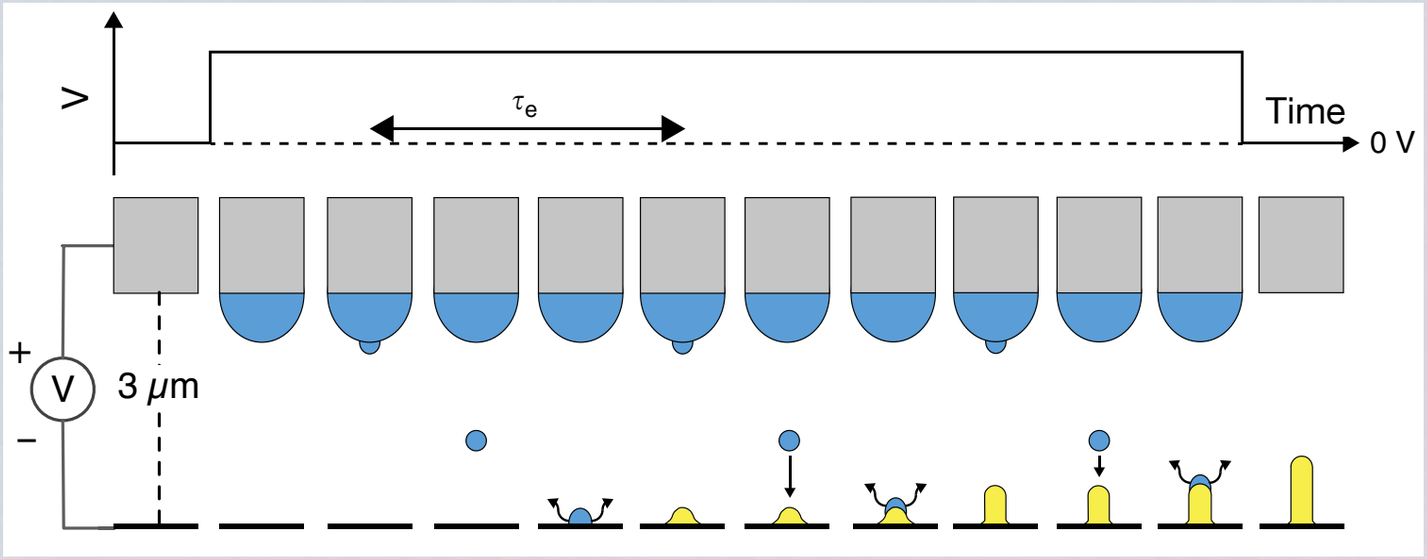
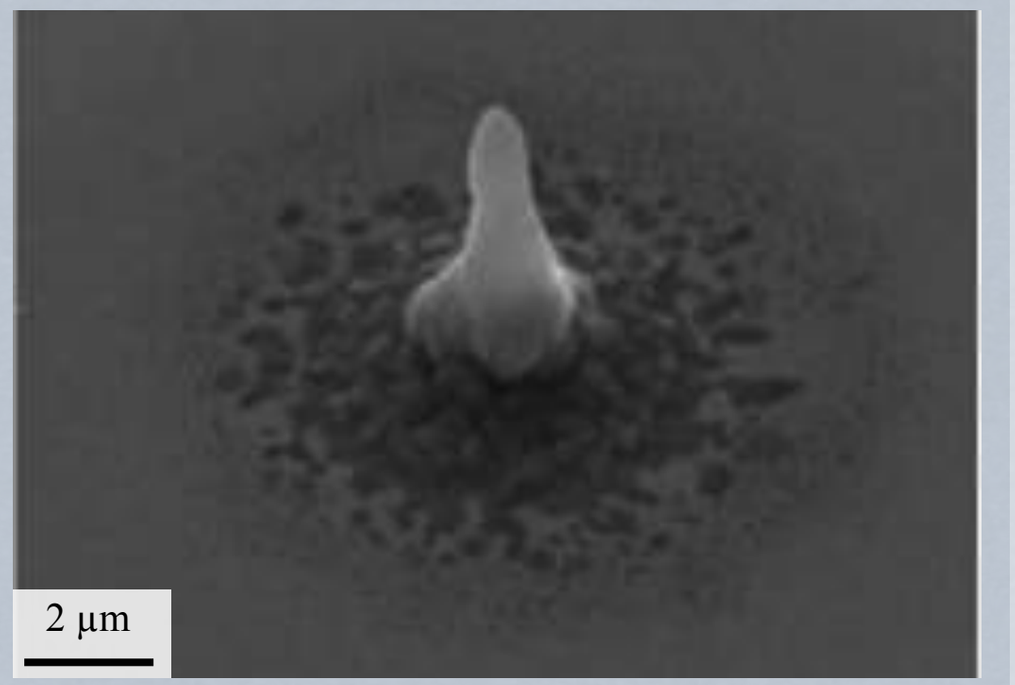
Nano-inkjet Printing

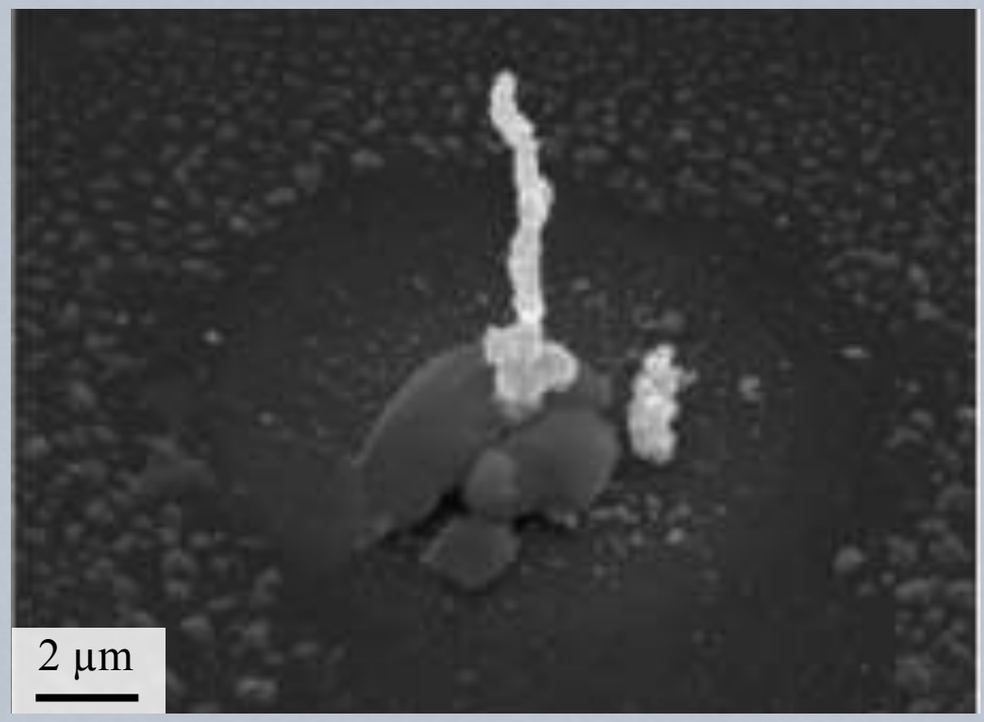
- Nano-scale additive manufacturing
- Reactive inks
  - excellent material properties
  - reduced clogging

- Current research
  - Printable metamaterials
  - Ag/SiO_2 stacks



Nano-inkjet printing





P. Galliker, J. Schneider, H. Eghlidi, S. Kress, V. Sandoghdar, D. Poulikakos, Nature Communications 2012, 3, 890.

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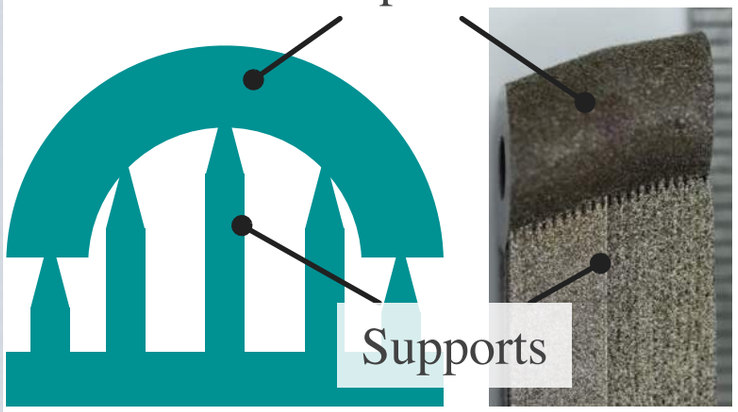
Dissolvable Supports in Metals

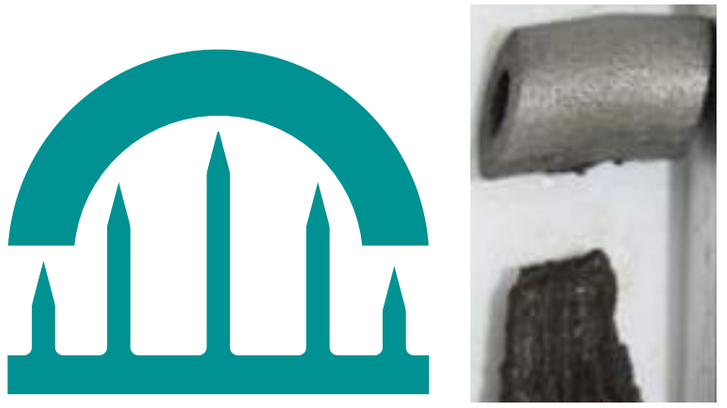
Dissolvable Supports for Powder Bed Fusion

Print Part



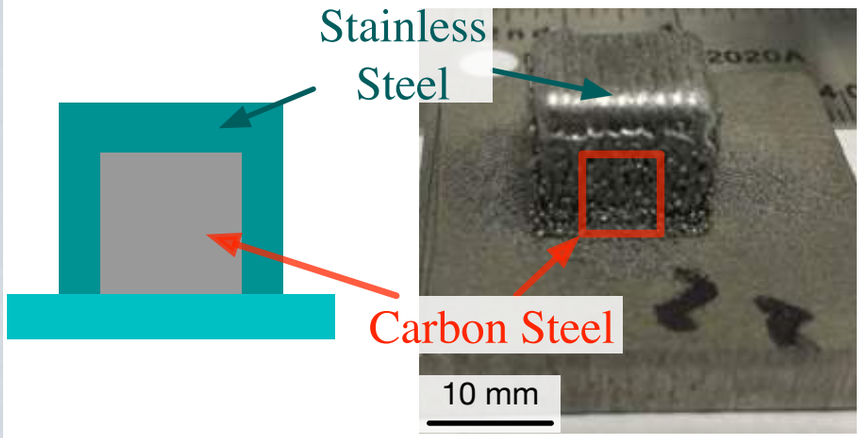
Sensitize Surface

Dissolve Sensitized Surface

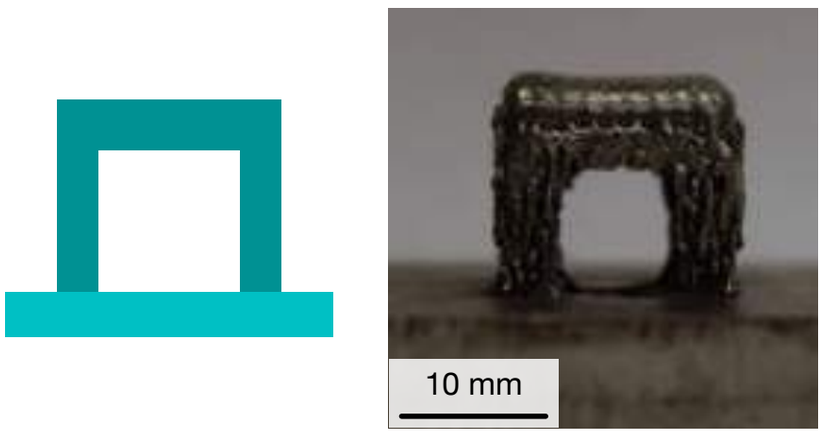


Dissolvable Supports for Directed Energy Deposition

Print Component w/ Support Material



Dissolved Support Material



= Stainless Steel Component

= Carbon Steel Support

= Stainless Steel Build Platform

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Acknowledgements

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