Inkjet Printing of Nanocomposite High-Explosive Materials for Direct Write Fuzing

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54th Fuze Conference
13 May 2010
Kansas City, MO

Acknowledgements

- Chris Morris, Luke Currano and Madan Dubey (ARL)
- Dennis Polla (DARPA)
- Carl Kime (Lodestar Strategies)
- Michael Bobrik (Systems Planning Corp.)
- James Zunino, III and Daniel Schmidt (ARDEC)
- Daniel Stec, III (SAIC)

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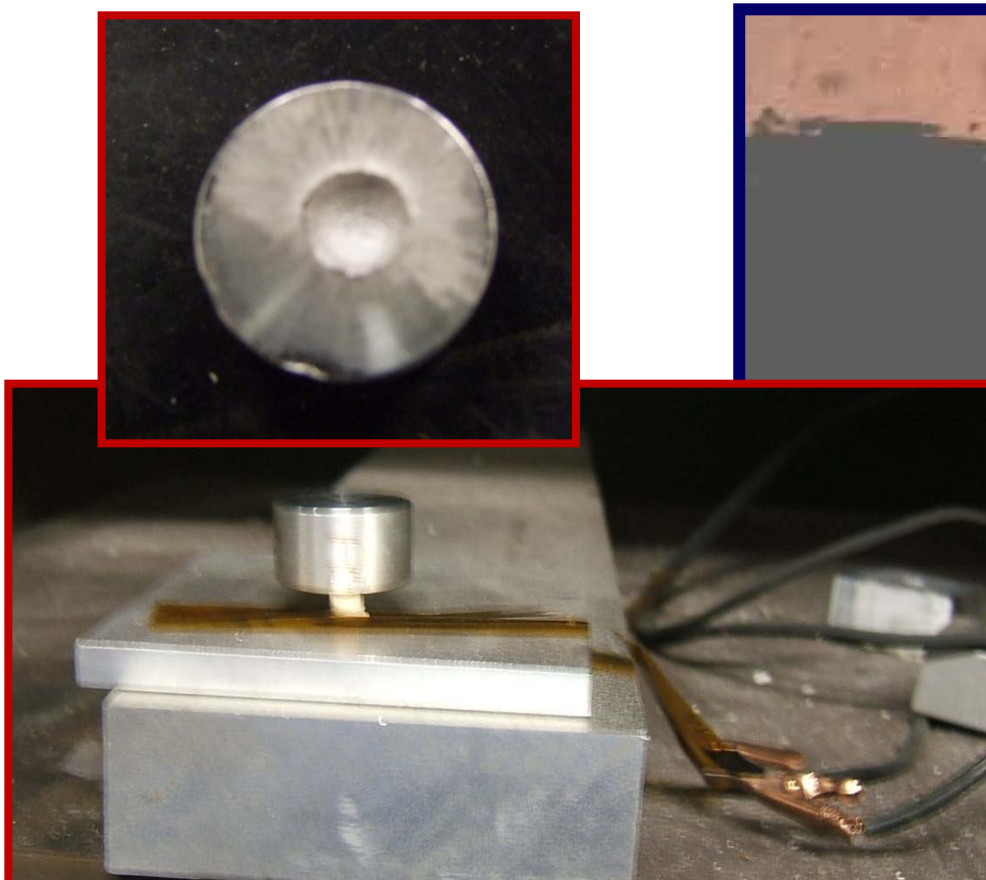
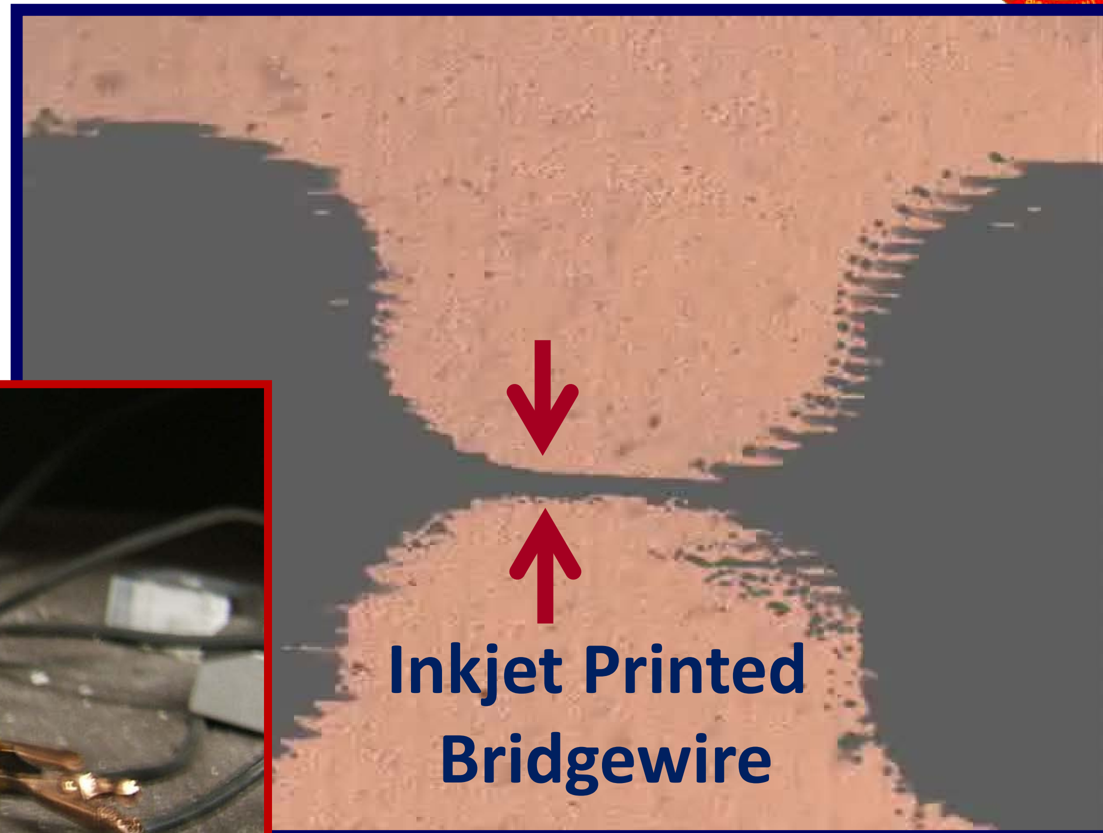
Direct Write Technology

- The direct-write technology was developed for the rapid prototyping of electronic circuits, through a 1979 DARPA (Defense Advanced Research Projects Agency) program.[i]
- Syringe systems utilize direct displacement loading through a hollow pen point.
- Typical inks are conductive, such as those used for circuit boards or antennas. Ceramic and insulating inks have also been developed.
- The direct write techniques are advancing, with multiple companies making syringe type direct displacement machines. In 1999 DARPA invested $40 million dollars into direct write technologies[ii],[iii].
- EDF-11, a CL-20 based secondary explosive ink, has been developed for direct write loading of MEMS devices. It has been qualified by the US Army for use as a booster explosive.

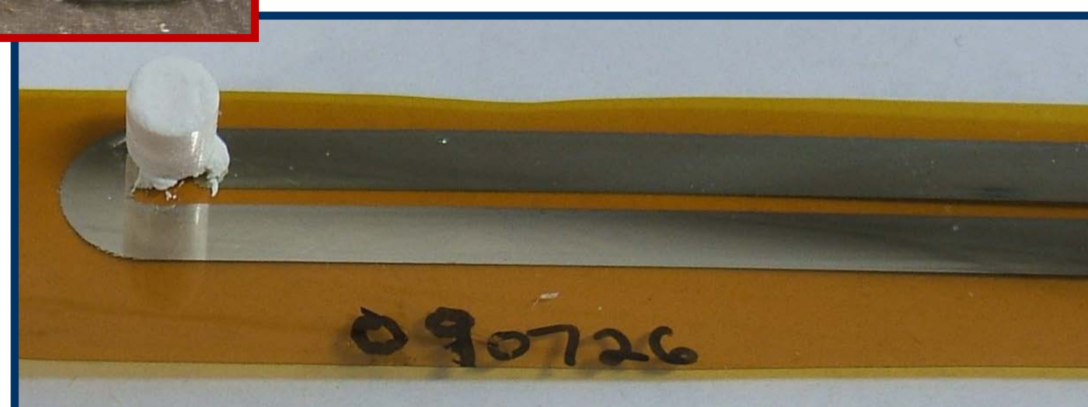
[i] Ohmcraft “Ohmcraft-A brief History” http://www.ohmcraft.com
- [ii] Pique, Alberto and Douglas B. Chriset “Direct-Write Technogies for Rapid Prototyping Applications” Academic Press San Diego Ca 2002.
- [iii] http://www.mesoscribe.com

What can the Army do Today?





Initiation to detonation with an explosive train



Integrated Flexible Energetics & Electronics (IFEE)

	Silicon Electronics	Flexible and Printed Electronics	Energetics
Feature Size	10^{-5} mm	10^{-2} mm	$\leq$1 mm
Infrastructure Cost	$2-3 billion	$10-200 million	----

Can we shrink the size of energetic materials for integration with flexible electronics?

**Electronics statistics from the FlexTech Alliance

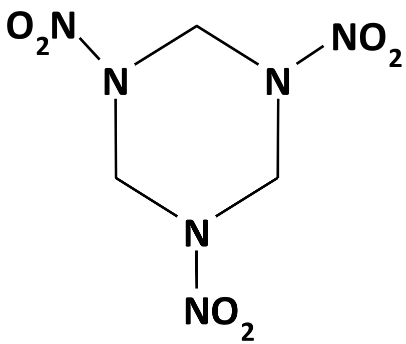
Goal of this Exploratory Study:

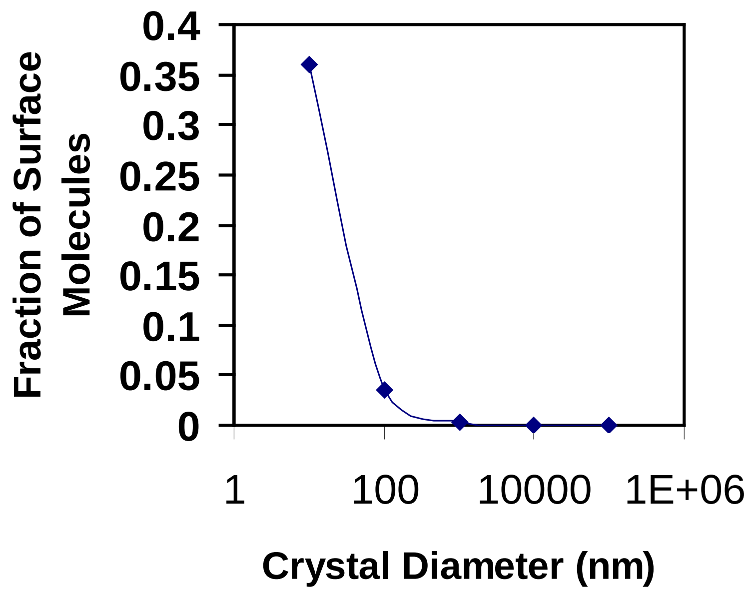
To inkjet print explosive materials with tailorable morphology for integrated flexible energetics and electronics.

Objectives:

1. Develop an ink to inkjet print and pattern explosive materials using a commercially available inkjet printer
2. Optimize ink for maximum spatial resolution
3. Characterize material to correlate printing variables to material structure and properties

Why Nano-Energetics?





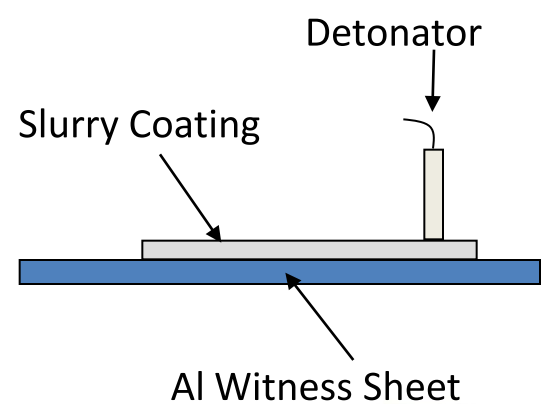
Higher Reactivity with Increased Surface Area:

- $N-NO_2$ bond dissociation energy 8-15 kcal/mol lower for surface molecules vs. bulk (M. Kuklia, 2001)
- Distributed "hot spot" network

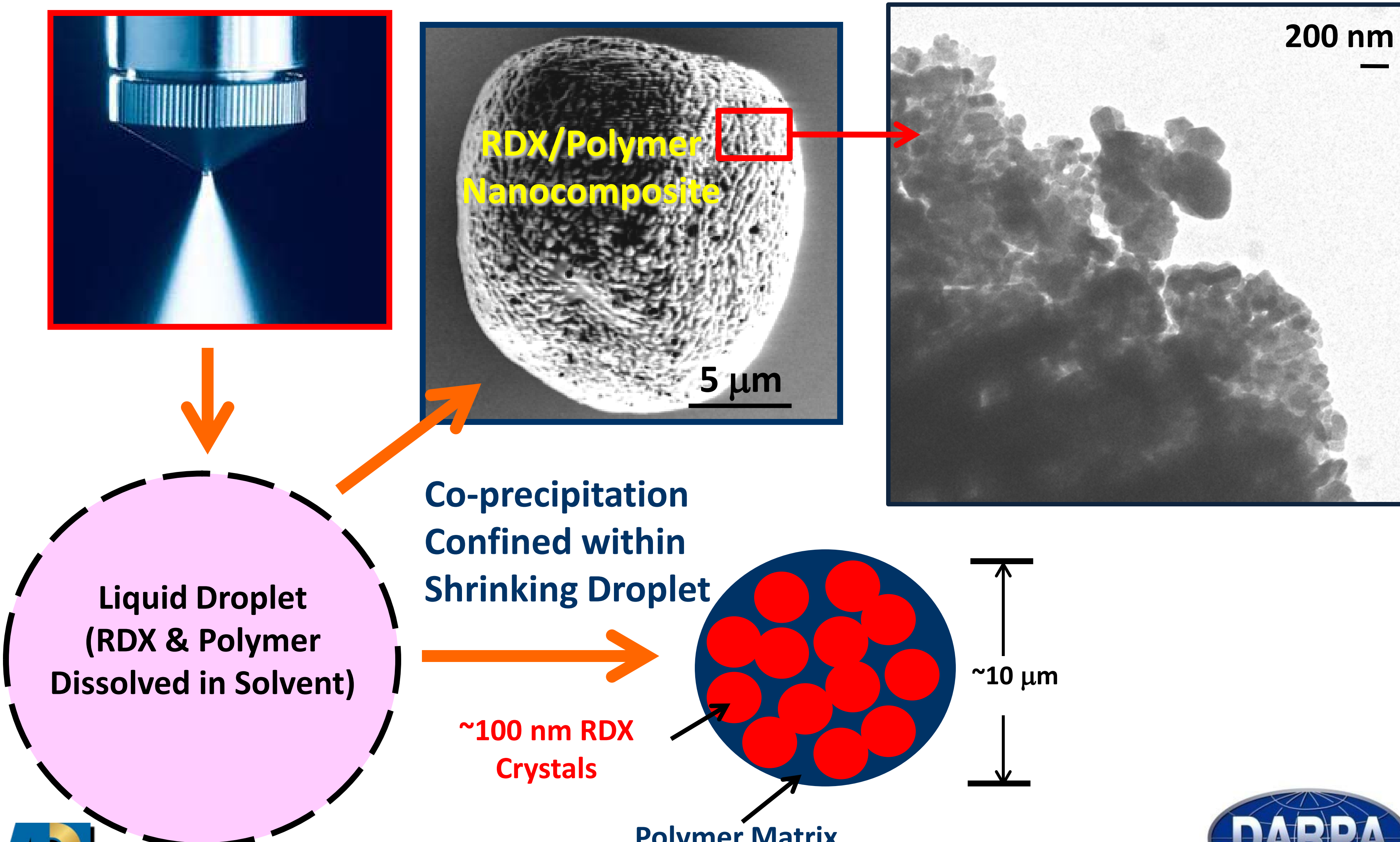
Reduction in Critical Detonation Thickness

Material	Thickness (mm)			
	1.27	0.75	0.64	0.25
Class-5 RDX	No Fire.			
Type A nano RDX	Fire	Fire	No Fire	
Type B nano RDX	Fire	Fire	Fire	No Fire

Coating Width: 5 cm



Confinement Effect in Nanocomposite RDX



Patent I (Pending)

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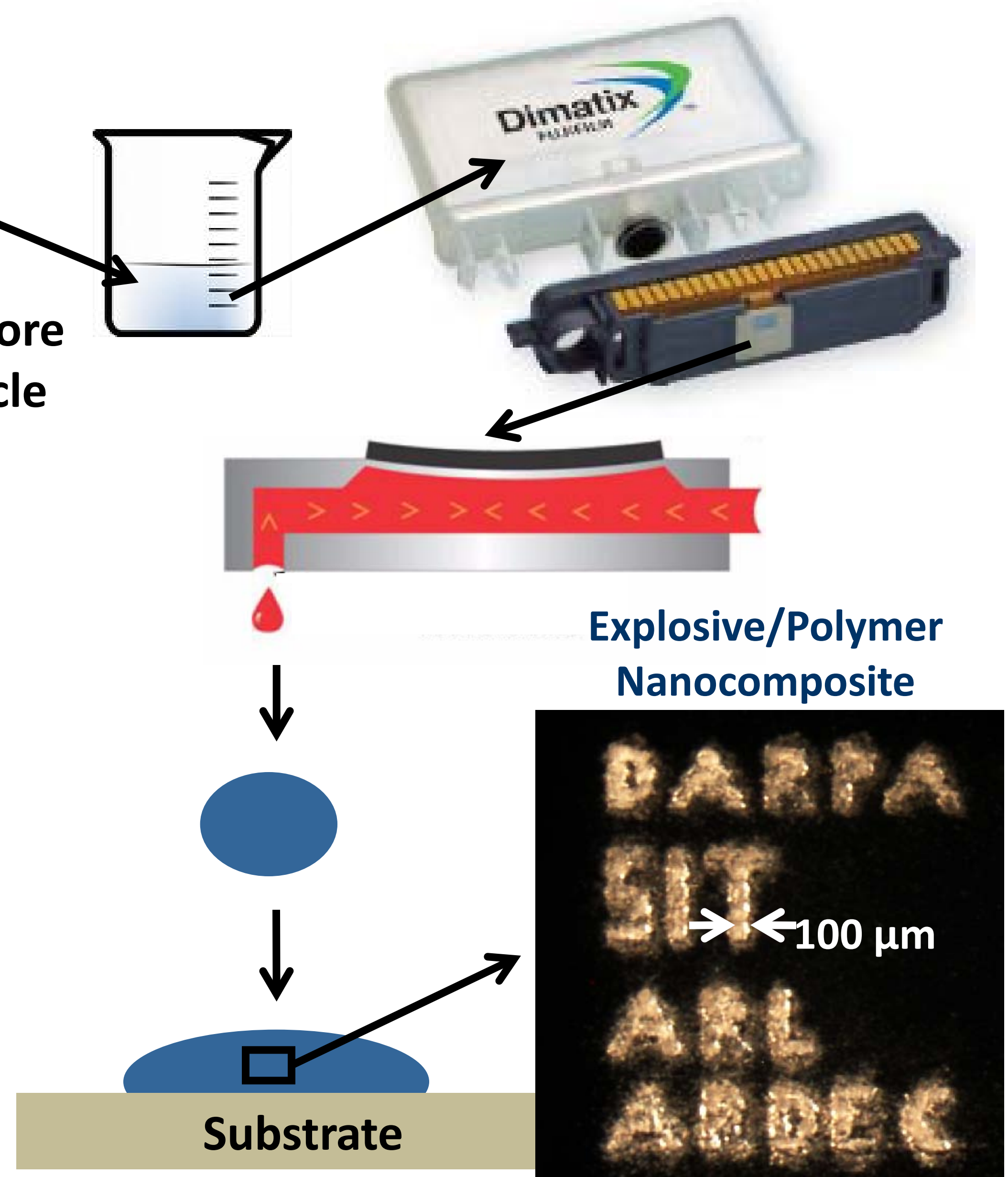
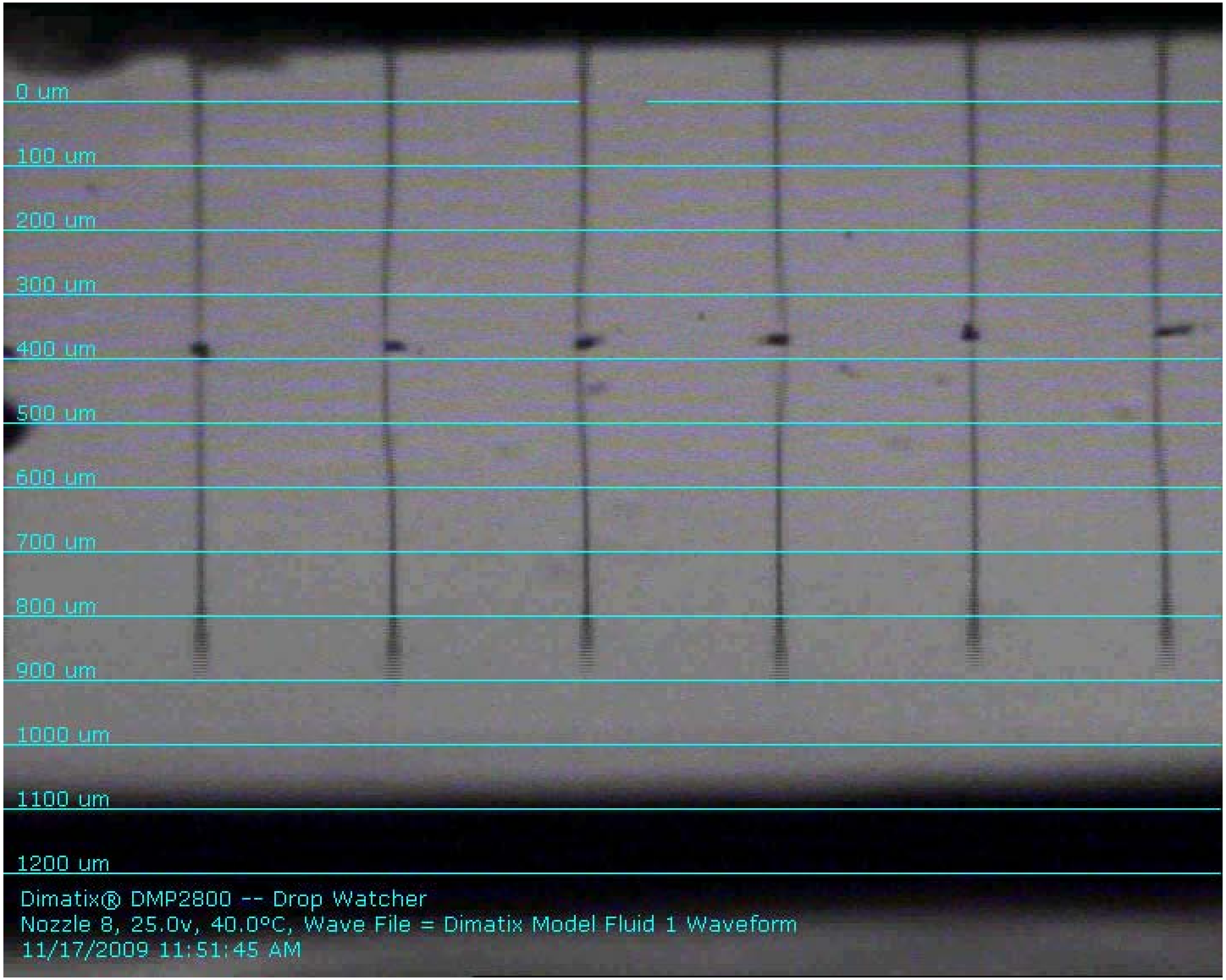
"One-Step" Printing Approach

- **All-liquid ink**
  - All desired ingredients are dissolved in an organic solvent
  - No colloidal suspension, therefore no issues associated with particle agglomeration, growth, dispersion, or clogging
- **One-step simplicity**
  - No issues associated with extra nanoparticle production and handling steps
  - Mitigated ESH concerns

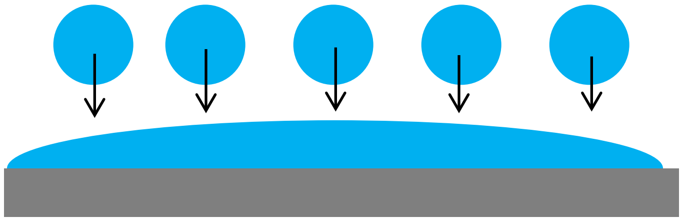


Patent II (Pending)

Jetting of One-Step Ink

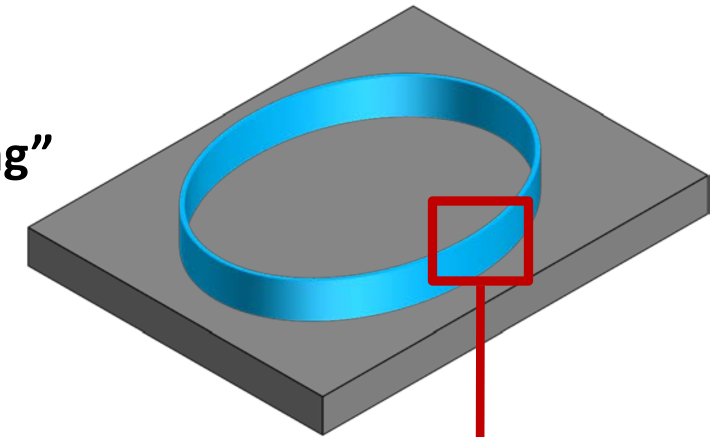


Pooling Effect in Inkjet Printing

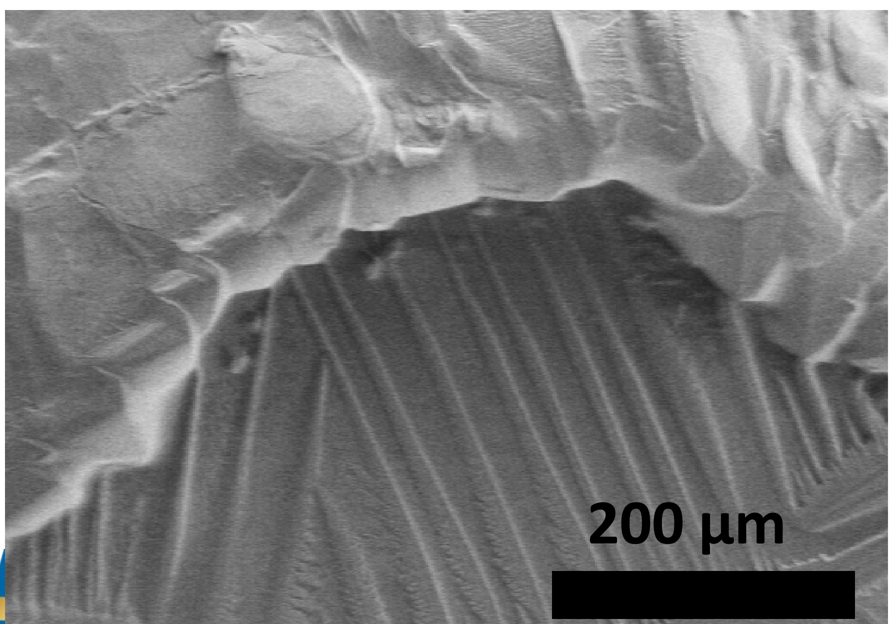


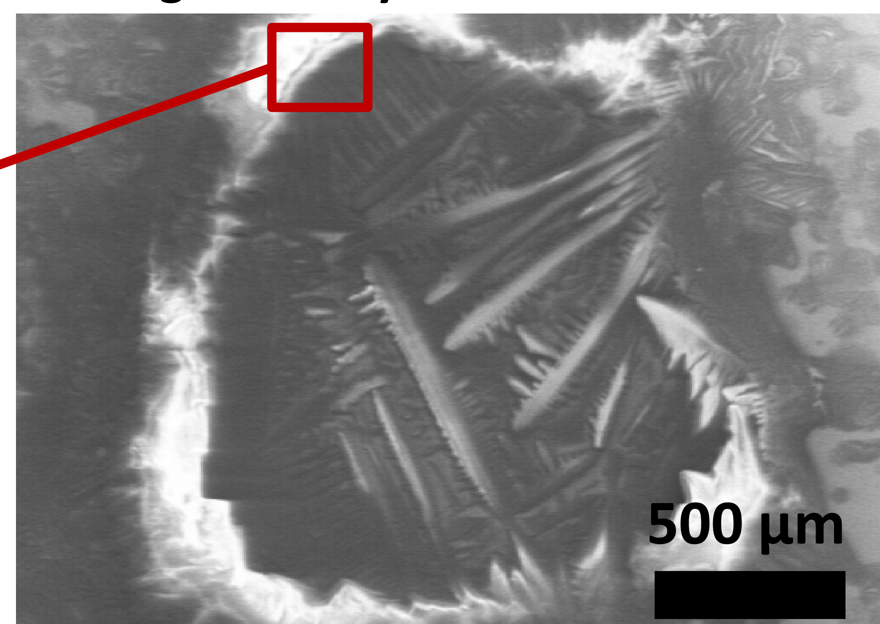
Pooling of Ink Droplets
with Fast Printing Conditions at
Ambient Temperature

Evaporates to
Form “Coffee Ring”

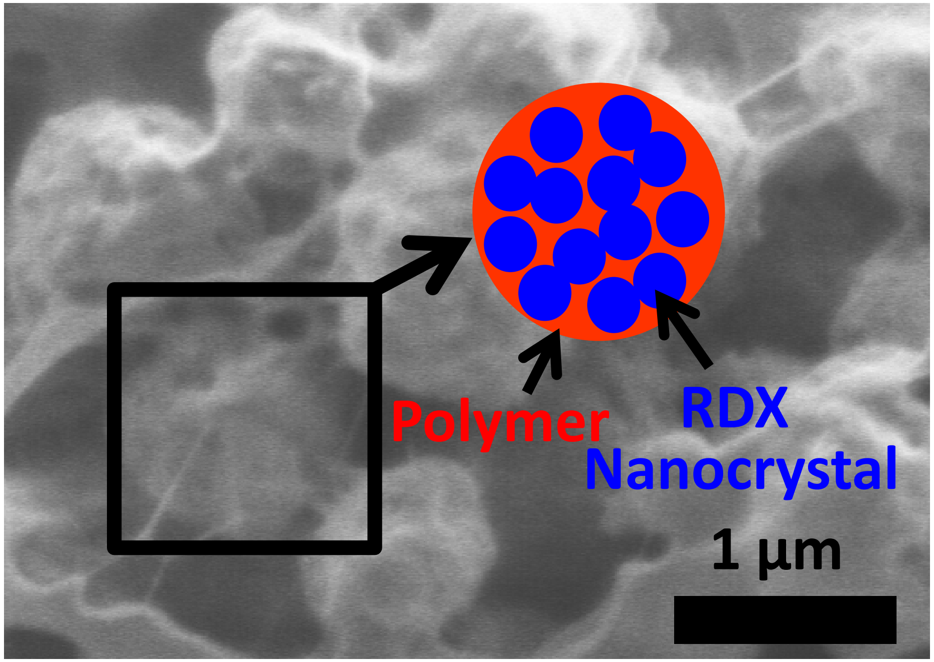


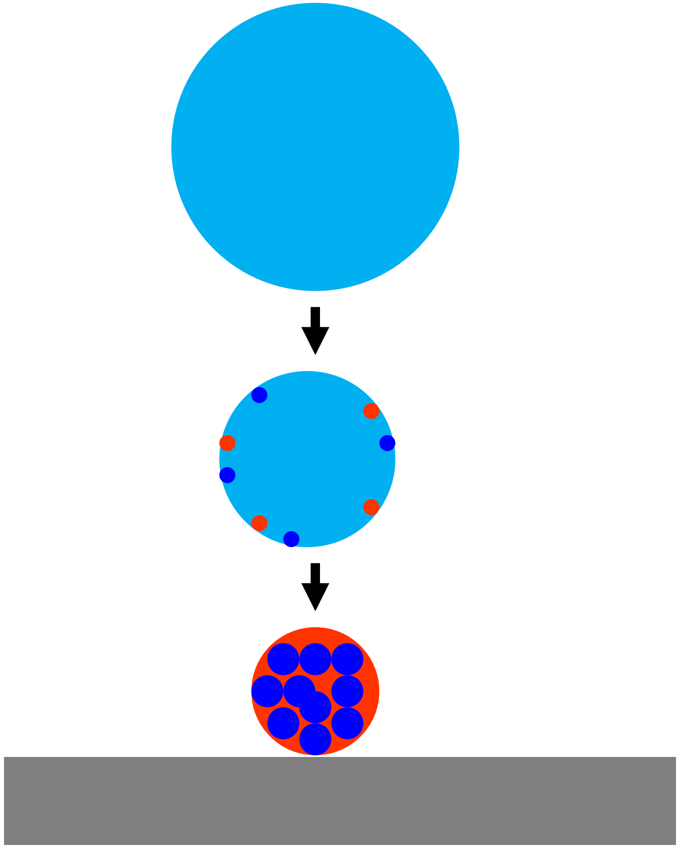
Uncontrolled Growth of
Large RDX Crystals





Confinement Effect in Inkjet Printing

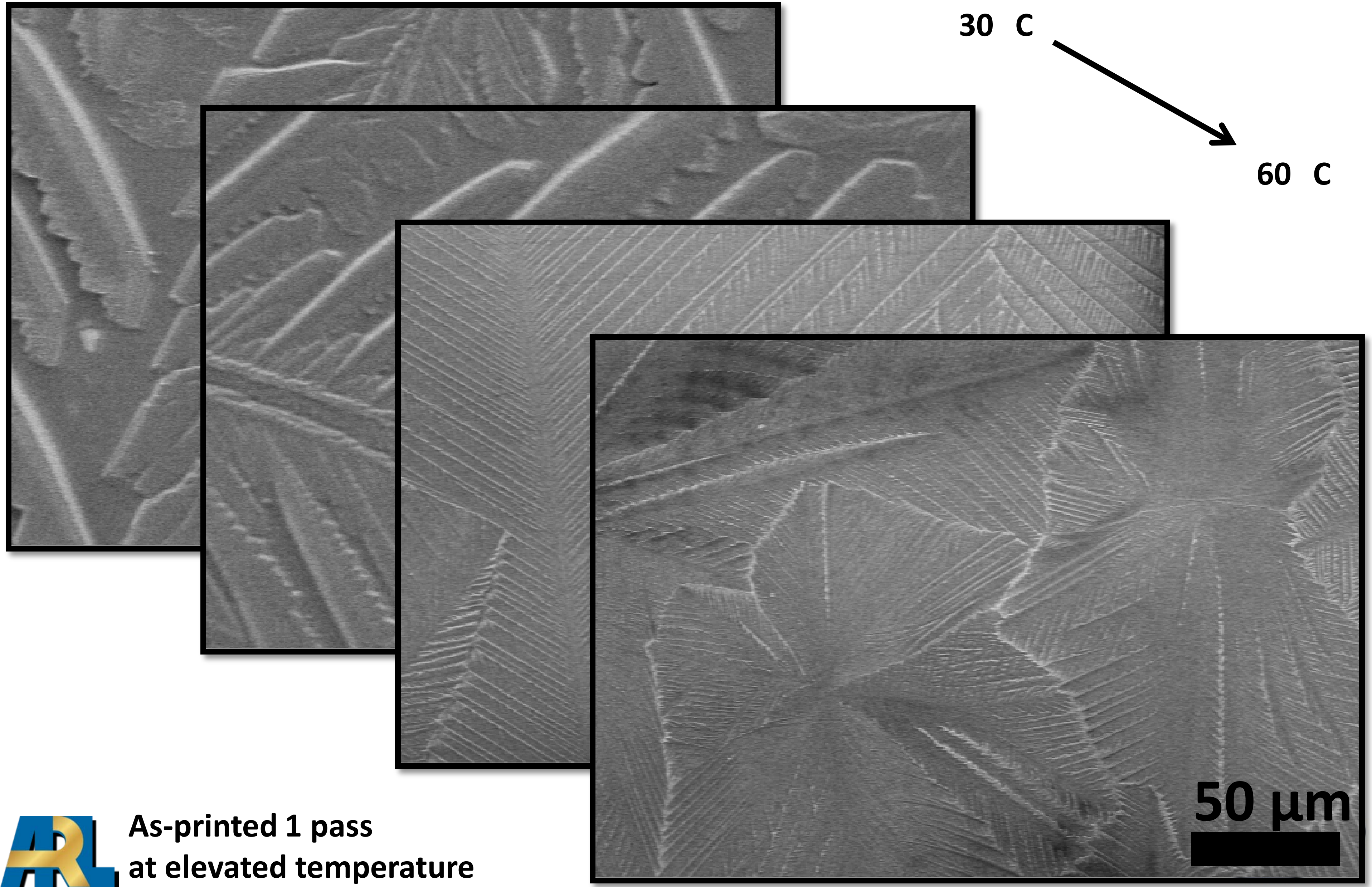




- Desired for nanocomposite structure formation

- In order to avoid "pooling" effect, (1) long wait between passes, (2) large distance between droplets to avoid droplet coalescence and (3) large distance between nozzle and substrate.

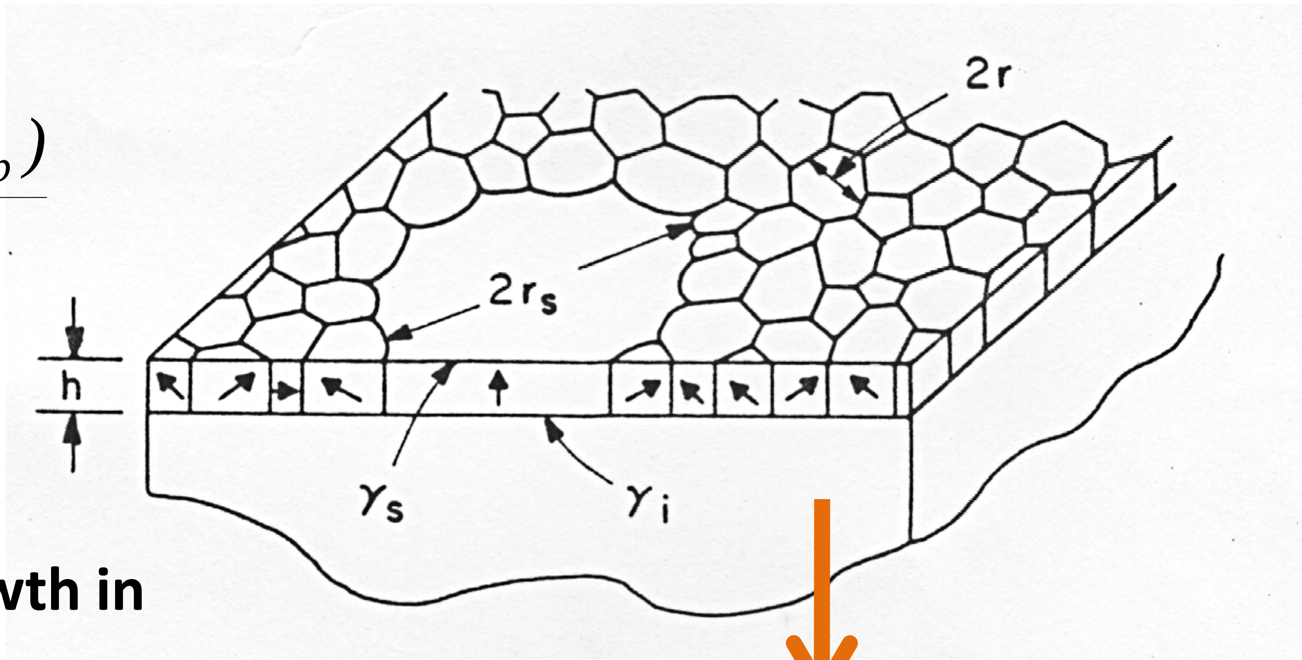
Temperature Effect on Grain Growth



As-printed 1 pass
at elevated temperature

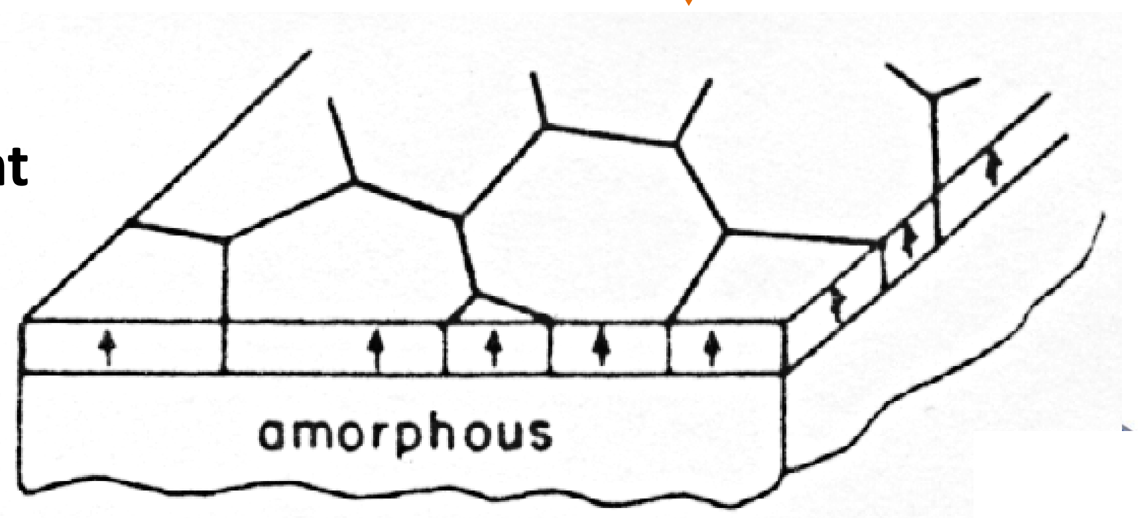
Abnormal Grain Growth Mechanism

$$\frac{dr_s}{dt} \cong M \frac{(2\Delta\gamma + \gamma_{gb})}{h}$$



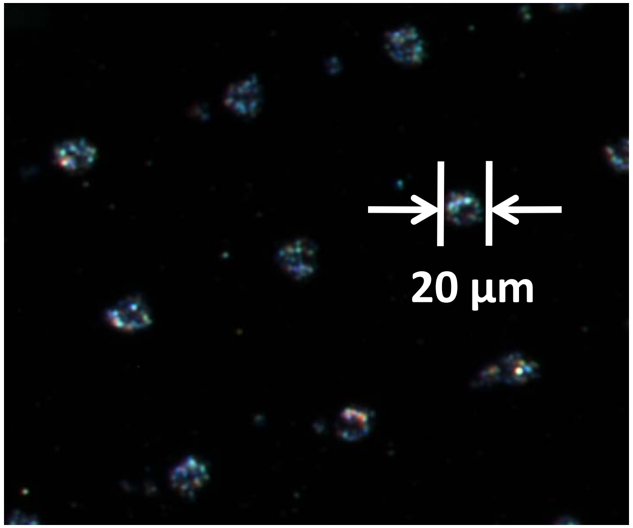
Abnormal grain growth in thin-films causes:

- **Lateral grain growth**
- **Texture development**



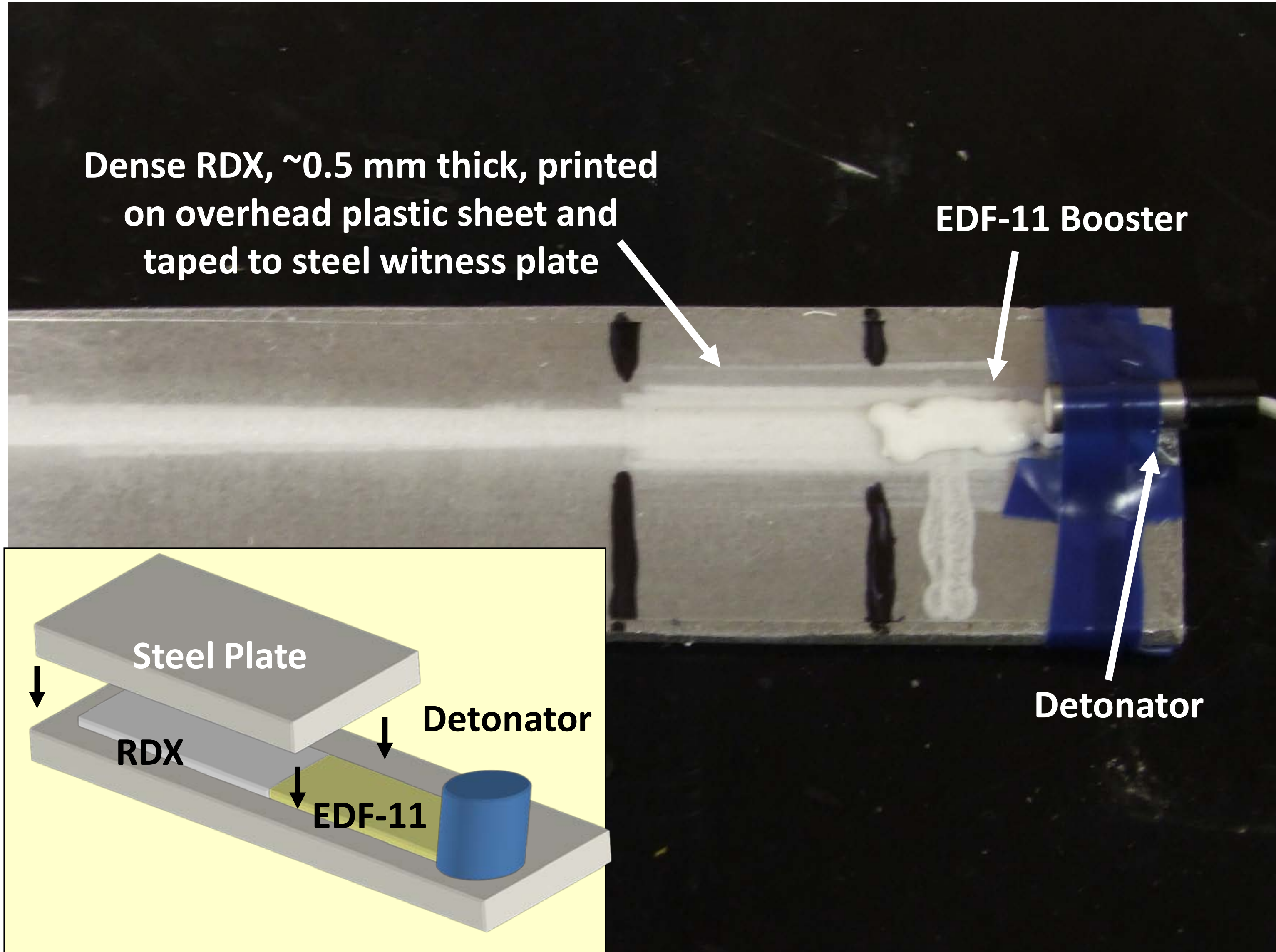
Thompson, 1990

Generation of Test Samples

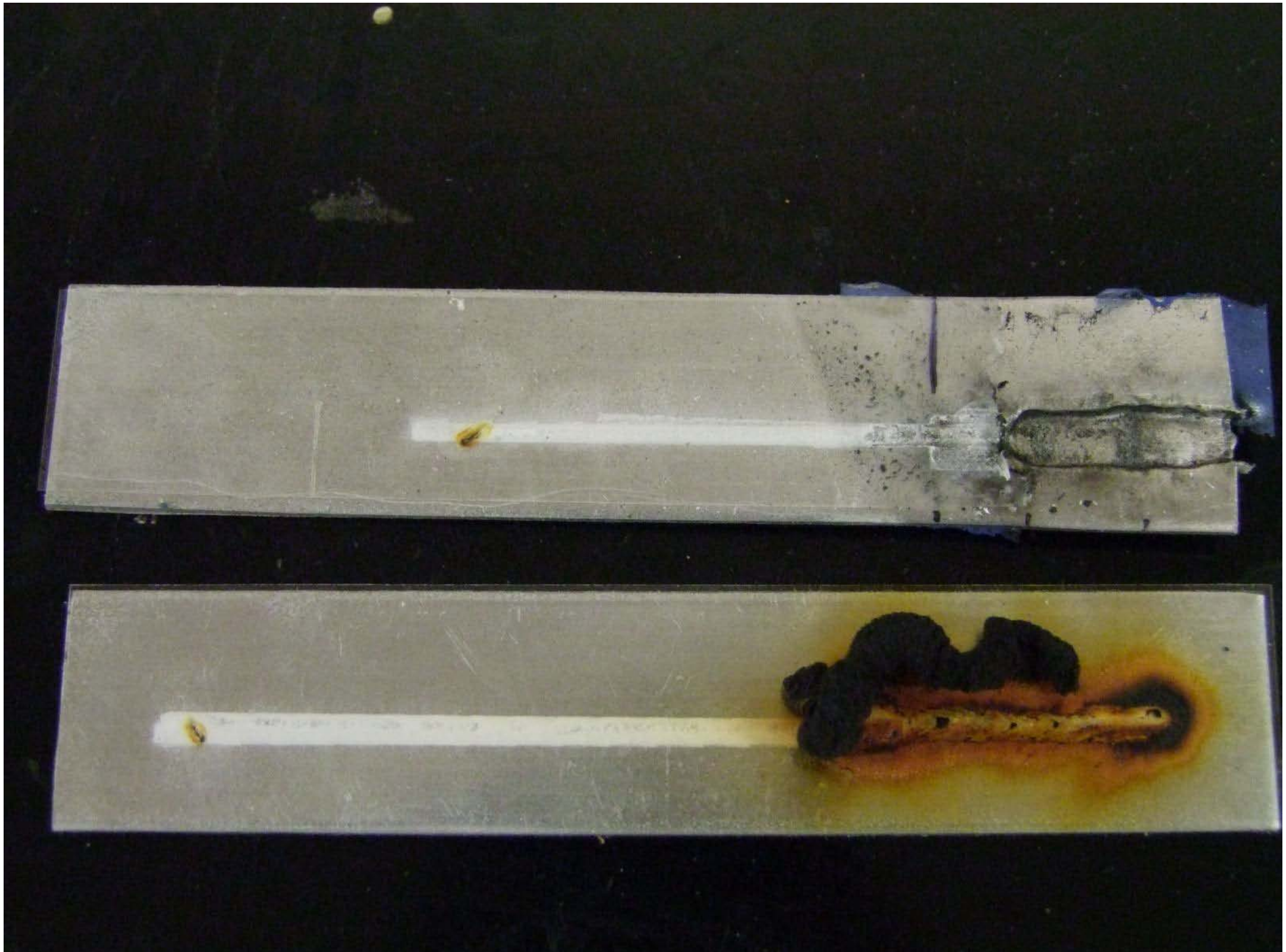


- Ink and jetting parameters were optimized for maximum spatial resolution
- Process to produce RDX nanocomposite morphology was unreasonably slow
  - Printing rate <100 µm/week
  - No samples generated for testing
- Heating the substrate produced dense morphology with abnormally grown grains
  - Printing rate ~30 µm/h

Example of Dense RDX Samples



Dense RDX Samples after Testing



Conclusions and Future Work

- Inkjet printing of explosive materials was demonstrated with:
  - Tailorable morphology
  - ~20 μm pattern resolution
- The nanocomposite RDX structure was produced, but was not tested due to unreasonably slow printing speed
- The dense RDX structure could be burned, but would not detonate at ~500 μm thickness
  - Without nanocrystalline RDX, sub-mm critical thickness to sustain detonation may not be achievable
- Current efforts aimed at printing alternative nanoenergetic materials for:
  - Critical thickness <100 μm
  - Printing speed >10 μm/h