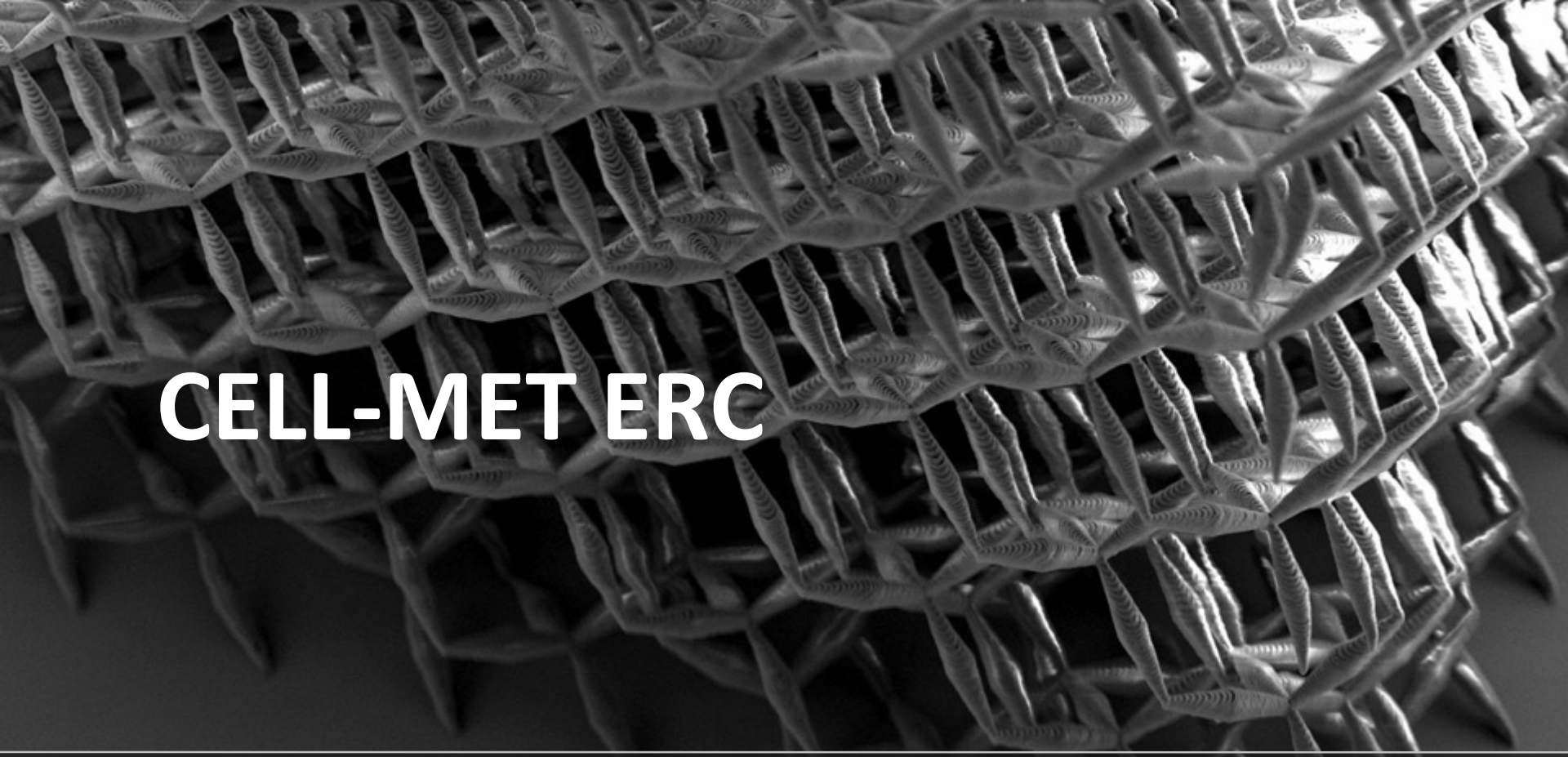

CELL-MET ERC

David J. Bishop

Director, CELL-MET ERC
Head, BU Division of Materials Science and Engineering
Professor of Electrical and Computer Engineering
Professor of Materials Science and Engineering
Professor Mechanical Engineering
Professor of Physics
Professor of Biomedical Engineering

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Heart Disease

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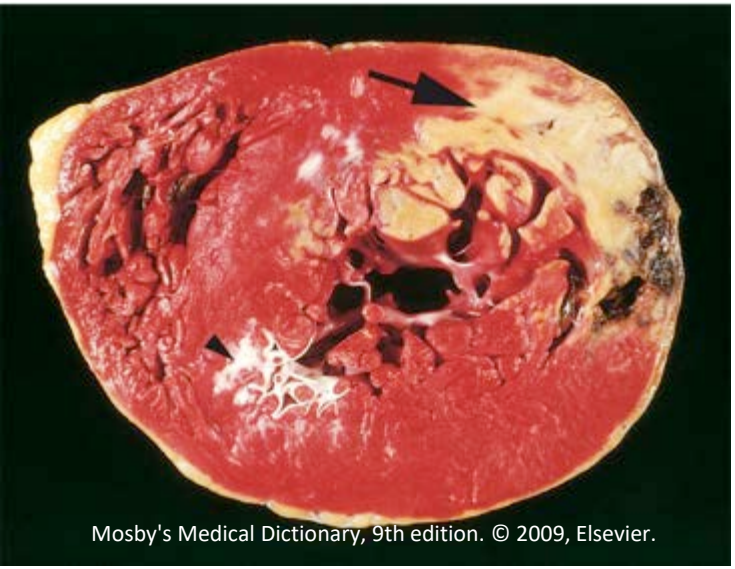
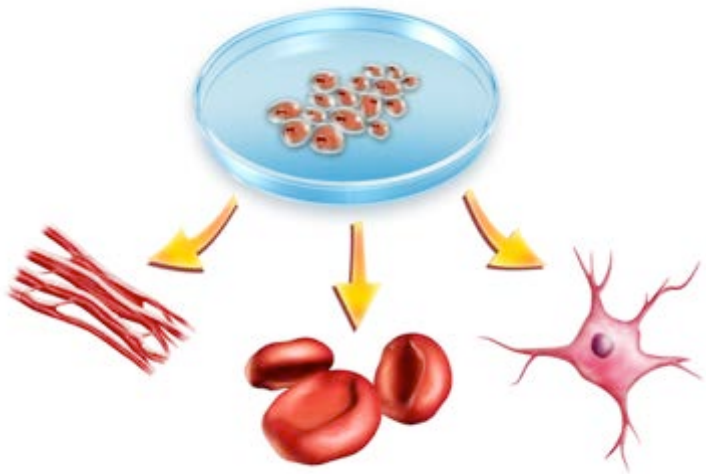
- Americans suffer **one million** heart attacks every year
- Heart disease is the leading cause of death in the US
- **2,000** people in the US die daily from heart disease, **~600k/year**
- **1 in 4** Americans will die from heart disease
- World-wide, **17 million** people per year die from heart disease

Heart Disease


Mosby's Medical Dictionary, 9th edition. © 2009, Elsevier.



http://www.lumacyte.com

- Until recently, tissue damage from a heart attack was considered irreversible.[1]
- Induced pluripotent stem cells (iPSC) can help repair or replace damaged tissue, differentiation and assembly are challenges.[2]
- Cardiac tissue engineering is limited by a lack of scalable, nano fabrication techniques.[3]
- Controlled nanoscale cell adhesion, appropriate microscale scaffold stiffness, adequate vascularization, and multiscale integration are needed to generate functional, engineered tissues.[4]

We aim to solve this engineering problem

[1] Jennings RB, *Circulation Research*, [113], 428-438, (2013)
[2] Laflamme MA, et al, *Nat Biotech*, [25], 1015-1024, (2007).
[3] Stevens KR, et al, *Tissue Eng Part A*, [15], 1211-1222, (2009).
[4] Eschenhagen T, et.al *American Journal of Physiology – Heart and Circulatory Physiology*, [303], H133-H143, (2012).

Our Thesis

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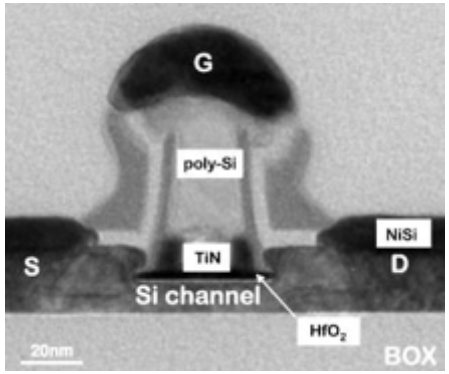
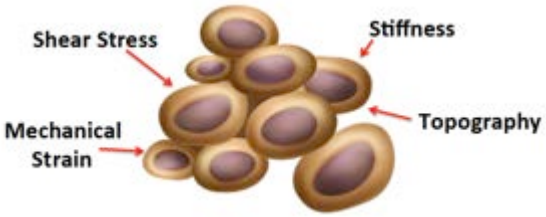
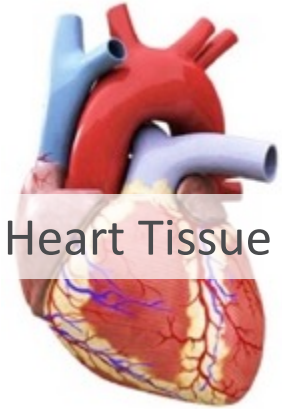
Scalable nanomanufacturing technologies can produce clinically important cardiac tissues





Cardiac Muscle Cells



Heart Tissue

From One to Many

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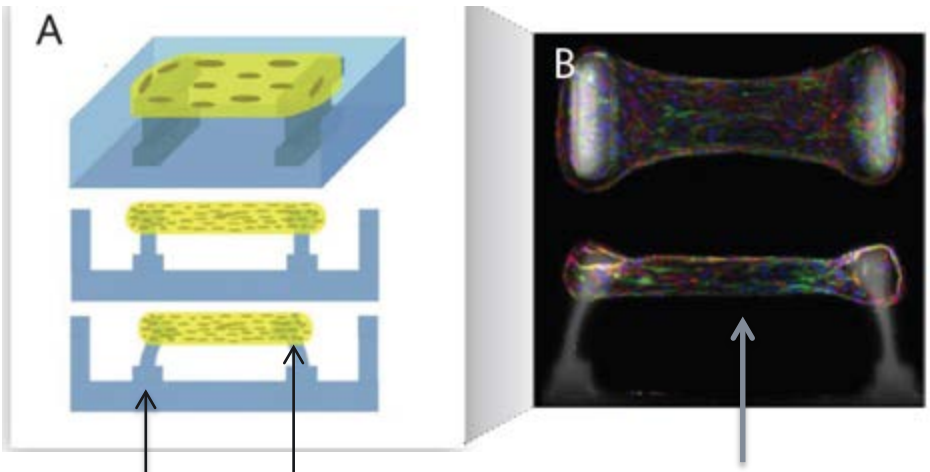
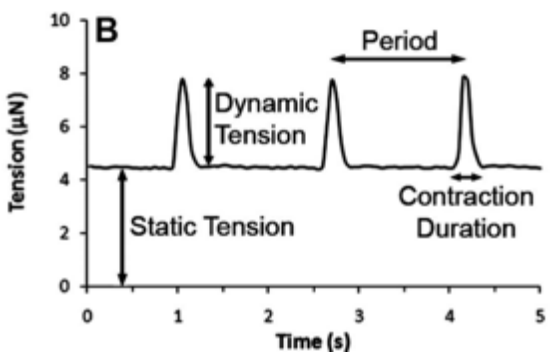
This is our "Transistor"



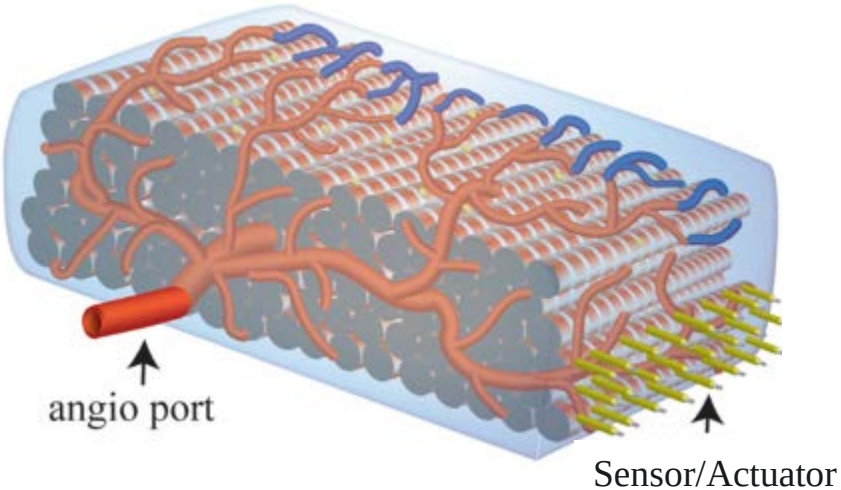
Flexible
Polymer Post

Focal Attachment Point
(Au-Thiol-Protein)

Beating Cardiomyocytes



This is our "Integrated Circuit"



- A cubic centimeter of cardiac tissue has **~billion cells**
- Silicon VLSI chips have **~billion transistors**

The Scientific Vision

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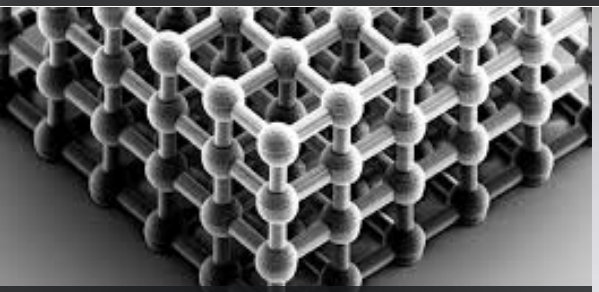
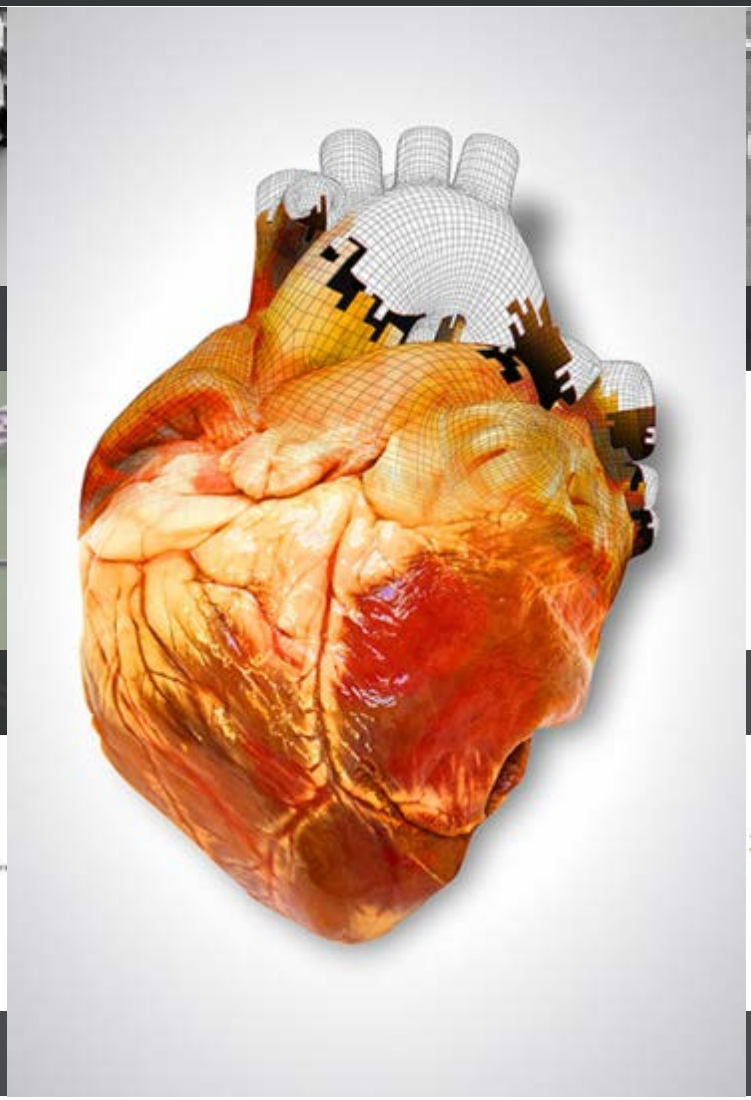
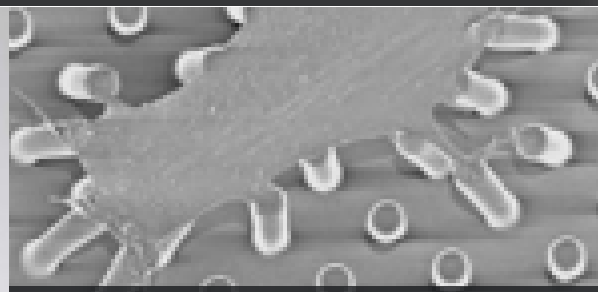
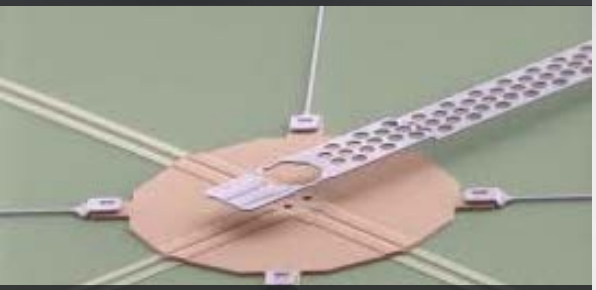


Nano-Mechanics

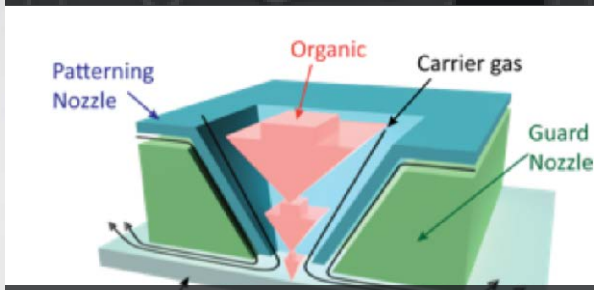




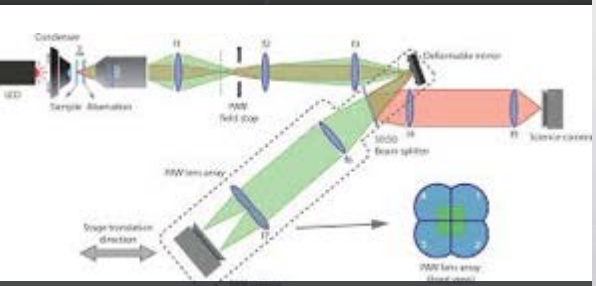
Cell Engineering



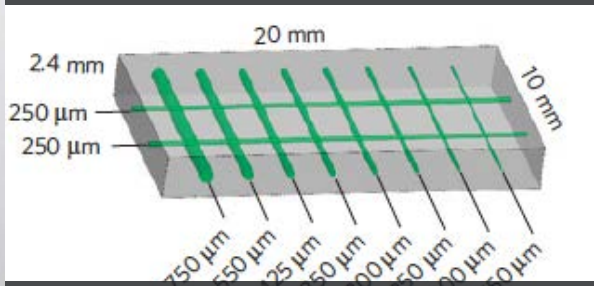
Atomic Calligraphy



Organic Vapor Jet Printing



Adaptive Optics



Lab on a Chip

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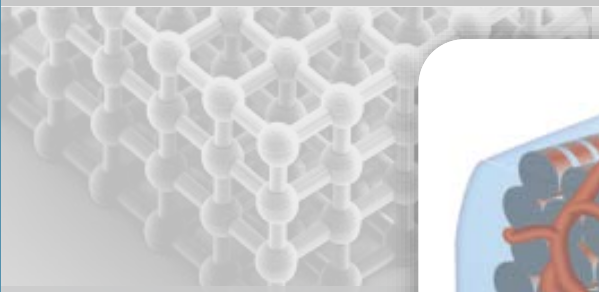
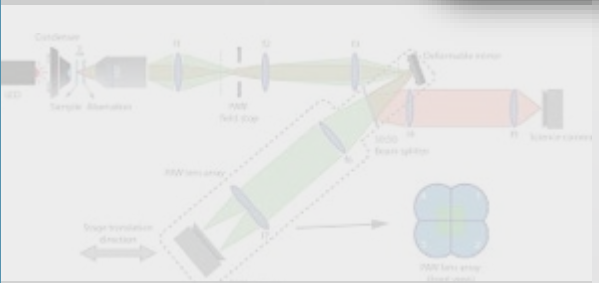
The Scientific Vision

CELL-MET

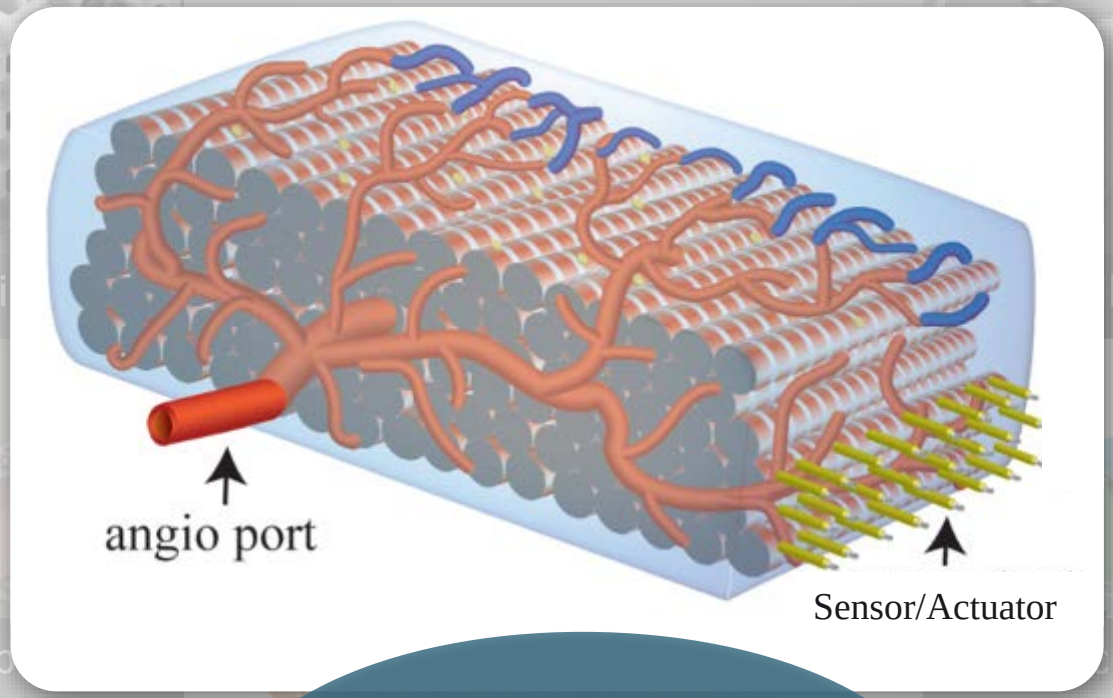


Nano-Mechani

Atomic Calligrap

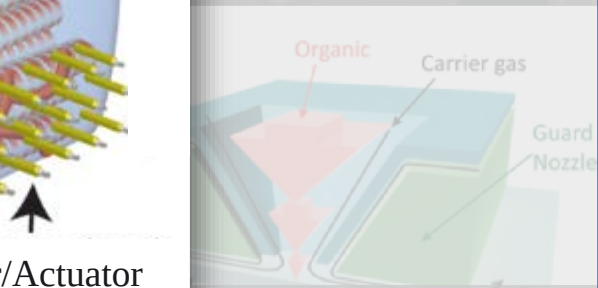


Adaptive Optics

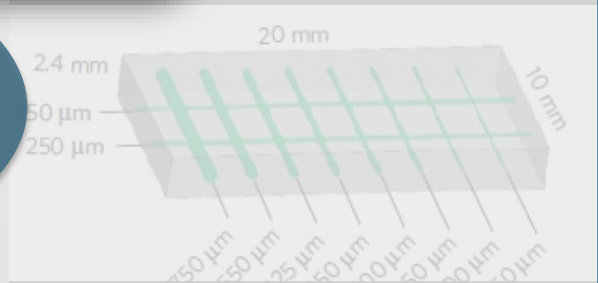


Centimeter scale, multi-functional cardiac tissues

Engineering



Vapor Jet Printing



Lab on a Chip

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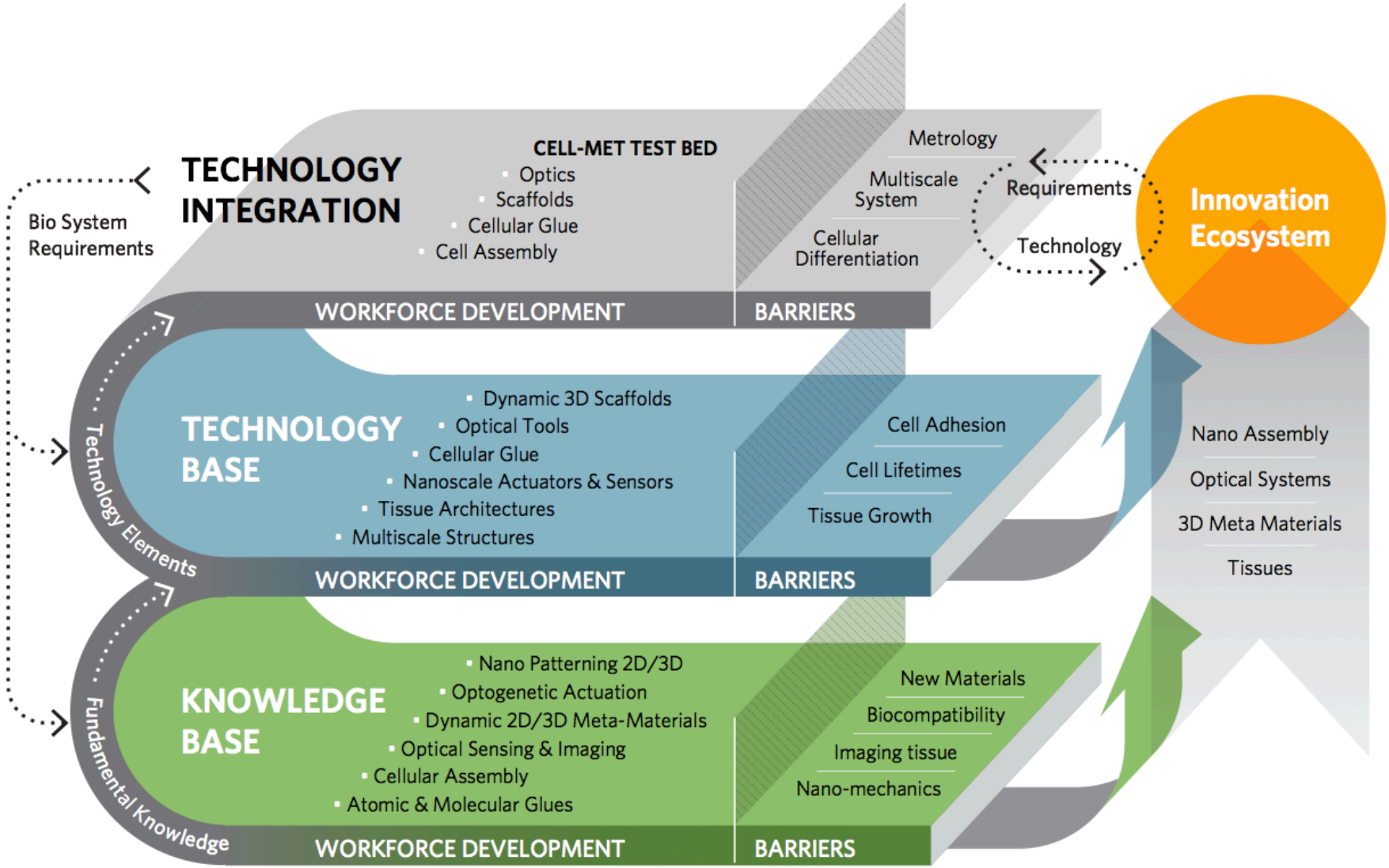
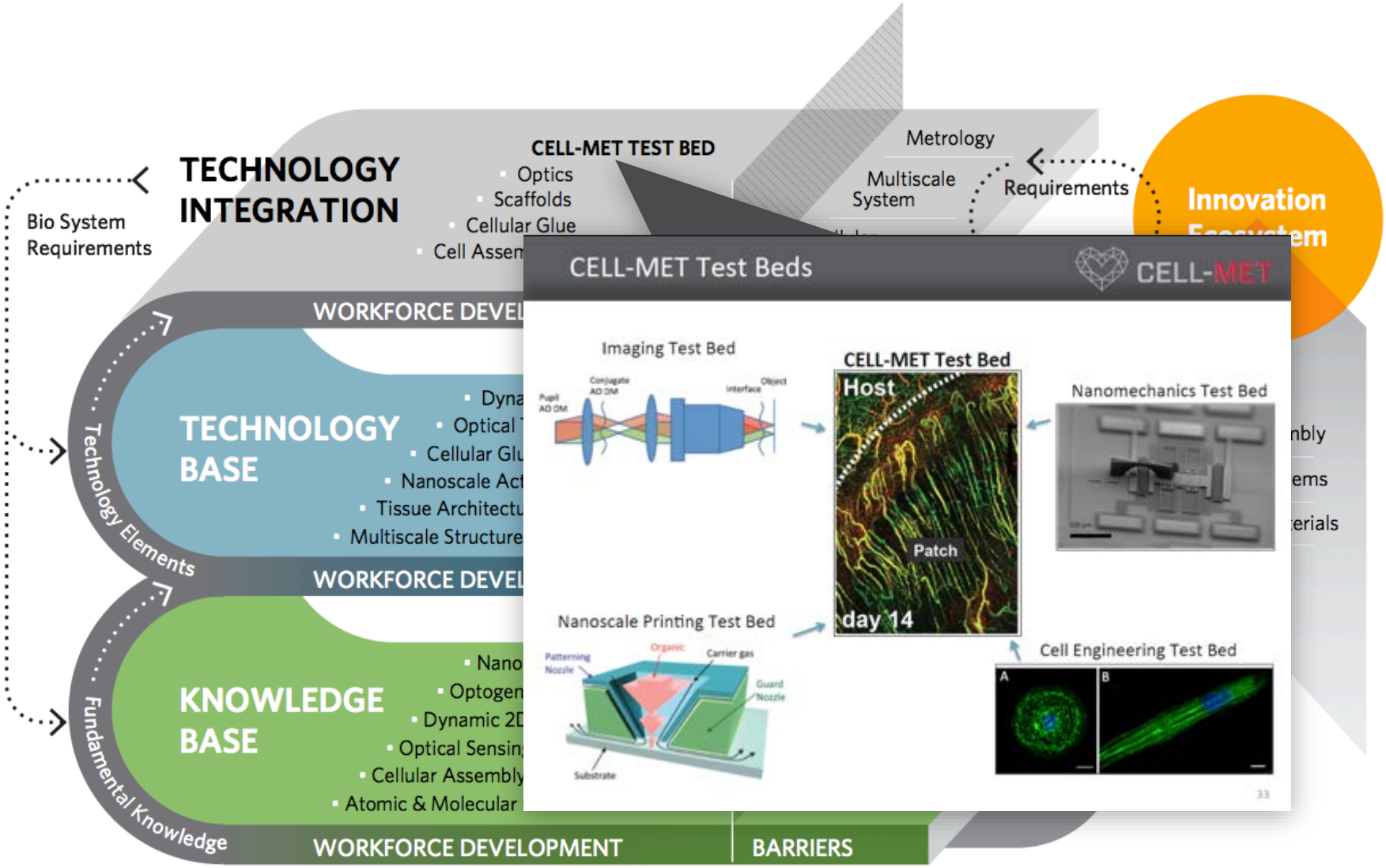
Three Plane Diagram



Three Plane Diagram



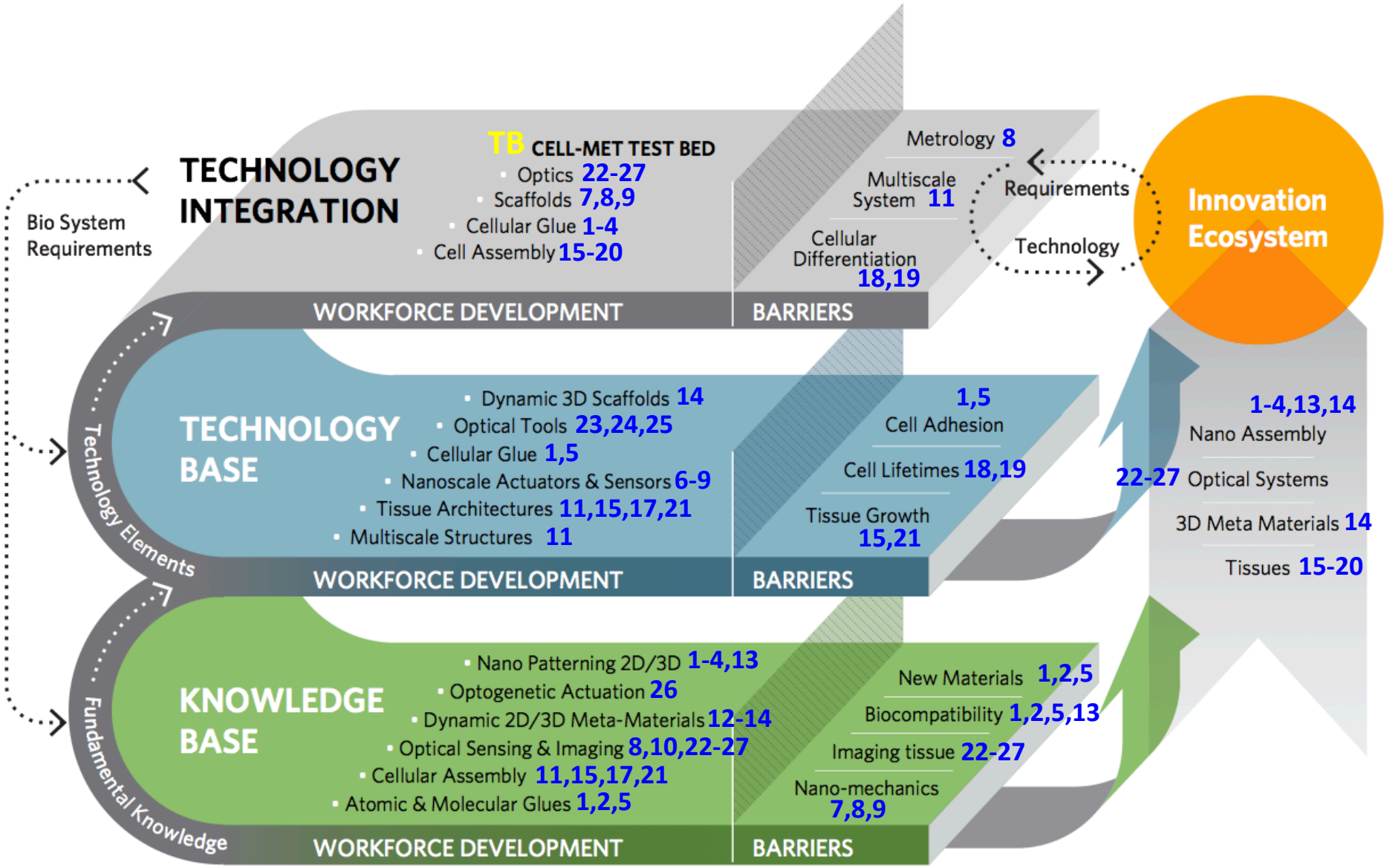
Year 1 Projects

CELL-MET

Project	Lead
001: TA1 - Micron scale adhesion point patterning	Shtein
002: TA1 - 3D patterning with biocompatible inhibitors	Lahann
003: TA1 - Scaling OVJP for 3D patterning	Forrest
004: TA1 - Metallic printing using atomic calligraphy	Bishop
005: TA1 - FIB deposition for embedded wiring	Bishop
006: TA2 - Water soluble resists	Grinstaff
007: TA2 – Mechanical characterization of scaffolds	Agarwal
008: TA2 – Biosensors test bed development	Li
009: TA2/TA3 – Magnetic actuator test bed development	Bishop
010: TA2 – Optical biosensors of cardiomyocyte metabolism	Li
011: TA2 – Vasculature monitoring	Ekinci
012: TA2/TA3 – Dynamic microfluidic-driven scaffolds	White
013: TA2 –Patterning metals on 3D scaffolds	Bishop
014: TA2 – Direct-write scaffolds for tissue growth	White
015: TA3 - Sarcomere force differences in cardiomyocytes	Chen
016: TA3/TA4 – Genetically encoded voltage sensors	Chen
017: TA3/TA2 - Effects of hemodynamics on remodeling	Chen
018: TA3 – Optimized media for cardiomyocyte maturation	Vunjak-Novakovic
019: TA3 – Maintenance of mature single-cell cardiomyocytes	Vunjak-Novakovic
020: TA3 - Adhesions in mutant cardiomyocytes	Seidman
021: TA3 / TA1 - Spatial control of sarcomere assembly	Chen
022: TA4 - Widefield voltage imaging of tissue	Bifano
023: TA4 - Adaptive scanning optical microscope	Bifano
024: TA4 – Reverberation multiphoton microscopy	Mertz
025: TA4 – Fast imaging with multi-z microscopy	Mertz
026: TA4/TA3 – Optogenetic control of cardiac tissue	Han
027: TA4 - Scanning ion conductance microscopy	He

Year 1 Projects

CELL-MET



A World-Class Scientific Team

CELL-MET

Kamil Ekinci
BU
5k Citations, h index 24
1 US Patent

Tom Bifano
BU
4k Citations, h index 34
6 US Patents

Chris Chen
BU/Wyss
29k Citations, h index 75
3 US Patents

Steve Forrest
Michigan
103k Citations, h index 144
302 US Patents

Max Shtein
Michigan
4k Citations, h index 26
22 US Patents

Chenzhong Li
FIU
5k Citations, h index 34
9 US Patents

Xue Han
BU
3k Citations, h index 24

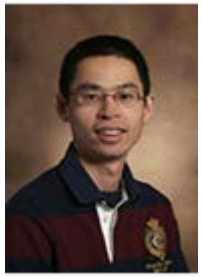
Joerg Lahann
Michigan
10k Citations, h index 50
14 US Patents

Jon Seidman
Harvard
41k Citations, h index 108
7 US Patents

Mark Grinstaff
BU
14k Citations, h index 64
24 US Patents

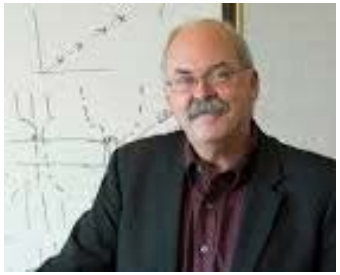
Christine Seidman
Harvard
30k Citations, h index 95
3 US Patents

Arvind Agarwal
FIU
5k Citations, h index 38
2 US Patents



Jin He
FIU
2k Citations, h index 20
2 US Patents

Gordana Vunjak-Novakovic
Columbia
31k Citations, h index 101
10 US Patents



Dave Bishop
BU
20k Citations, h index 80
47 US Patents

Daniel Lopez
Argonne
4k Citations, h index 31
27 US Patents

Alice White
BU
7k Citations, h index 38
5 US Patents

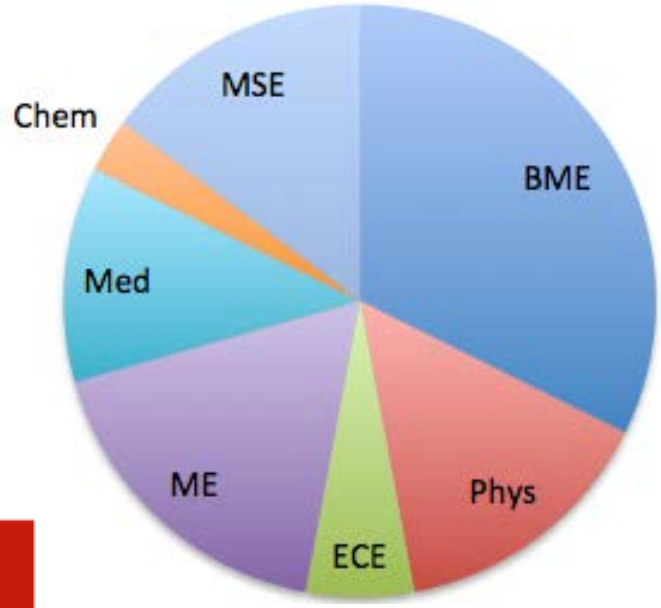
A World-Class Scientific Team

CELL-MET

Argonne NATIONAL LABORATORY

HARVARD UNIVERSITY

BU



CNEA
Comisión Nacional de Energía Atómica

M

FIU

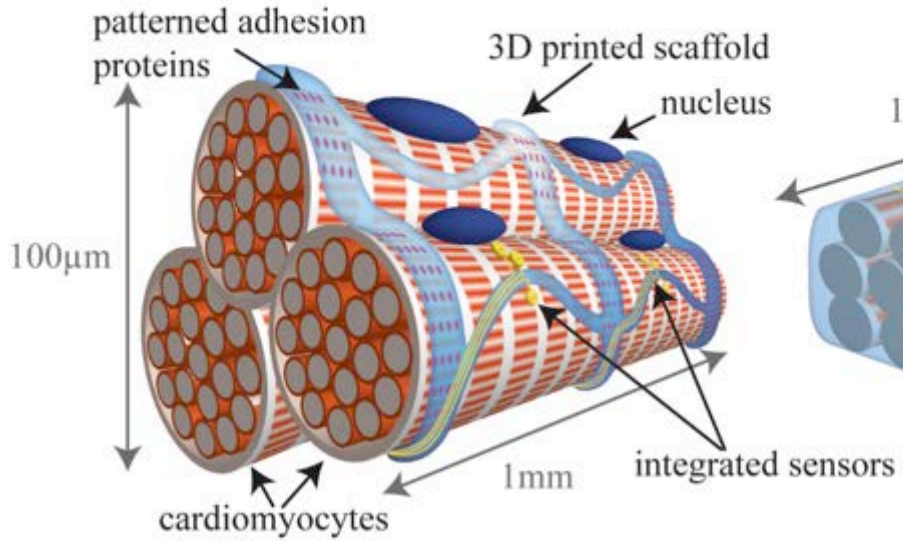
EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

COLUMBIA UNIVERSITY

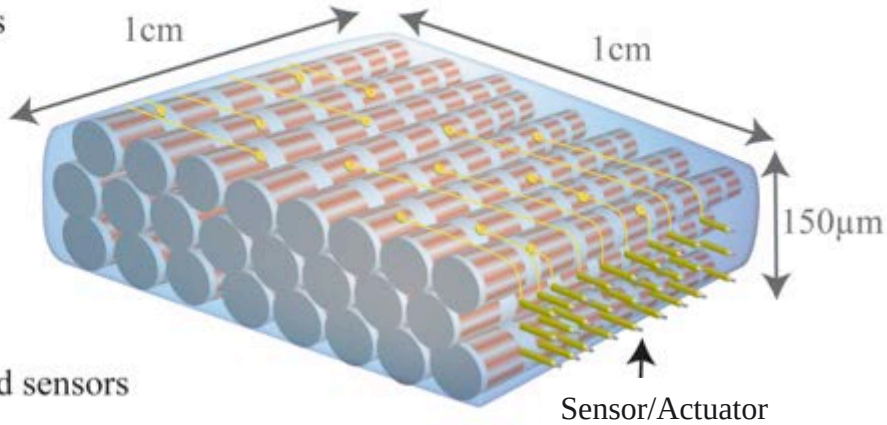
WYSS INSTITUTE

CELL-MET Deliverables

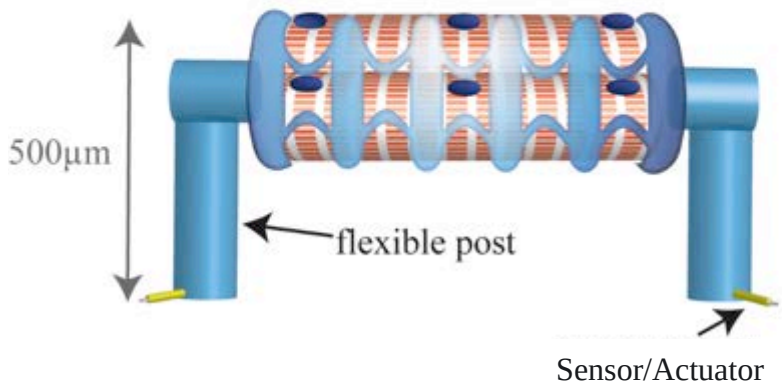
Cardiomyocytes



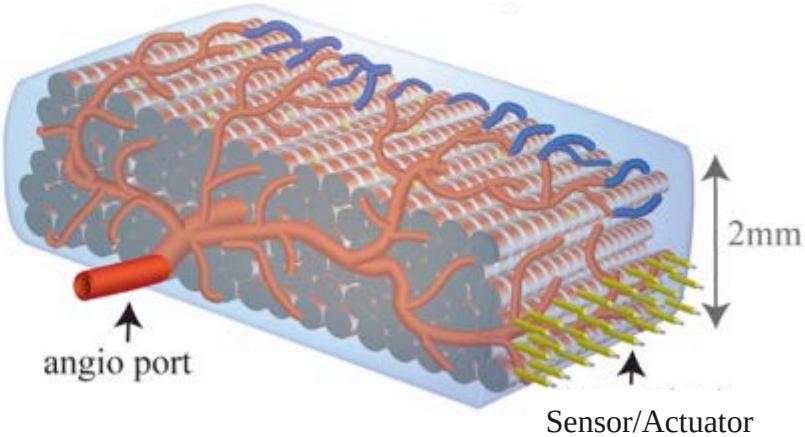
Instrumented Cardiac Sheet



Cardiac Microbundle



Vascularized Cardiac Patch



Our Ten Year Vision

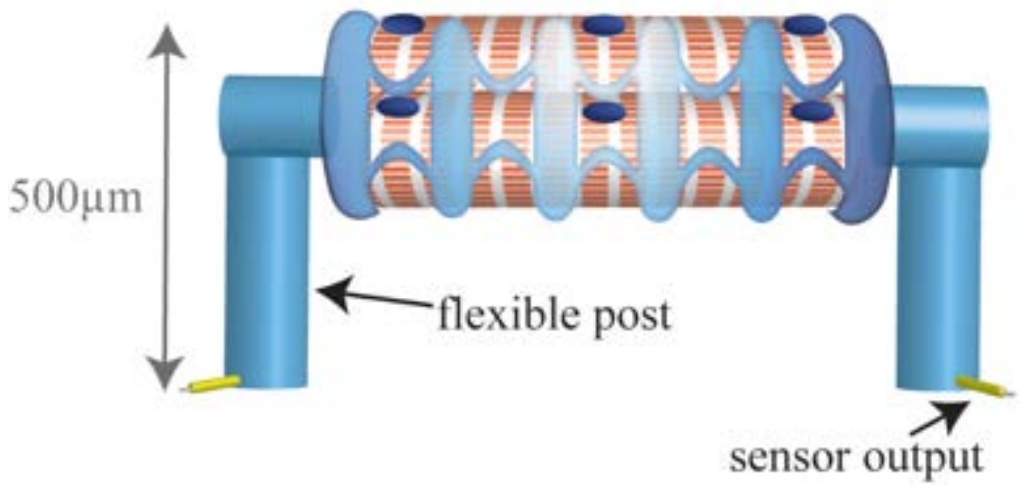
CELL-MET

	YEAR 1	2	3	4	5	6	7	8	9	10	10 +
Imaging	Microscope development		Imaging and optogenetically controlling cardiac tissues			Increase throughput and depth penetration of imaging/ optogenetic techniques and develop embedded optical sensor networks			Centimeter scale cardiac tissue with large vessel trees		Centimeter scale cardiac tissue with complex functionality including heart chambers, large vessel trees, cardiac valves and conduction system
Cell Eng.	2D cardiac bundles	3D cardiac tissue without vasculature "Patches"		3D cardiac tissues with vasculature		3D macro assembled vascularized cardiac tissues					
Scaffolds	2D scaffolds	3D scaffolds with embedded sensors and actuators				3D scaffolds with complex functionality such as vessel trees, valves and conduction system					
Nano Manuf.	2D printing	3D printing development				Direct printing of all structures needed for cardiac tissue with complex functionality					
Products	2D Cardiac Tissues on a Chip for Drug Development				Cardiac Tissues with implanted Sensors for Monitoring Cardiac Function				Muscle Tissues that can Assist Cardiac Function		Cardiac Tissues Beyond Muscles

Ten-Year Timeline

CELL-MET

CARDIAC MICROBUNDLE

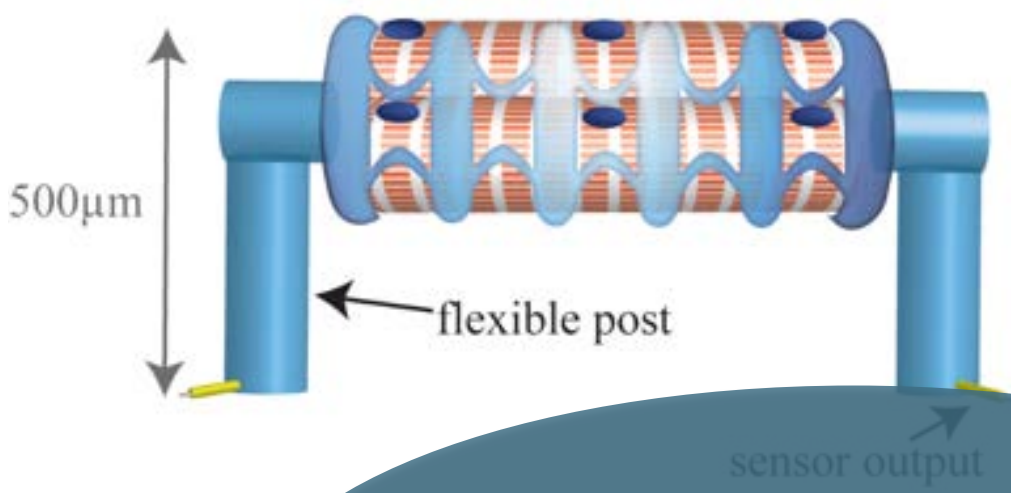


	YEAR 1	2	10	10 +
Imaging	Microscope development			Centimeter scale cardiac tissue with complex functionality including heart chambers, large vessel trees, cardiac valves and conduction system
Cell Eng.	2D cardiac bundles	3D c tissu vasc "Pat	scale ue with trees	
Scaffolds	2D scaffolds	3D s sens		
Nano Manuf.	2D printing	3D p	complex functionality	
Products	2D Cardiac Tissues on a Chip for Drug Development	Cardiac Tissues with implanted Sensors for Monitoring Cardiac Function	Muscle Tissues that can Assist Cardiac Function	Cardiac Tissues Beyond Muscles

Ten-Year Timeline

CELL-MET

CARDIAC MICROBUNDLE



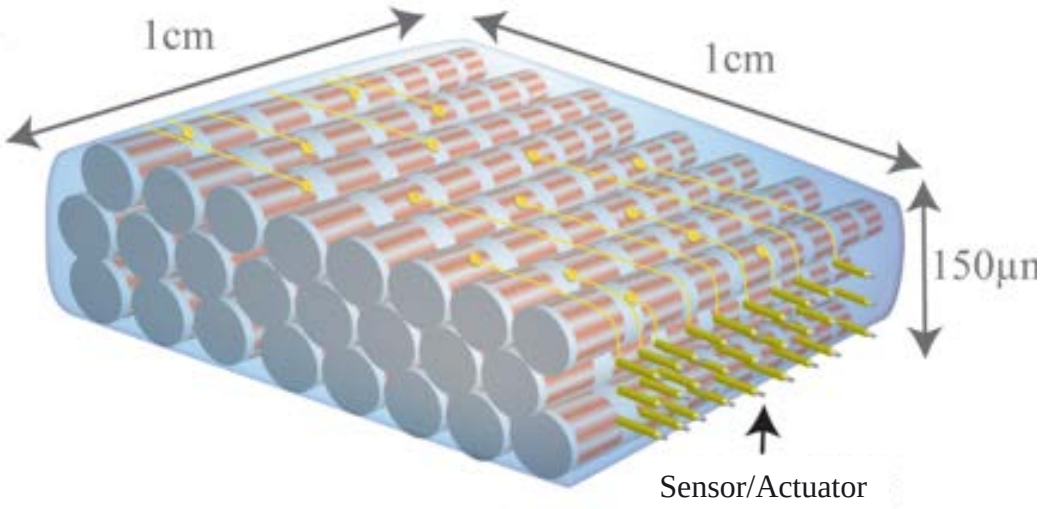
- Minimal functional model of a human heart
- Platform for disease modeling
- Test bed for drug testing and development, therapeutic drugs and drug side effects

	YEAR 1	2	10	10 +
Imaging	Microscope development			Centimeter scale cardiac tissue with complex functionality including heart chambers, large vessel trees, cardiac valves and conduction system
Cell Eng.	2D cardiac bundles	3D c tissu vasc "Pat	scale e with trees	
Scaffolds	2D scaffolds	3D s sens		
Nano Manuf.	2D printing	3D p		
Products	2D Cardiac Tissues on a Chip for Drug Development		Cardiac Tissues with Implanted Sensors for Cardiac Function	Cardiac Tissues Beyond Muscles

Ten-Year Timeline

CELL-MET

INSTRUMENTED CARDIAC SHEET

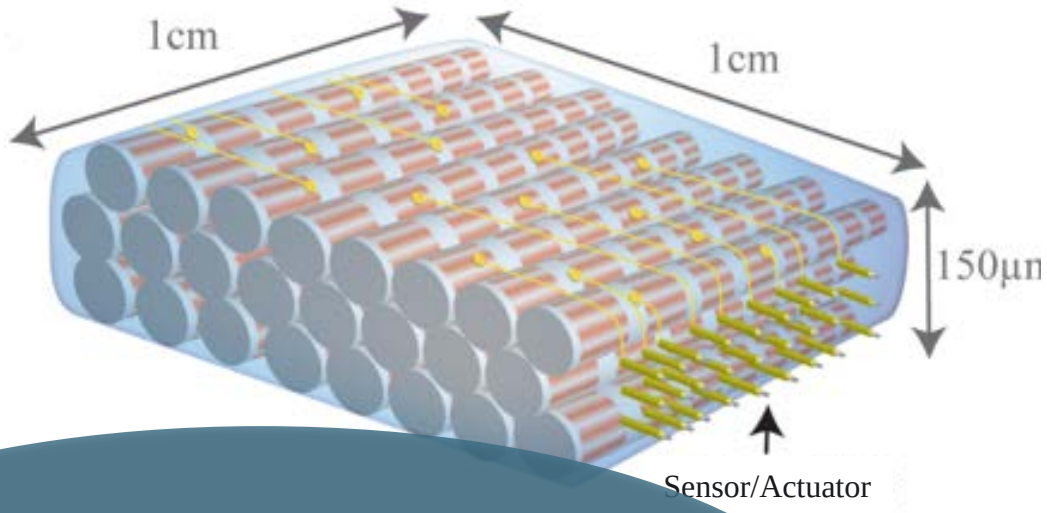


	YEAR 1	2	10	10 +
Imaging	Microscope development			Centimeter scale cardiac tissue with complex functionality including heart chambers, large vessel trees, cardiac valves and conduction system
Cell Eng.	2D cardiac bundles	3D c tissu vasc "Pat	scale ue with trees	
Scaffolds	2D scaffolds	3D s sens		
Nano Manuf.	2D printing	3D p	complex functionality	
Products	2D Cardiac Tissues on a Chip for Drug Development	Cardiac Tissues with implanted Sensors for Monitoring Cardiac Function	Muscle Tissues that can Assist Cardiac Function	Cardiac Tissues Beyond Muscles

Ten-Year Timeline

CELL-MET

INSTRUMENTED CARDIAC SHEET



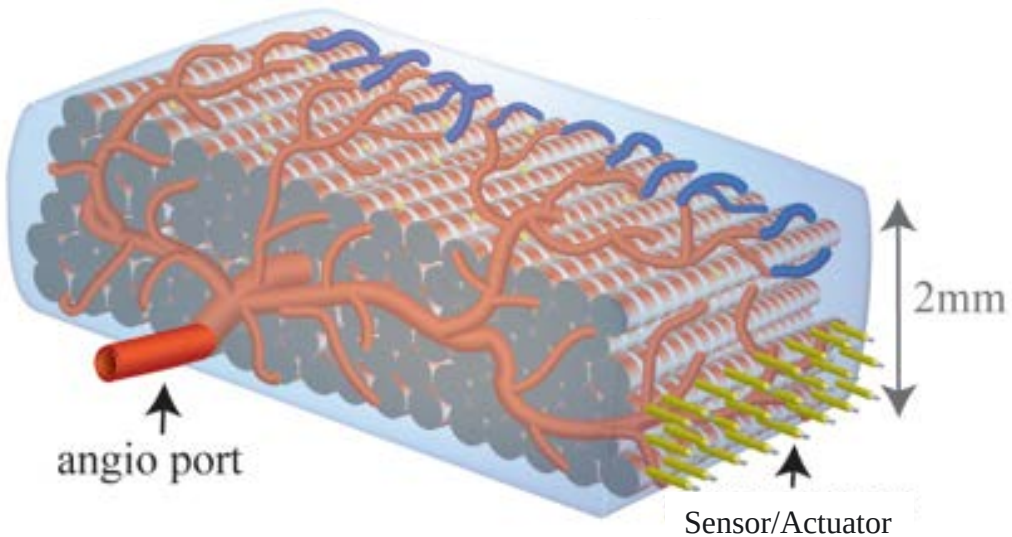
- Functional model of human heart tissue
- Platform for wave propagation studies
- Test bed for drug testing and development
- Integrated sensors for measurements

	YEAR 1	2	10	10 +
Imaging	Microscope development			Centimeter scale cardiac tissue with complex functionality including heart chambers, large vessel trees, cardiac valves and conduction system
Cell Eng.	2D cardiac bundles	3D c tissu vasc "Pat	scale ue with trees	
Scaffolds	2D scaffolds	3D s sens		
Nano nuf.	2D printing		complex functionality	
Products	2D Cardiac Tissues on a Chip for Drug	Cardiac Tissues with Implanted Sensors unction	Muscle Tissues that can Assist Cardiac Function	Cardiac Tissues Beyond Muscles

Ten-Year Timeline

CELL-MET

VASCULARIZED CARDIAC PATCH

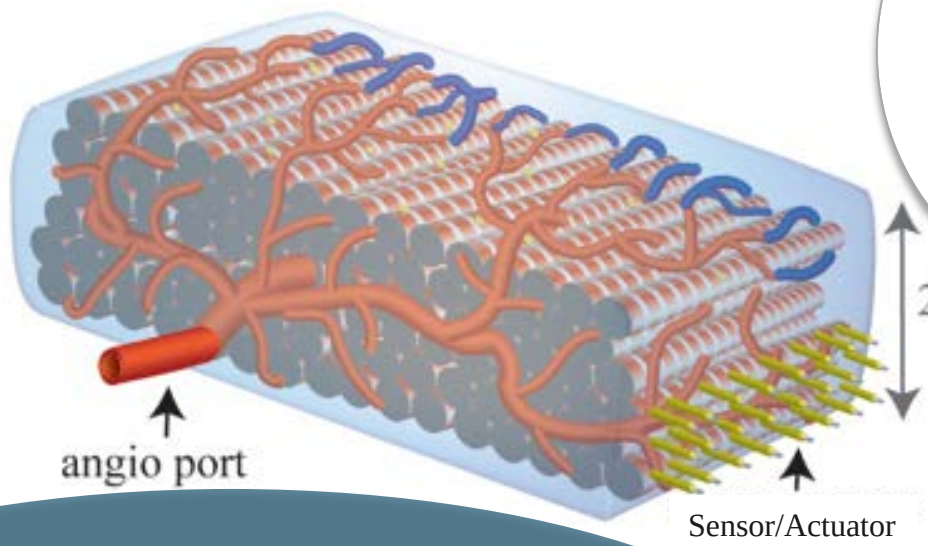


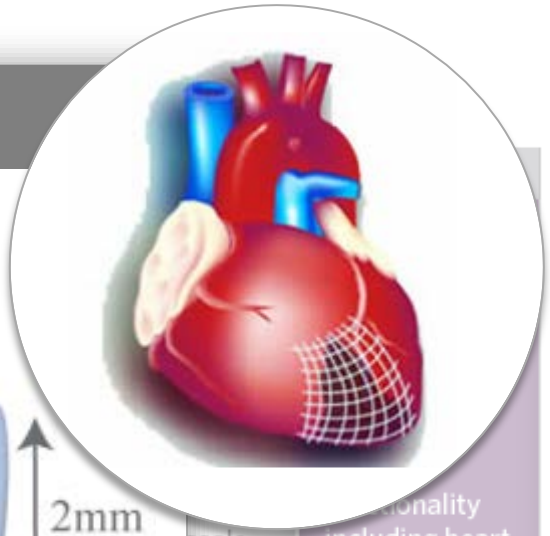
	YEAR 1	2	10	10 +
Imaging	Microscope development			Centimeter scale cardiac tissue with complex functionality including heart chambers, large vessel trees, cardiac valves and conduction system
Cell Eng.	2D cardiac bundles	3D c tissu vasc "Pat	scale ue with trees	
Scaffolds	2D scaffolds	3D s sens		
Nano Manuf.	2D printing	3D p	complex functionality	
Products	2D Cardiac Tissues on a Chip for Drug Development	Cardiac Tissues with implanted Sensors for Monitoring Cardiac Function	Muscle Tissues that can Assist Cardiac Function	Cardiac Tissues Beyond Muscles

Ten-Year Timeline

CELL-MET

VASCULARIZED CARDIAC PATCH

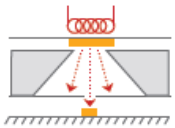
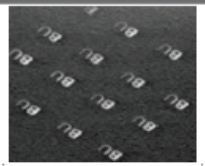
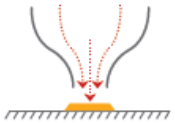
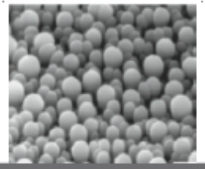
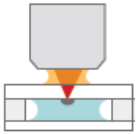
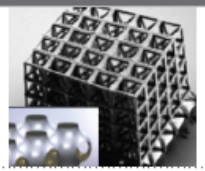
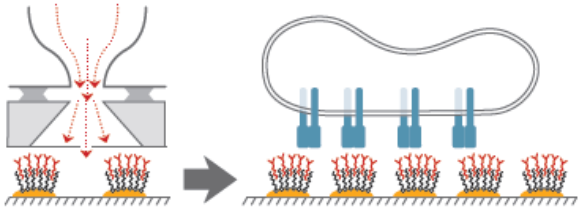
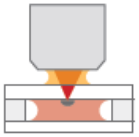
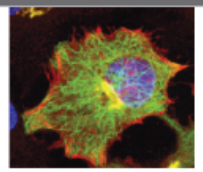




- Multifunctional model of human heart tissue
- Platform for fluid transport studies
- Test bed for drug testing and development
- Implantable tissues to assist cardiac function

Technology Tasks and Flows Between TAs

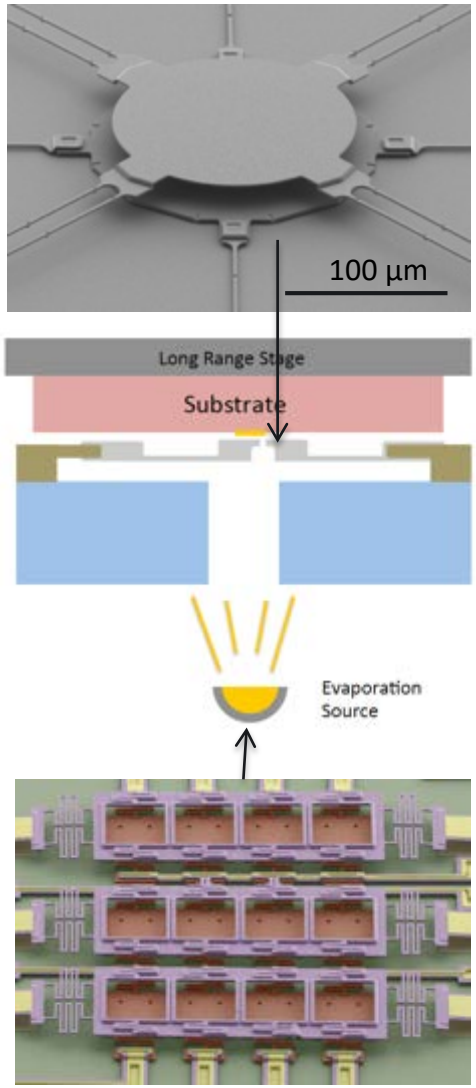
CELL-MET

	TECHNIQUE	MATERIALS	STRUCTURES	FEATURE	PURPOSE	WHO
THRUST AREA 1						
Atomic Calligraphy		Au, Ag, Ni, Al, etc.		<50 nm	High resolution patterns of metal that template organic/cellular assembly	BU
OVJP		C60, fluorescent, Pc OTS, HMDS, PEGDA, dPMT, pluronic, thiols, other organics, linear & cyclic RGD		< 2 µm	Functional coatings to create attachment points for cells	UM
THRUST AREA 2						
Nanoscribe		PEG, PEO, PMMA, etc.		<1 µm	3D nanoscale structures to act as scaffolds for cells and sensors/actuators	BU FIU ANL UM
AC + OVJP +Scaffolds				< 50 nm	Patterned 3D structures with focal attachments that direct cell binding, motion and function	BU UM
THRUST AREA 3						
Tissue Assembly				< 50 nm	Complex surfaces and 3D scaffolds for cell binding/ proliferation-multiscale, hierarchical, dynamic, embedded sensing	BU Harvard Columbia
THRUST AREA 4						
Imaging & Actuation		fluorescent proteins, quantum dots		< 1 µm	Deep 3D tissue imaging, fluorescent tagging, optogenetic actuation of tissue	BU FIU

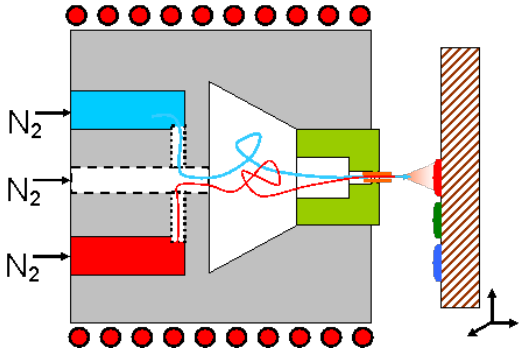
TA1: Nanopatterning Technologies

CELL-MET

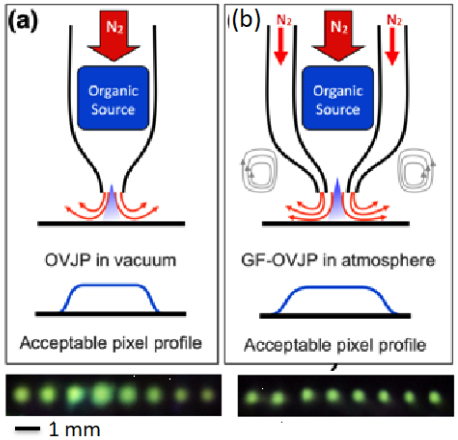
Atomic Calligraphy



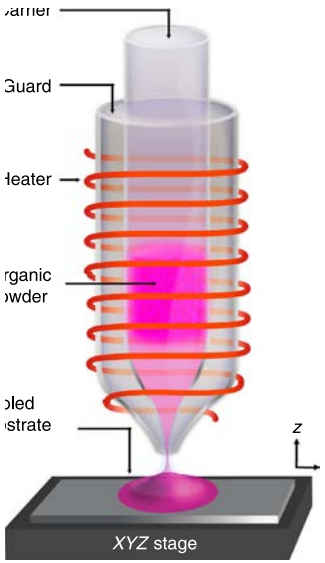
Organic Vapor Jet Printing



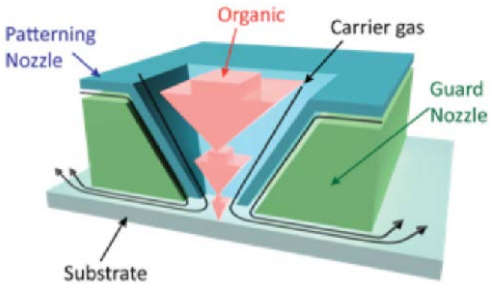
OVJP with guard flows



GF-OVJP



MEMS-Based OVJP



Stephen Forrest	EECS/Physics	UM
Brendan Baker	BME	UM
David Bishop	ECE/MSE	BU
Joerg Lahann	BME	UM
Max Shtein	MSE	UM

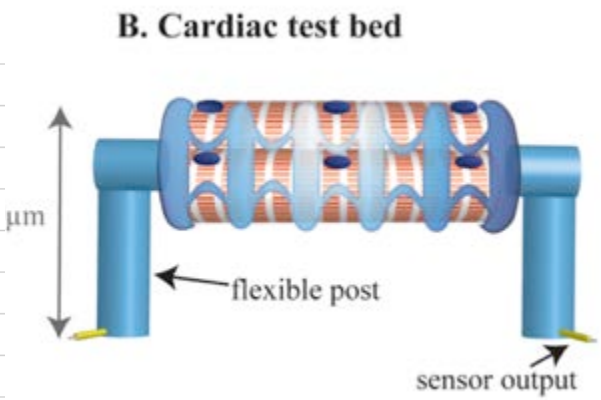
TA2: Dynamic Scaffolds Provide Cues to Direct Cells

CELL-MET

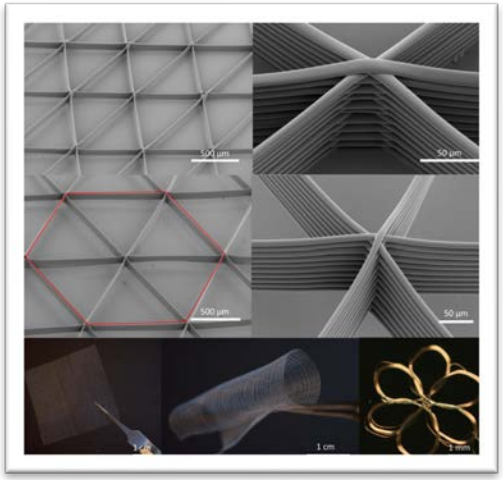
Novel Technologies for Micro- and Nano- Scaffolds

Alice White	ME	BU
Arvind Agarwal	MSE	FIU
David Bishop	ECE/MSE	BU
Kamil Ekinci	ME	BU
Mark Grinstaff	Chem/BME	BU
Joerg Lahann	BME	UM
Chenzhong Li	BME	FIU
Daniel Lopez	Physics	ANL

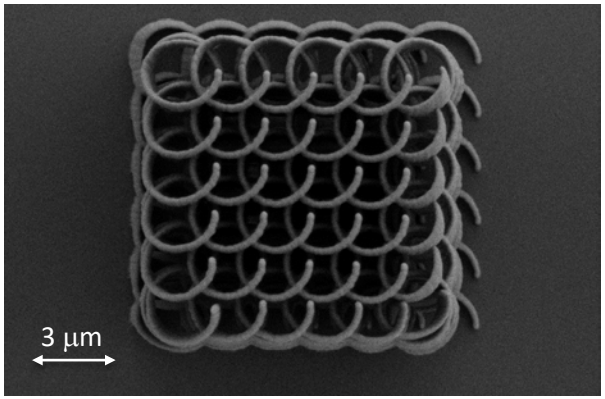
Nanoscribe Direct Laser Writing (BU)

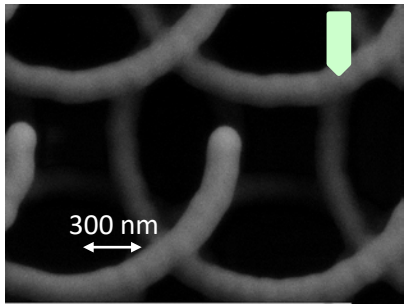


3D jet-printing (UM)

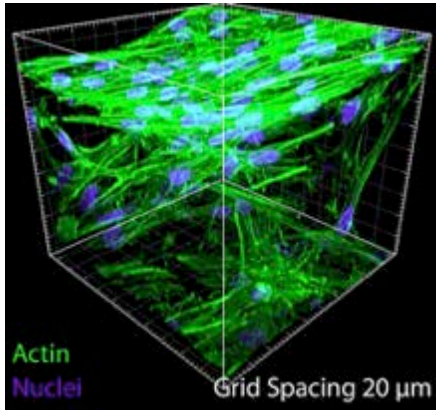


Interlocking Helices





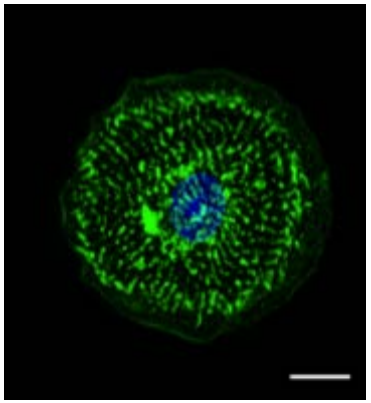
Stem Cells on Biomimetic ECM

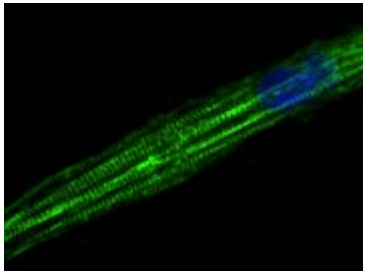


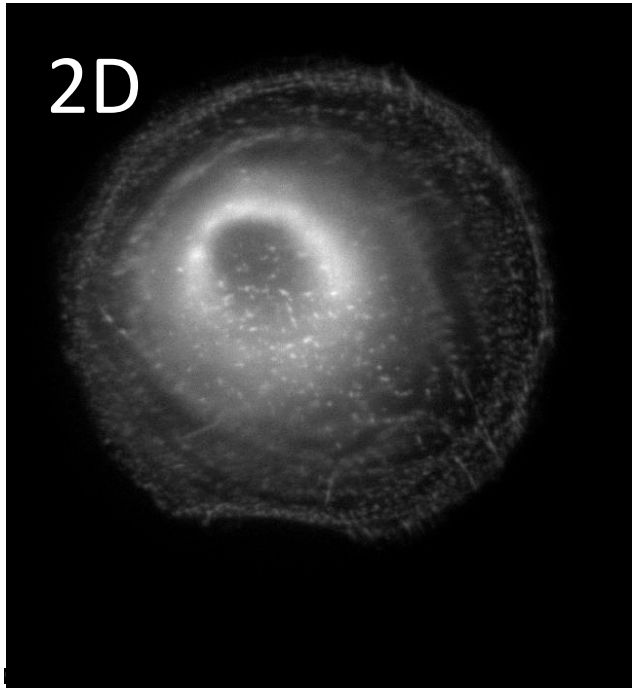
TA3: Tissue Assembly

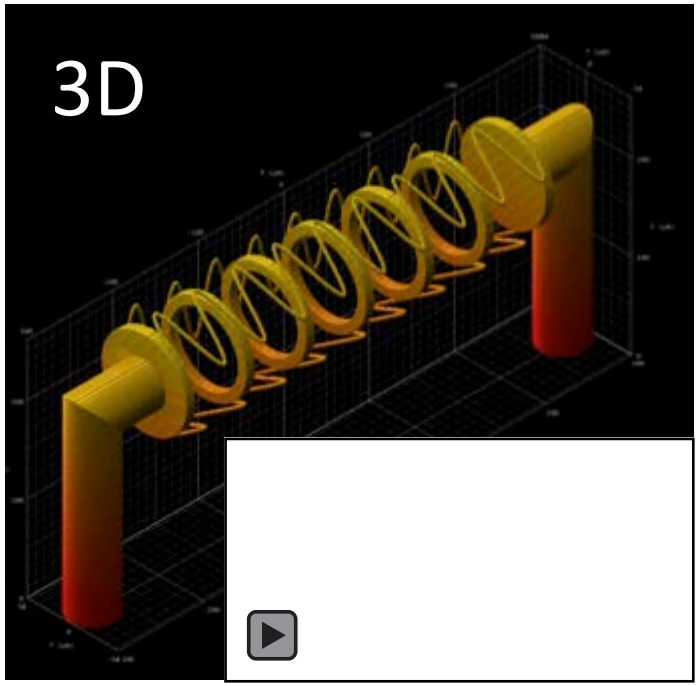
CELL-MET

- Biocompatibility of glues, patterns, materials, sensors.
- Effects of 3D scaffolds, nanoarchitectures, anisotropic mechanics, and nanopatterned glues, on cardiomyocyte structure, maturation, and function









Christopher Chen	BME	BU
Jennifer Lewis	BME	Harvard
Christine Seidman	Medical Sch	Harvard
Jonathan Seidman	Medical Sch	Harvard
Gordana Vunjak-Novakovic	BME	Columbia

TA4: Optical Engineering

CELL-MET

An ERC technical challenge: Light used to image engineered tissue is absorbed, scattered, and aberrated by muscle cells and and scaffolds

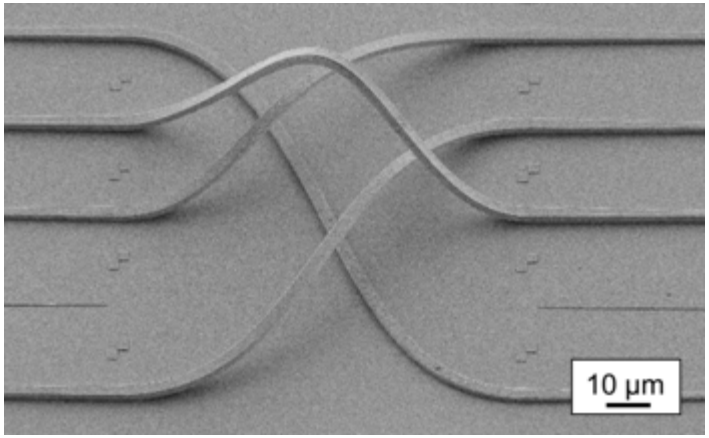
***Proposed areas of research*:**

1)Advanced Microscopy: Wider FOV, deeper imaging, faster

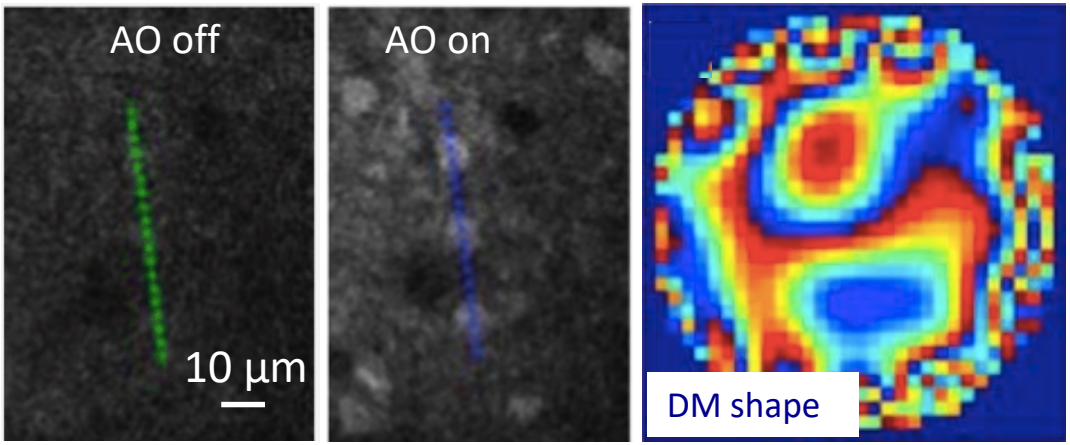
2)Light-based control of photosensitized tissue

3)Micro-optical scaffold networks

Thomas Bifano	**ME**	**BU**
Xue Han	**BME**	**BU**
Jin He	**Physics**	**FIU**
Jerome Mertz	**BME**	**BU**



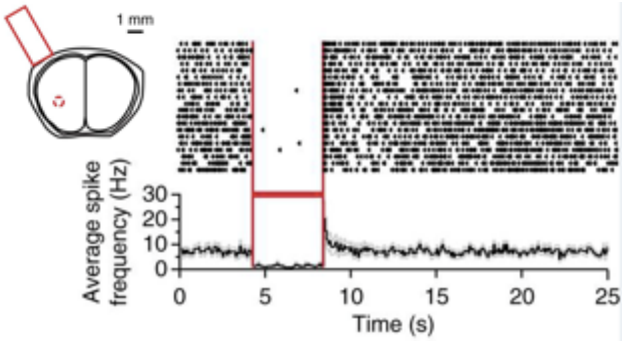
Optical Conduits



Adaptive optics (AO) 3-photon imaging, 400µm deep in tissue

FOV enhancement using conjugate AO

Optogenetic cell silencing 3mm deep in tissue



Broader Impacts of Education, Workforce Development, and Diversity

CELL-MET

PROGRAM GOALS

1. ***Create evidence-based education*** derived from CELL-MET research to broaden participation of URGs in STEM disciplines and careers.
2. ***Create an inclusive training environment*** that supports and sustains URG interest to pursue STEM workforce

RESEARCH QUESTIONS

1. What ***skill-based experiences*** are most influential in strengthening and maintaining students' interest in STEM disciplines and careers throughout their training?
2. What ***interventions*** positively influence university and precollege faculty confidence to deliver relevant STEM lessons based on CELL-MET?
3. How do ***collaborative relationships*** and programmatic supports influence students' sense of belonging and community and increase retention?
4. What drivers ***motivate URGs*** to pursue careers within an emerging sector of the workforce?

EWD: Summary of goals

CELL-MET

- **University undergraduate, graduate, and postdoctoral research and education programs** strategically designed to produce graduates who are:
  - Creative, adaptive, and innovative
  - Skilled in areas currently in demand
  - Knowledgeable of industrial practice, technology advancement, entrepreneurship, and innovation
- **Long-term pre-college partnerships** that will**:**
  - Bring engineering concepts and experiences to K-12 learners
  - Increase enrollment in college-level engineering degree programs
- **ERC evaluation plan** will inform**:**
  - Our operations / the way we collaborate and work together
  - Refinement and development of educational programs

Integrating Inclusivity & Diversity in CELL-MET

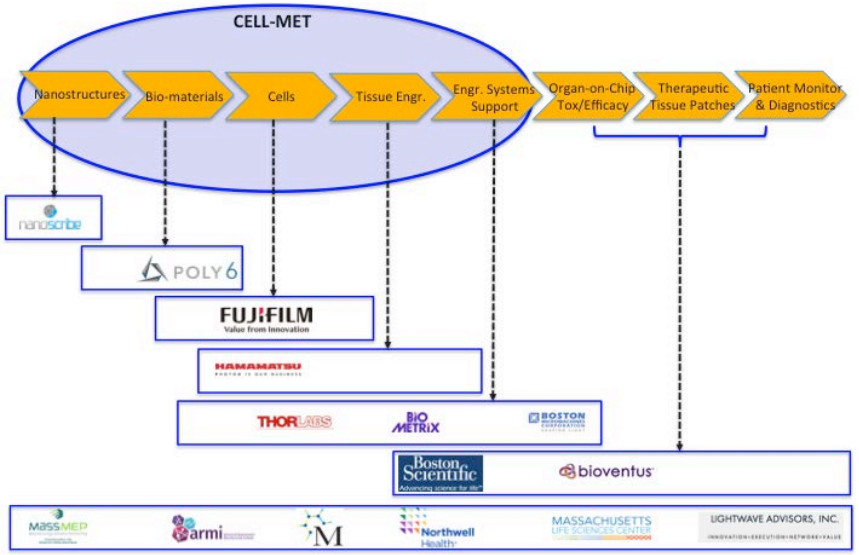
Integrating Inclusivity & Diversity in CELL-MET

1. Science Communication Training
2. Inclusive Excellence & Mentoring Training
3. Common Shared Language of Technology
4. Internships
5. Graduate Chapters of Professional Societies
6. Working with REM/REU/RET participants
7. K-12 Outreach at schools with high populations of URG's in engineering
8. Relationships with NSF INCLUDES & other ERC's

Innovation Ecosystem

CELL-MET

Value Chain:



8 Members, 3 Contributing Orgs, 4 Innovation Partners

Tech Transfer:

- Established and implemented IP Policy.
- BU Ignition Award to MEMS technology spin-out.
- Cultivate small company membership (i.e. endorsements of SBIR proposals - Avery Therapeutics).
- Recruit companies to Business Innovation Center (i.e. Matregenix).
- Sponsor Business Plan competition at TERMIS.
- Judge SPIE and Ignition Award start-up competitons (over 30 start-ups reviewed).
- 3 Provisional Patents/2 Licensing discussions in progress.

Student Training:

- IP Training (B. Pilz).
- Entrepreneurship Training (J. Fay/M. Shtein).
- Paid Internships:
  - Bioventus (2 engineering undergrad plus hosted non-ERC RET student.
  - Poly6 (1 engineering undergrad, 1 MBA).
- Student participation in meetings with industry, networking events and in trade shows.

Center Promotion:

CELL-MET Video

Created animations

Student support at Cell & Gene Therapy Show

Organized for Success

CELL-MET

Council of Deans
Kenneth Lutchen (BU), Alec Gallimore (UM), John Volakis (FIU)

Director: *David Bishop*
Deputy Director: *Christopher Chen*

Scientific Advisory Board
Industrial/Practitioner Advisory Board
Academic Policy Board
Workforce Development Adv Board

TA 1
Nanomanufacturing
Stephen Forrest

TA 2
Scaffolds
Alice White

TA 3
Cell Engineering
Christopher Chen

TA 4
Imaging
Thomas Bifano

Diversity
Helen Fawcett

Innovation Ecosystem
Thomas Dudley

Workforce Development
Sarah Hokanson

Administration
Robert Schaejbe
Cynthia Kowal

CELL-MET Test Bed
Christopher Chen

Student Leadership Council
Ayse Muniz
Maedeh Mozneb
Victoria Wiedorn

Our Dream

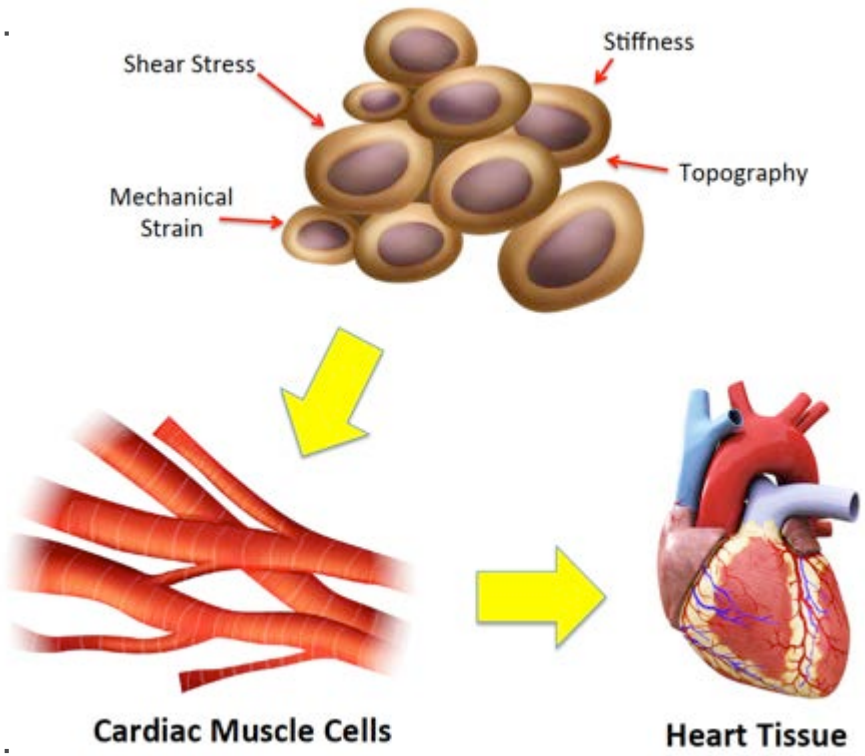
CELL-MET

Workforce Development

Culture of Inclusion

Innovation Ecosystem

Experienced Management Team



World-Class Scientific Team

Strong Institutional Support

State of the art Facilities

How we won an ERC (I think)

CELL-MET

- Work on solving an important and widely recognized societal problem or issue
  Final funding decision is made by the NSF Director. Think big. You need to select a problem where convergent research is required to solve it.
- Put together the strongest team you can in all areas (technical, culture of inclusion, workforce development and education, innovation ecosystem and administration.
  The process will find your smallest flaws and weaknesses. You need to be brutal because the selection process is.
- Your broader impacts programs need to be at least as important to you as the engineering you wish to do. If you commitment to those programs is less than absolute, the process will find you out. Your MSI is a critical element in your BI plans.
- It helps if your Director has had experience in leading big, complex organizations.
  This is a job unlike any normal academic position. I've spent my entire adult life leading R&D organizations at Bell Labs including a $350M/year USG R&D business and this is easily the hardest job I've ever had. The members of your team will need to have loving and supportive families because your families will pay a serious price when you all commit to do this. You should be honest with them before you start.
- The process is beyond arduous. In our year, 203 teams started. After 2 years, 4 had won.
  When we won, I looked at my folder of ERC files and we had generated ~750 documents, most large and complex. The due diligence the NSF needed to go through after a final list of potential winners was selected took ~9 months.

How we won an ERC (I think)-2

CELL-MET

- Have an honest discussion with your university about the level of institutional commitment required to compete for and win an ERC as well as support it after you win.
  The institutional commitments are large and never ending. Everybody needs to go into this with their eyes open. I suggest that everything from space to teaching releases should be discussed and agreed to in an MOU. It will come in handy later.
- Find a really talented graphic artist who can make your presentations and documents look as good as the content they contain. Appearances do actually matter.
- Be friends with your team, you will spend a lot of time together. You will need to help each other and cover for each and support each other through thick and thin.
- Gather together a group of trusted advisors who can help you during the process. Former and current ERC directors are an incredibly important and valuable resource. To a person, I have found them to be committed to the program and generous with their time. I have benefited from their help in many ways large and small through the selection process.
- You probably won't win the first time.
  We didn't. Every painful and unpleasant thing that happens to you is a chance to get smarter. Learn from failure, internalize the lessons and vow to do better next time.

How you lead an ERC (still figuring this out)

CELL-MET

- After you win, the work just begins. Annual reports (our most recent one was 532 pages), annual meetings, other NSF meetings, data gathering, retreats, progress reports, patent fillings, papers, industry meetings, research (with luck), summer programs, etc. will consume you.
  You will on occasion ask yourself why you actually wanted this to happen to you.
- Not everybody who worked with you on the proposal and helped you to win it will be with you throughout the life of the project. Nobody is entitled to ERC funding although many will feel they are. The seasoned Directors say the hardest job of the Director is asking people off your team if their interests diverge from where the project needs to go.
- ERCs are immortal but people and their interests are not.
  Succession planning for every job (including yours) is a crucial activity that can't be ignored.
- You need a strategic plan and need to follow it but that plan will need to change and evolve as the world changes. Striking the right balance between having a plan and following it and allowing a group of the world's most talented people the freedom to discover new things that solve your problems in unexpected ways is a never ending challenge. You will lose a lot of sleep pondering this. If you have the right team, patience is usually rewarded with extraordinary results but you will obsess about it some.

How you lead an ERC (still figuring this out)

CELL-MET

- After you win, the work just begins. Annual reports (our most recent one was 532 pages), annual meetings, other NSF meetings, data gathering, retreats, progress reports, patent fillings, pape[illegible] mmer programs, etc. will consum[illegible]
  You wi[illegible] u.
- Not [illegible] e with [illegible] any
- [illegible]
- You [illegible]
  evolve [illegible] and
  following it [illegible] reedom
  to discover new thi[illegible] ys is a never ending
  challenge. You will lose a lot of sleep p[illegible] g this. If you have the right team, patience
  is usually rewarded with extraordinary results but you will think about it some

Competing for and winning an ERC is a lot of work. Leading it after you win is also a lot of work. But when you win, society gives you and your team $50-100M and ten years to work on solving a problem that kills millions of your fellow human beings every year. As a scientist and a person, how could you not want to do this? If you win, you are indeed fortunate.

CELL-MET

Thank You

Administration Thrust Area

CELL-MET

Support all of CELL-MET's Strategic Goals

• Operational management, financial management, and support of strategic initiatives:

-- data collection and reporting

-- I/T, website, publicity and other communications -- cost-sharing among partners

-- industry revenues and in-kind commitments

--coordinate meetings, boards, councils, NSF site visit, retreats, etc.

• Coordination with central offices and affiliated departments at Boston University, partners, and affiliated institutions

• Support non-technical components such as Innovation Ecosystem, Workforce Development, and Diversity/Culture of Inclusion, e.g. administration of IPAB projects, REU and RET recruitment, safety training

• Review subaward invoices with component leads and expedite payments. Execute Leadership plans to augment subawards: coordinate NSF Prior-Approval requests with Sponsored Programs, follow-through for modifications

Administration Thrust Area

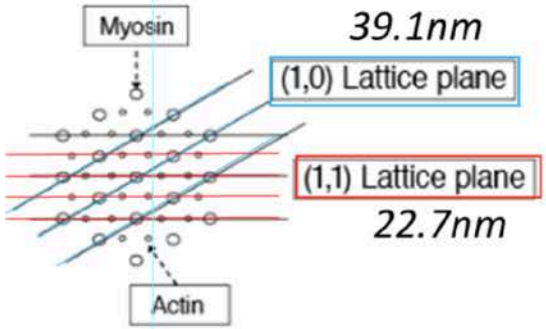
CELL-MET

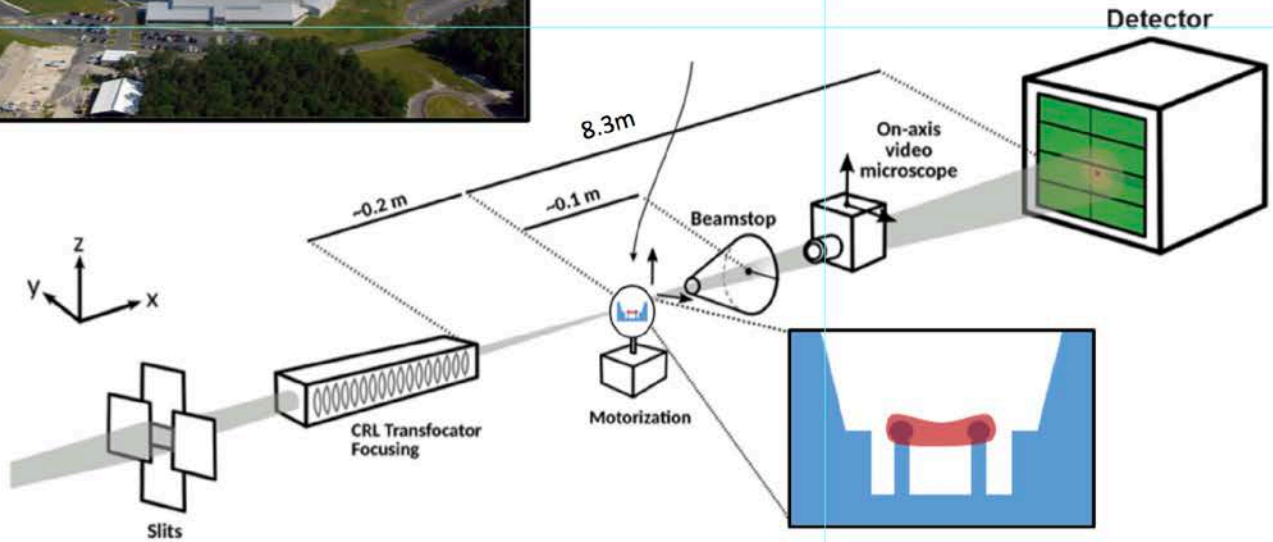
Support all of CELL-MET's Strategic Goals

- Operational management, financial management, and support of strategic initiatives:
  - -- data collection and reporting
  - -- I/T, website, pub[illegible] sharing among partn[illegible]
  - -- [illegible]
  - -- [illegible]
- Coordina[illegible] niversity, partners, and affilia[illegible]
- Support non-technical components such as Innovation Ecosystem, Workforce Development, and Diversity/Culture of Inclusion, e.g. administration of IPAB projects, REU and RET recruitment, safety training
- Review subaward invoices with component leads and expedite payments. Execute Leadership plans to augment subawards: coordinate NSF Prior-Approval requests with Sponsored Programs, follow-through for modifications

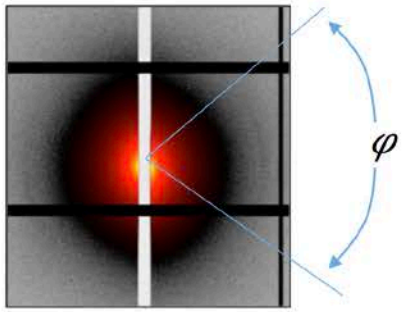
This Thrust Area is fully staffed, functioning at a very high level and was a crucial element in our Year 1 success

Synchrotron Small Angle Xray Scattering (SAXS)

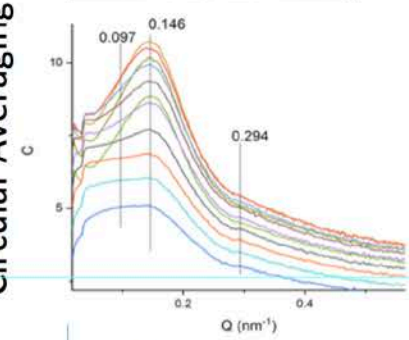




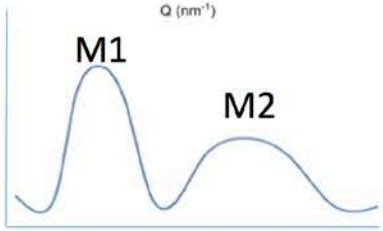
Scattering



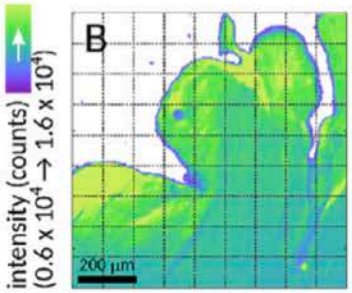
Circular Averaging



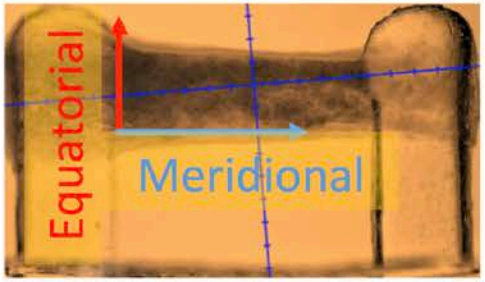
Fitting

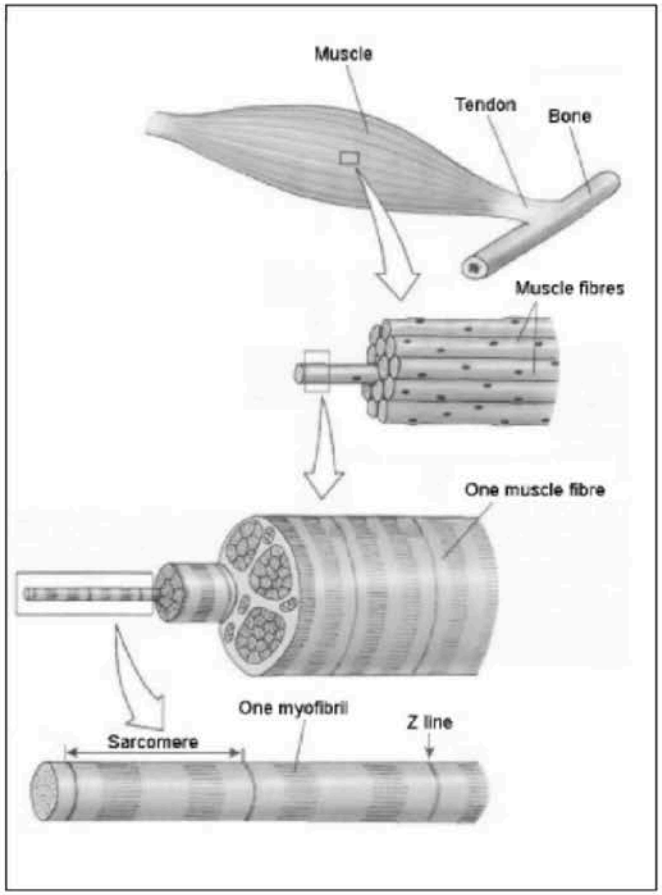


Mapping

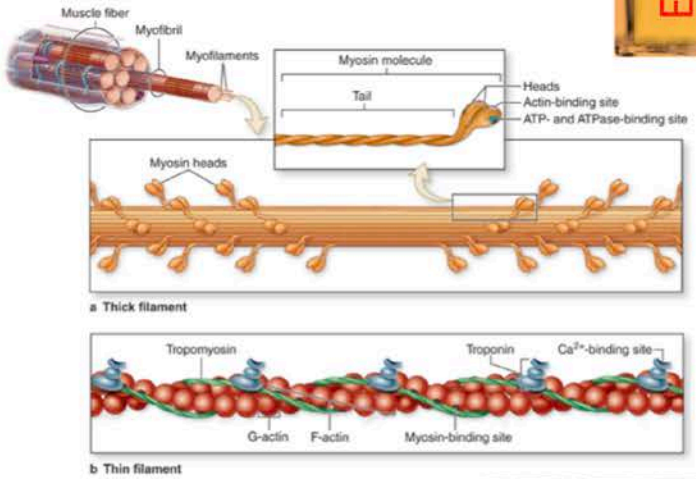


Ideal Cardiac Tissue Structure

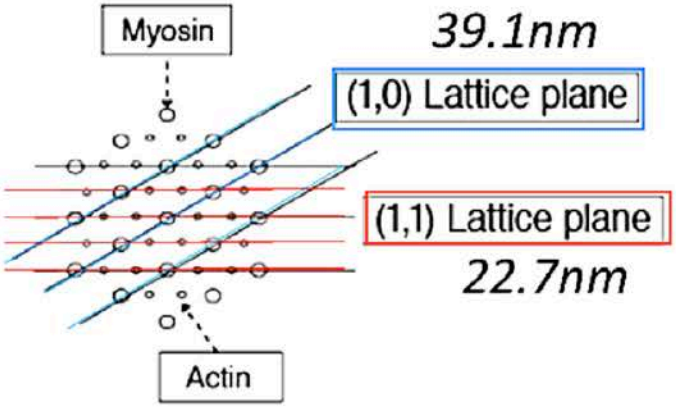




Meridional

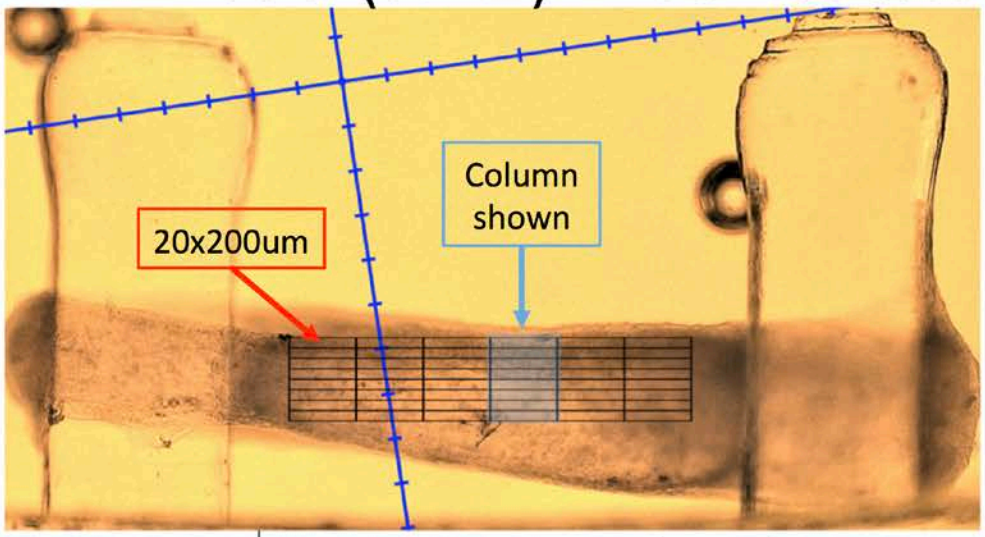


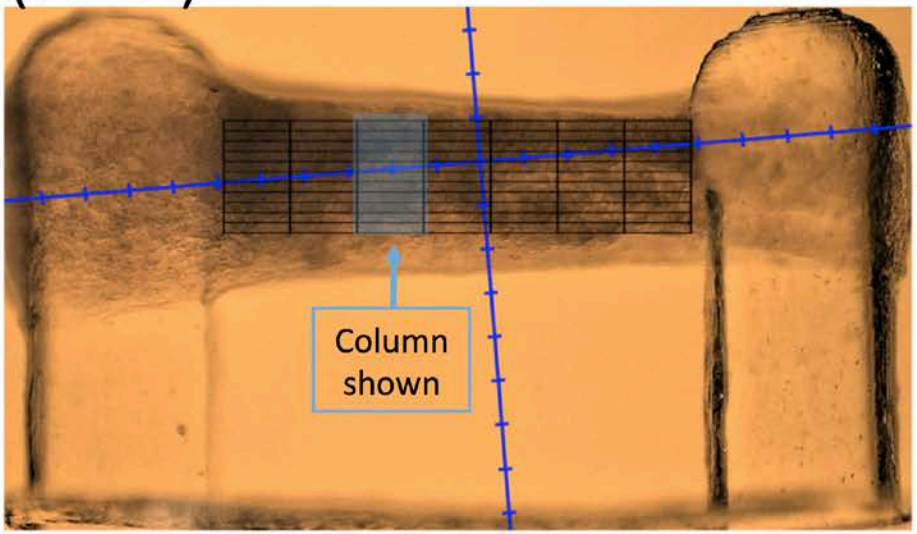
Equatorial

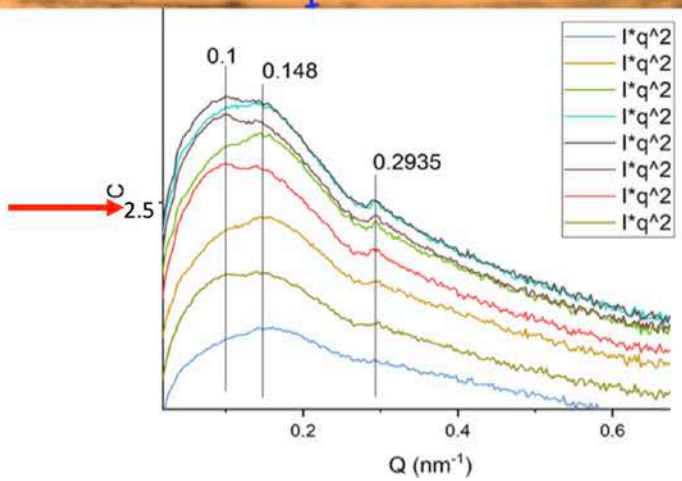


Meridional		
M1	0.014	1/A
M2	0.029	1/A
M3	0.044	1/A
Equatorial		
[1,0]	0.016	1/A
[1,1]	0.026	1/A

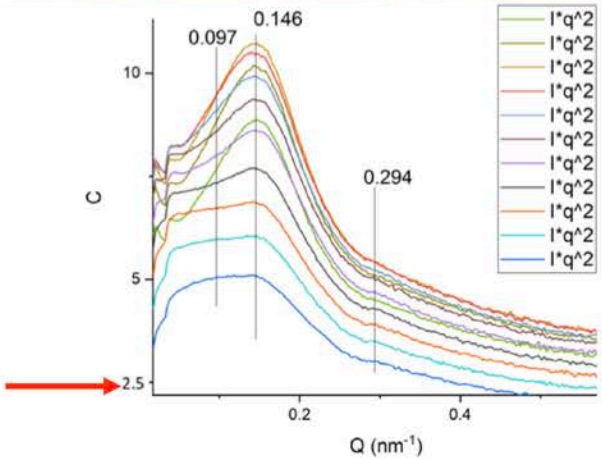
WT (N=2) vs HCM (N=2)







Wild Type



Hypertrophic Cardiomyopathy

A World-Class Scientific Team

CELL-MET

Brendan Baker
Michigan

Jennifer Lewis
Harvard/Wyss

Jerome Mertz
Boston University

Xue
B
3k Citations, h index 24

oerg Lahann
Michigan
10k Citations, h index 50
14 US Patents

ex 144

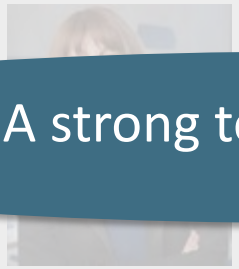
ong Li
h index 34
tents

Mar
14k Citations, h index 64
24 US Patents

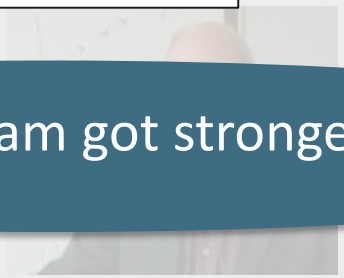
eidman
rd
30k Citations, h index 95
3 US Patents

Arvind Agarwal
FIU
5k Citations, h index 38
2 US Patents

Jin He
FIU
2k Citations, h index 20
2 US Patents



Gordana Vunjak-Novakovic
Columbia
31k Citations, h index 101
10 US Patents



Dave Bishop
BU
20k Citations, h index 80
47 US Patents

Daniel Lopez
Argonne
4k Citations, h index 31
27 US Patents

Alice White
BU
7k Citations, h index 38
5 US Patents

A strong team got stronger