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A 3D Printable Art Media: Alginate-based Bioinks Doped with Vibrant Mica Pigments

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U.S. DEPARTMENT OF ENERGY BATTELLE

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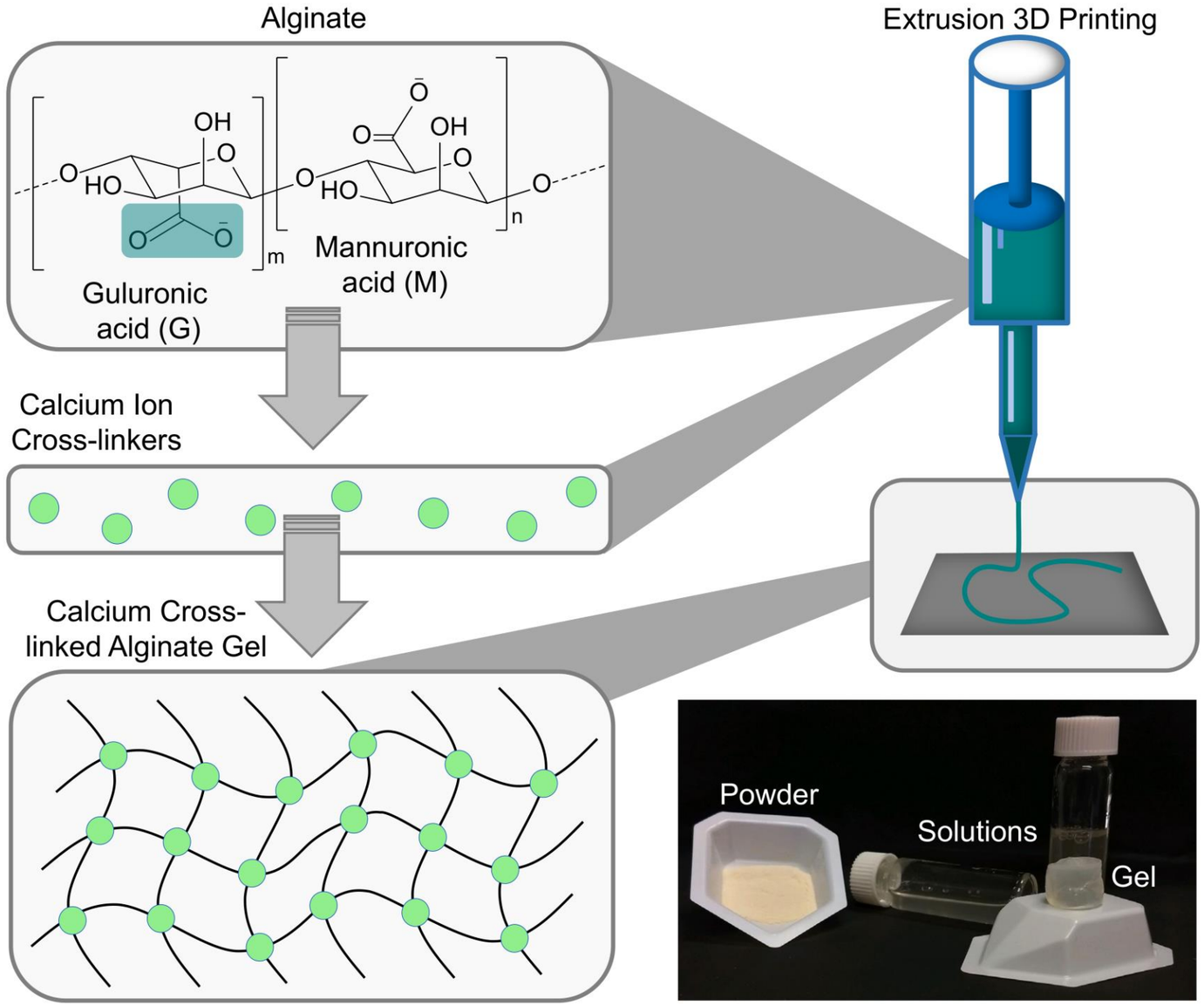
Motivation: 3D printing cells for tissue regeneration

- Traditional 3D printing uses high heat to melt plastic filament
- High heat will kill cells
- Bioinks are used as an alternative to plastics because they can be printed at room temperature

https://www.3dnatives.com/en/fused-deposition-modeling100420174/

Chemical structure of sodium alginate creates a liquid that can be 3D printed into a stable solid

- Sodium alginate is a biopolymer derived from seaweed
- Carboxylic acid groups on polymer chains can bind calcium ions
- Calcium ions form bridges between polymer chains to create a network



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Sodium alginate is an ideal binder for a 3D printable bioink composites

Bio Art Attack Submission

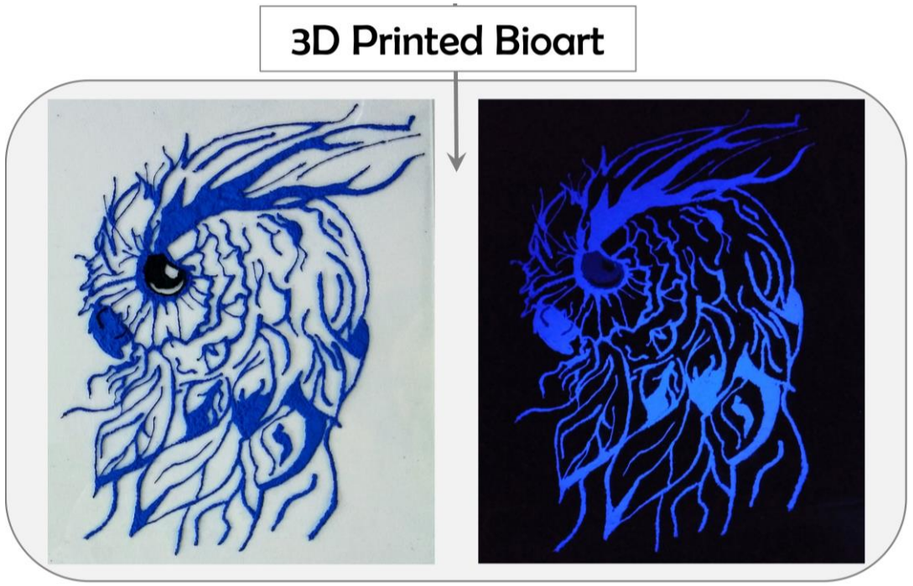

Table 1. Criteria Considered when Selecting Alginate as the Binding Medium for Bioink Composite	
Similar physicochemical properties compared to commercial binding medium	Xanthan gum is used as a binding medium in commercial acrylic products, suggesting alginate, which has similar physicochemical properties, could also serve as a successful binding medium
Tunable Cross-linking	Alginate cross-linking can be achieved rapidly, at room temperature using calcium chloride in a tunable fashion for optimal workability
Minimal Color	Reduces color dampening of pigments
Moderate Opacity	Opacity of the binding medium promotes substrate coverage
Optimal Consistency, Workability, & Stiffness	8% (w/v) alginate solutions have optimal consistency to suspend pigments up to 8 days and stiff enough to retain a 3D form, but are not too thick to hinder workability
Low-Cost	≤ $0.10 USD / g (as of February 2021)
Widely Available	Available for purchase from industrial and retail suppliers
Water Dispersible at Neutral pH	At neutral pH values, water is a biologically and environmentally friendly solvent, eliminating hazards associated with other solvent systems
Non-toxic & Biocompatible	Alginate serves as an essential food additive and is used in pharmaceutical and biomedical products

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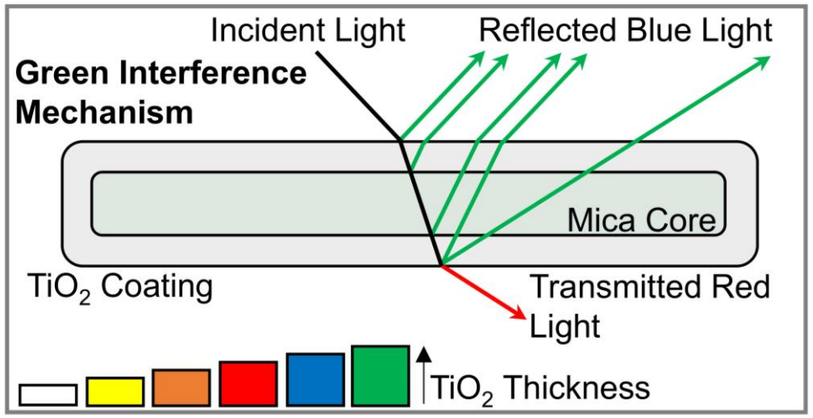
Mica pigment powders as an additive to sodium alginate bioinks

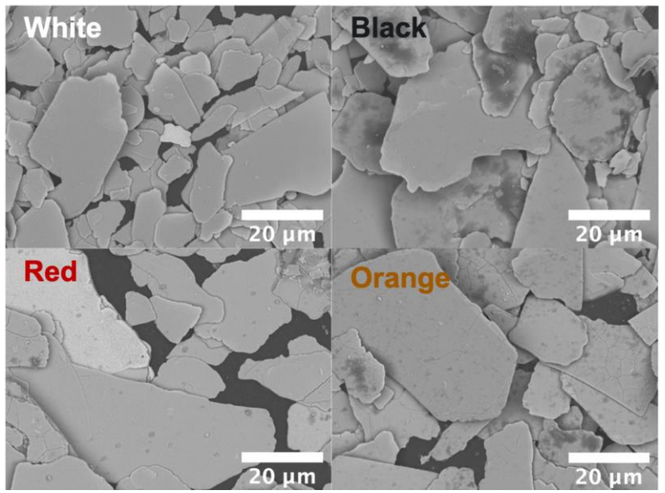
- Mica powders are vibrant, pearlescent pigments
- Mica flakes are coated in a thin metal oxide layer, which dictates the color via an interference mechanism
- Flake size and shape imparts pearlescence effect

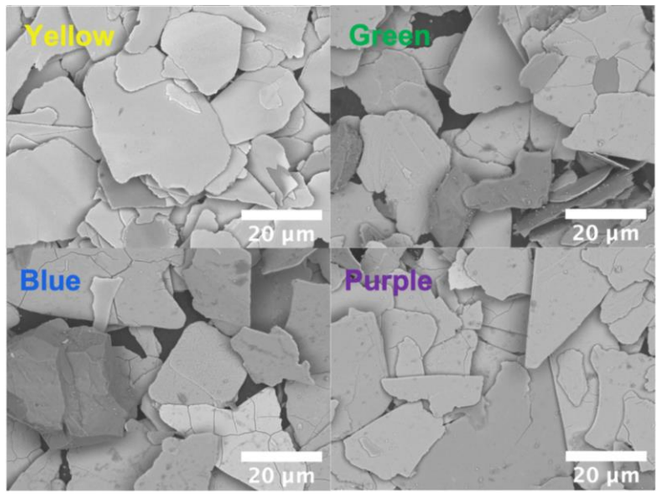
Mica Pigment Powders

Mica Color Produced by an Interference Mechanism



Scanning Electron Microscopy Images of Mica Flakes (~20 µm)





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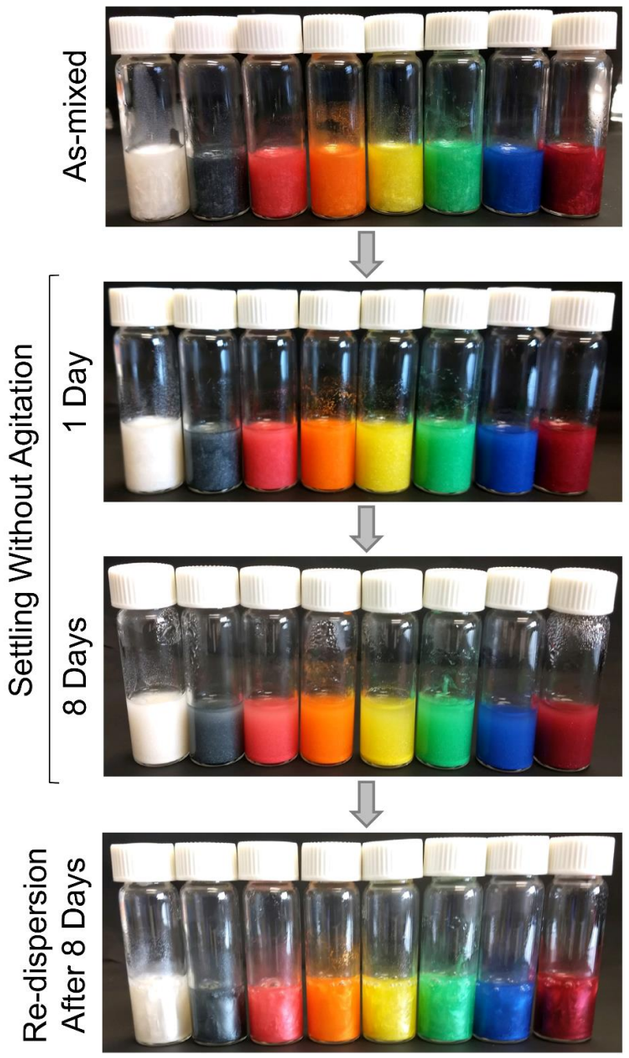
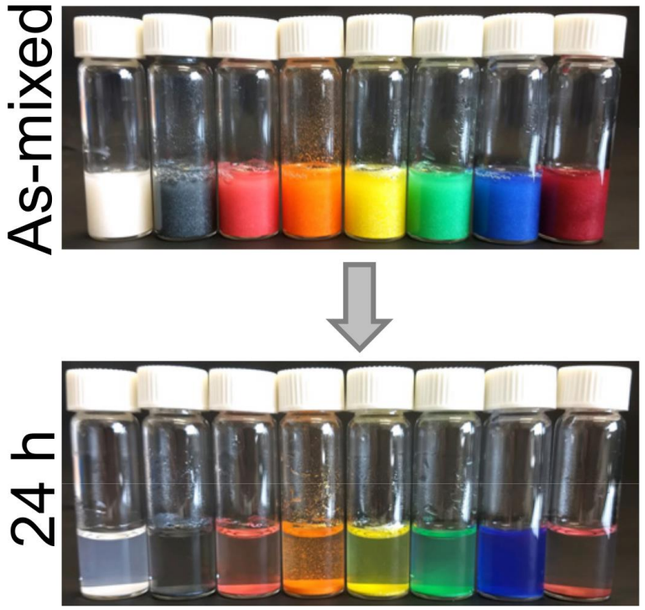
Sodium alginate bioinks loaded with mica pigments are shelf-stable

- Mica pigments remain dispersed in sodium alginate up to 8 days
- Mica pigments are easily re-dispersed in sodium alginate
- Sodium alginate-mica bioinks are shelf-stable on the order of months
- Mica pigments serve as a surrogate for nanoplatelets

Mica Pigments Dispersed in Sodium Alginate



Mica Pigments Dispersed in Water



Poor Dispersion

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Sodium alginate-mica bioinks can be prepared in any color

Images courtesy of Andrea Starr

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Sodium alginate-mica bioinks can be 3D printed by hand to create unique 2D or 3D compositions

Images courtesy of Andrea Starr

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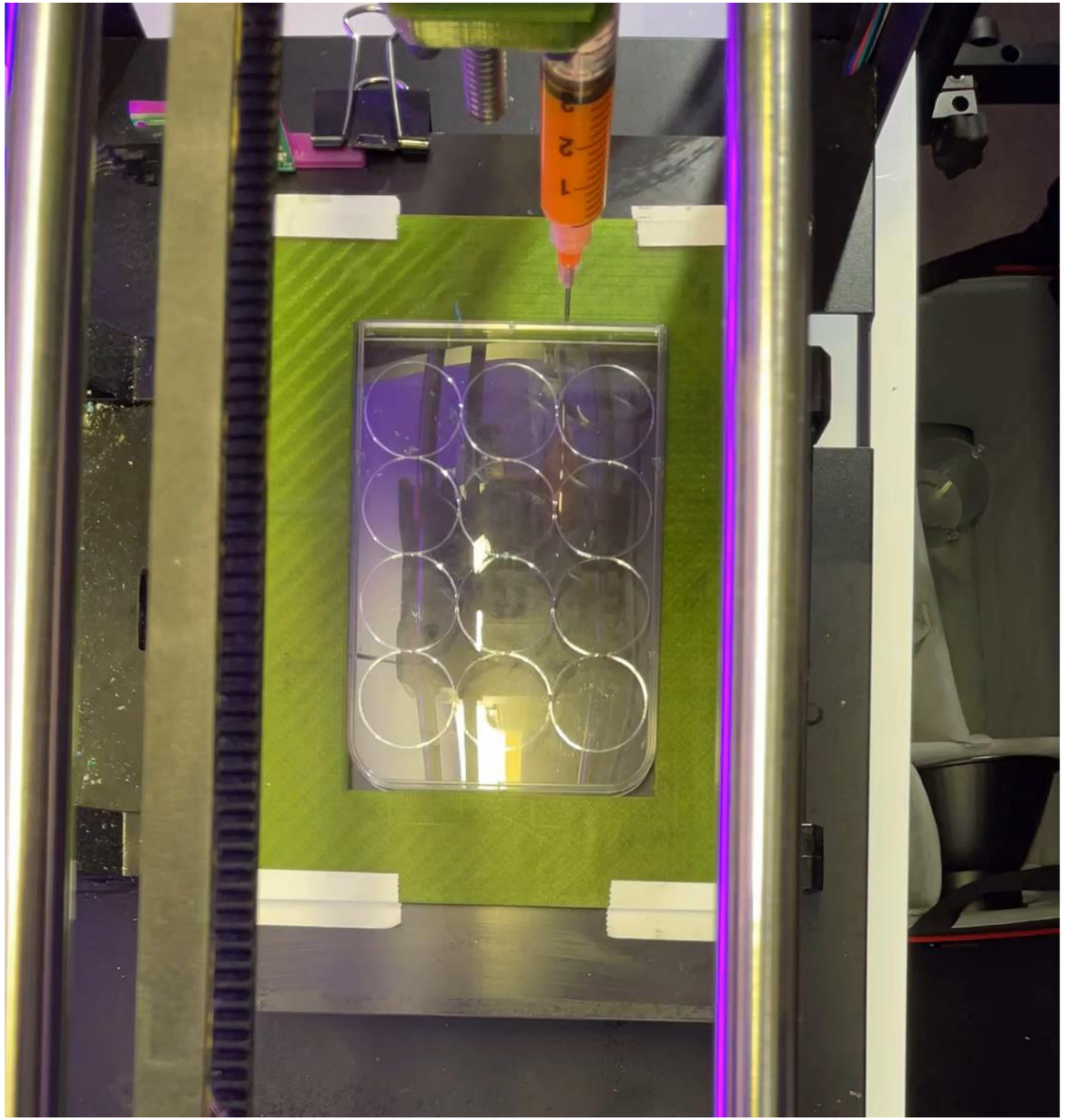
Sodium alginate-mica bioinks can be 3D printed using dedicated hardware

- After printing, constructs can be crosslinked further with calcium chloride to provide more structure
- Prints can be preserved in a solution of 200 mM calcium chloride
- Prints are biodegradable and biocompatible for future mammalian cell printing



Video courtesy of Graham Bourque

Conclusions

- Addition of mica pigments to sodium alginate bioinks creates vibrant, pearlescent inks, and serve as a surrogate for nanoplatelets
- We have also explored additional additives (e.g., paint, glow in the dark, etc.) with success
- Our sodium alginate formulation can be 3D printed at room temperature with biocompatible properties
- Sodium alginate-mica bioinks can be 3D printed by hand or with dedicated printing hardware
- Biocomposites will advance tissue engineering

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Thank you