Funding Opportunities at NSF

Steven R. Schmid, Program Director,
Manufacturing Machines and Equipment
NSF Directorate for Engineering (ENG)

Emerging Frontiers and Multidisciplinary Activities (EFMA)
Sohi Rastegar

Office of the Assistant Director
Dawn Tilberry, Assistant Director
TBD, Deputy Assistant Director (Acting)

Senior Advisor for Science and Engineering
Mihail Roco

Chemical, Bioengineering, Environmental, and Transport Systems (CBET)
S. Perretti

Civil, Mechanical, and Manufacturing Innovation (CMMI)
Deborah Goodings

Electrical, Communications, and Cyber Systems (ECCS)
Fil Bartoli

Engineering Education and Centers (EEC)
Mario Rotea

Industrial Innovation and Partnerships (IIP)
Gracie Narcho (Acting)
NSF ENG Strategy

- Attract, stimulate, catalyze and challenge research communities to think big, enable transformational advances, and expand national innovation capacity

- Portfolio balance between fundamental, applied and translational as well as small, medium and large projects

- New approaches to address engineering education challenges

- Collaborate and partner within and outside NSF to maximize opportunity for the engineering research and education community to address major national priorities
Funding Mechanisms

- Core/Unsolicited
  - Individual/small collaborative teams
- Solicitations
  - Early Career – CAREER
  - Instrumentation – MRI
  - Centers – ERC, STC
  - Small Business Innovation - SBIR, STTR
- International Collaborations
- Workshops/Conferences
CMMI Areas of Interest

Advanced Manufacturing
- transformative advances in manufacturing and materials processing, with emphases on efficiency, economy, sustainability and scalability

Mechanics and Engineering Materials
- understanding the properties and use of materials in engineered and natural systems

Resilient and Sustainable Infrastructures
- innovation to advance resilience and sustainability of civil infrastructure and distributed infrastructure networks

Operations, Design and Dynamic Systems
- decision-making aspects of engineering, including design, control, optimization and systems science

TWO submission windows: September 1-15, February 1-15 (** Jan 1-13, 2017 **)
Engineering Education and Centers

Centers and Networks

Engineering Research Centers (ERC)
Keith Roper, Lead
Deborah Jackson
Carmiña Londoño

Nanoscale Science & Engineering Centers (NSEC)
Keith Roper

Network for Computational Nanotechnology (NCN)
Keith Roper

Division Director (Acting)
Mario Rotea
Deputy Division Director
Don Millard

Engineering Education Research

Research in the Formation of Engineers (RFE)
Elliot Douglas

Research Initiation in Engineering Formation (RIEF)

Engineering Workforce Development

Research Experiences for Undergraduates (REU)
Mary Poats

Research Experiences for Teachers (RET)
Mary Poats

Broadening Participation in Engineering
James Moore

Nanotechnology Undergraduate Education (NUE) in Engineering and Computer Science
Mary Poats
Frederick Kronz
Yvette Weatherton
Engineering Centers and Networks

- Large-scale research investments in ENG
- Supports collaboration with industry and other stakeholders to promote innovative research and education

**Engineering Research Centers (ERC)**
- Three generations (50 centers total) since 1985
- New Nano-Systems ERCs (NERCs) in FY12

**Nanoscale Science and Engineering Centers (NSEC)**
- 19 NSECs since 2001
- 3 graduated NSECs from FY01 class

**Network for Computational Nanotechnology**
- Cyber-resource for nanotechnology theory, modeling and simulation
- nanoHUB.org gateway for nanotechnology research and education
- > 180k users globally
Industrial Innovation and Partnerships Division (IIP)

- fostering partnerships to advance technological innovation
- small business research proposals aimed at pursuing opportunities to commercialize products and services
- Solicitations only
Considerations for NSF Proposals 2018

• NSF’s enabling legislation requires a focus on fundamental science.
• All proposals (except EAGER) go through an NSF review system
  • No COIs allowed
  • Portfolio Balance
• Big Ideas program to be expanded, encouraged
• Most programs will see a budget reduction.
The research objective of this proposal is to establish the relationship between the operating parameters of a manufacturing process that combines freeze casting and ultrasound directed self-assembly, and the mechanical properties of the resulting porous engineered materials fabricated using this technique.

[1] Adapted from Wegst UGK, Schecter M, Donius AE, Hunger PM. "Biomaterials by freeze casting." Philosophical Transactions of the Royal Society A (2010);368:2099-2121.
Manufacturing of Engineered Materials with User-Specified Microstructures using Freeze Casting and Ultrasound Directed Self-Assembly
Steven E. Naleway and Bart Raeymaekers, University of Utah

**Experimental setup**
- PZT/mold
- Function generator and amplifier
- Freeze caster

**Initial results**
- Microstructure images with scale bars.

**Outreach**
- Images of outreach activities.
## Project Collaborative Research: Improved Freeform Measurement through Fiber-based Metrology

<table>
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<th>Project</th>
<th>Collaborative Research: Improved Freeform Measurement through Fiber-based Metrology</th>
<th>Fund</th>
<th>National Science Foundation</th>
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<td>Period</td>
<td>04/15/2017 ~ 03/31/2020</td>
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### Target

- **T1.** Quantify cosine error in freeform surface measurement
- **T2.** Create and characterize a cosine error-free OMM tool
- **T3.** Create automated measurement tool path planning method

### Application

Measuring instruments

### Group

C. Lee (Tennessee Tech)  
J. Tarbutton / T. Schmitz (UNCC)

### Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>Literature Survey</th>
<th>Kick-off Meeting</th>
<th>Research T1</th>
<th>Research T2 &amp; T3</th>
<th>OMM tool Characterization</th>
<th>OMM Integration</th>
<th>Machining +OMM Error budget</th>
<th>Final Review</th>
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### Task

1. **Quantify cosine error in freeform surface measurement**
   - 1) Identify measurement error sources of existing measuring tools for freeform optical surfaces
   - 2) Quantify error budget of conventional OMM methods (touch probe method, multi-probe method)
   - 3) Assess maximal allowable limit in OMM for freeform optical surface measurement

2. **Create and characterize a cosine error-free OMM tool**
   - 1) Develop algorithm to separate surface characteristics: primary form, roughness, and waviness
   - 2) Create test workbench: fiber-based OMM (autofocusing, Fizeau interferometry).
   - 3) Characterize the performance boundary of fiber-based OMM tools.
   - 4) Characterize error budget of OMM tools for freeform optical surface measurement.

3. **Create automated measurement tool path planning method**
   - 1) Investigate the interchangeable NC algorithm for OMM and machining and comparison between two NC codes.
   - 2) Characterize critical OMM NC limits (max measuring feedrate, NC interpolation error, noise due to surface quality…)
   - 3) Verify that the proposed OMM system can produce NC codes for error compensation machining.

### Remarks

OMM (On-Machine Measurement); NC (Numerical Control)
Experiment Setup

Schematic of fiber-coupled system.  

Schematic of freeform surface OMM.

Expected Outcomes

1. Freeform surface metrology tool.
2. NC algorithm architecture interchangeable for both machining and measurement.
3. Benefit to society through higher-profit and better-quality U.S. manufacturing.
4. Education program to foster promising talent in cutting-edge precision metrology.
Ultrasound Based In-line Assessment of Porosity for Laser-Sintered Parts

- Goals:
  - Develop scattering theory to accurately quantify porosity from backscattered ultrasound signals
  - Develop a laser-based ultrasound system for a new method of porosity assessment based on the scattering theory

Test System for In-Line Monitoring

- Build Chamber w/ Build Platform Controlled by Stepper Motor
- Powder Dispenser Chamber w/ Dispenser Plateform Controlled by Stepper Motor
- Optical Module w/Fiber Optic Coupling to Lasers
- 3-Axis Stepper Motor with Gantry to Control Position of Lasers
- Stepper Motor w/ Blade Attachment to Lay Powder Layer

Image of Pores from X-Ray CT

Flat Bottom Hole in AM Part Experiment

FEM Model

5 MHz
FUNCTIONALLY GRADED ADHESIVE JOINTS WITH IMPROVED STRENGTH & STABILITY

Scott Stapleton
Mechanical Engineering
UMass Lowell

Daniel Schmidt
Plastics Engineering
UMass Lowell
Title: Functionally Graded Adhesive Joints with Improved Strength and Stability
PIs: Scott Stapleton, Daniel Schmidt
Institution: University of Massachusetts Lowell
Funding: $318,491 (2 students, 3 years)
Time: April 2017-April 2020
Program: Manufacturing, Machines, and Equipment (MME)
Motivation

- Adhesive joints suffer from stress concentrations
  - Grading adhesive properties spreads stress
    - Increases strength of joints (up to 60% shown)
- Graded adhesives still not used in practice
  - Unstable/irreproducible property gradients
  - Difficult/costly manufacturing processes
- **Manufacturing**
  - Dual-cure epoxy adhesives
    - Initial (conventional) cure sets joint geometry
    - Subsequent (radiation) cure sets final properties as a function of dose
- **Computational Modeling**
  - Parametric study
  - Virtual Experiments
    - Optimize gradation design
- **Proof-of-concept**
  - Test ungraded vs. graded adhesive joints

**Solution**

- High-energy radiation ($\gamma$, e$^-$)
- Thermoplastic radiation shielding
- Conventionally cured adhesive
- Functionally graded adhesive
- Radiation curing
The Developing Landscape for Biomanufacturing

NSF Opportunities
What is Bioprinting?

- Bioprinting is the controlled deposition of any living or non-living biological (DNA, protein, bacteria, mammalian cells, viruses) material into a computer-aided design or pattern.

- Pattern resolution (spot size) can vary from a continuous sheet (macroscale, e.g. skin) to tens of microns (microscale, e.g. microcapillaries & vessels).

- Deposition speeds can exceed 1000 droplets per second (high throughput).

- Deposition volumes range from $10^{-3}$ mL to $10^{-10}$ mL per printed droplet.

- 2D (single layer) and 3D (multi-layer) applications.
Federal Investment Highway for Regenerative Medicine

Source: R. Hunziker, NIH
Potential for Far-Reaching Impact

Healthcare
- Transplants and regenerative medicine applications (pancreatitis, type I diabetes, parathyroid transplant, hepatic tissue transplantation, renal transplants, lung transplants, heart transplants, skin)
- Infectious disease modeling *in vitro*

Pharmaceutical
- Drug testing/screening (toxicity, efficacy)
- Biomarker discovery (diagnostics, vaccine and therapeutics)
- Oncology (tumor models, efficacy, biomarker testing/screening)
- Replace and/or supplement (pre-screen) animal models

Medical Devices
- Hybrid devices (living/non-living)
- Prosthetics/implants

Defense and Homeland Security
- Chem/Bio assessment in vitro tissue models (human clinical trials impossible)
- Agnostic chemical threat sensors (based on 3D bioprinted cellular systems)
- Skin replacement; bio-artificial limbs
Biomanufacturing Landscape – Overview

Bioprinting of Tissue
- Example: Bioprinting of organs
- TRL 1-4

Advanced Tissue Biofabrication
- Example: Soft tissue for reconstruction
- TRL 3-6

NIIMBL – Biomedicine, protein/gene therapies
- Example: >100 Phase II trials ongoing
- TRL 5-9

Energy Intensification - Pharma
- Drive down energy needs
- Convert to continuous processing
- TRL 5-9

Materials, Protein Therapies and Vaccines
- Scaffolds, resorbable materials, biological countermeasures, implants, devices, etc
- TRL 7-9; Basic research in many areas
Bioprinting of Tissue

**Biolomedical research needs:**
- “Inks” for providing structure
- Strategies for vascularization, etc.
- In situ cell deposition
- Cell Manufacture (CBET)

**Manufacturing research needs:**
- Move from proof of concept (out of laboratory)
- Advanced bioprocess models and controls for larger-scale bioreactors
- Biological metrology
- Virtual validation
Advanced Tissue Biofabrication Institute awarded end of 2016 to Deca (Dean Kamen); Government funds = $80 million, 1:1 match required

Biology research needs:
- Instrumentation
- Improved bioreactors

Manufacturing research needs:
- Development of regulatory pathways
- Improved and standardized raw materials
- Quality control and assurance

Note: Schmid representing NSF on proposal evaluation team, assisted by Lucas from CBET
Cell/Gene Therapies, BioMedicines - NIIMBL

- NIST funds = $70 million; $120 million cash match.

- Biology research needs:
  - Varied, but in general requires de-risking of laboratory scale research
  - Mass production of cells

- Manufacturing research needs:
  - Scale up and out
  - Regulatory hurdles lowered
  - Real time release/testing
BioPharma Manufacturing

- Pharmaceutical manufacturing is well understood; drugs and countermeasures remain a research concern
- DOE Institute on Energy Intensification announced; BioPharma explicitly mentioned as a target industry. ($70 million, 1:1 match, large consortium, etc.)
- Transform to continuous processing, driving down costs and risk
• Supported by assorted NSF, NIH, DOD programs; significant industry investment.

• Biology research needs:
  • Varies by application. Can include antibiotic materials, treatments for illness, resorbable materials

• Engineering research needs:
  • Varies by application. Scaling of efforts (up and out), greener and less energy-intensive production, quality control and metrology, reduced cost.
Landscape Assessment

- Biomanufacturing represents a major multidisciplinary research thrust with great potential.

- DOD established ATB Institute at end of 2016 ($200 million total). DOE to include BioPharma in Energy Intensification Institute ($150 million). NIST investment in NIIMBL ($300 million).

- Catapult: £70M; Australia CRC: $79M; Japan: CiRA: ¥20B.

- Bioprinting of tissues remains open and complimentary to other (NNMI) efforts. This is the unfunded basic research area of biomanufacturing.

- Realtime bioprocess analytics, control, biometrology, quality and yield remain needs.

- Requires blending of biomedical and manufacturing engineering.
Biomanufacturing Landscape – Overview

Bioprinting of Tissue
- Example: Bioprinting of organs
- TRL 1-4

Regenerative Medicine
- Example: Soft tissue for reconstruction
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BioPharma
- Drive down energy needs
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- TRL 7-9; Basic research in many areas
Not Just a Dream
Project Examples
Rapid, Robust Casting of Patterned Vascular Networks for Engineered Tissues

Open, interconnected carbohydrate-glass lattice is printed as the sacrificial element and encapsulated along with hepatocytes. Flowing cell media dissolves lattice (without damage to nearby cells) yielding a monolithic tissue construct with a continuous vascular architecture.

Interstitial stem cells surround open channels lined with endothelial cells. Scale bar = 2 mm.

Neovascularization via endothelial cell sprouting (arrowheads) from patterned channels.

Hepatocytes in agarose gels without (slab) or with (channel) vascularization. Metabolic state shown by urea (a) and albumin (b) secretion.

Chen and Bhatia
doi: 10.1038/NMAT3357
Endoscopic AM for *in situ* fabrication of tissue scaffolds

D. Hoelzle, Ohio State University

Robotic Architecture

Applications
Endoscopic AM research plan

D. Hoelzle, Ohio State University

Summary of aims of CAREER proposal project:
- Definition of the material delivery and positioning dynamics in endoscopic AM
- Study of two different actuation schemes
- Manufacturing test on an Endoscopic AM prototype

NSF CAREER CMMI-1552358 awarded on 1/19/2016
Additive Biomanufacturing Engineered Cell Microenvironments (NSF Award # #1554150; PI: Robert Chang, Stevens Institute of Technology)

Melt electrospin writing (MEW) process model design

Deep learning for 3D cell substrate design reliability

Cell shape metrology on MEW 3D microprinted fiber substrates as in vitro stem cell-based brain model

Melt electrospin writing process optimization

Non-dimensionalized “Printability Number” formulated:

\[
N_{PR} = \frac{1}{3} \frac{\gamma^{1/2} \varepsilon^{1/2}}{g^{1/2} \lambda \rho T_c d} \frac{Q \eta_o(T_{ref})}{T_m} \left[ \frac{1}{R_{ig}} \left( \frac{1}{T_m} - \frac{1}{T_{ref}} \right) \right]^{V_p} \]
Smart polymers from plant oil. (A) The U shape recovers its original shape in 40s. (B) The “GWU” recovered with different speeds. (C) The sample fixed in stages recovered one shape at 14 °C and another at 0 °C.

4D Bioprinting of Smart Tissue Constructs

Prof. Lijie Grace Zhang, The George Washington University

The printed constructs are able to change and mutate over time.

Final structure is controlled by pre-design

4D printing smart plant oil based tissue scaffold process and evaluation
**NSF MME Award # 1563160: Novel Biodegradable Materials for Additive Manufacturing of Complex Scaffolds for Algal Bioremediation Systems**

- **Overarching goal:**
  - Establish a scientific understanding of combined effects of scaffold composition, and texture on algal growth and scaffold biodegradation in water remediation reactors.

- **Methods:**
  - Investigate structure-processing-property relationships in extruded polylactic acid/cellulose nanocrystal (PLA/CNC) composite filaments and printed scaffolds
  - Expose scaffolds with different CNC chemistries and dispersion states to filamentous algal colonization in laminar flow conditions
  - Conduct multiple repeated harvests of algae from each surface to measure biomass production rate and scaffold degradation rate

- **Preliminary Data:**
  - Algal growth occurs on all tiles
  - CNC surface chemistry and dispersion method affect growth rates

- **Future Work:**
  - Investigate CNC concentration effects
  - Investigate more complex scaffold designs
  - Assess suitability of scaffolds for large scale algal farms for bioremediation
Questions?