COVER SHEET FOR GRANT PROPOSALS

State Board of Education

SBOE PROPOSAL NUMBER: (to be assigned by SBOE)	AMOUNT REQUESTED: **$1,999,366**

TITLE OF PROPOSED PROJECT: **Nucleic Acid Memory**

SPECIFIC PROJECT FOCUS: In 2016, the digital universe produced 16 ZB (1 ZB = 1 trillion GB) of data. In 2025 it will create 163 ZB. These data, once generated, cascade through the information lifecycle — from primary storage media in the form of hard disks and solid-state drives to archival media such as tape. While the semiconductor industry maximizes the density, stability, and energy efficiency of electronic and magnetic memory, both are fast approaching their physical and economic finish lines. As envisioned by the new Semiconductor Synthetic Biology Roadmap/Consortium, DNA-based massive information storage is a fresh start for memory manufacturing in the US. According to our study with Micron, Harvard, and the Semiconductor Research Corporation (SRC), DNA has a retention time that ranges from thousands to millions of years, 1 kg of DNA can store the projected digital universe in 2040, and DNA's energy of operation is 100 million times less than current electronic memory. As a result, nucleic acid memory has become a global conversation, a national investment, an industrial opportunity, and a local strength in ID.

Our vision is to pioneer a digital data storage paradigm in Idaho by designing, building, and testing accessible, editable, and non-volatile nucleic acid memory (NAM) technologies that are inspired by DNA circuits and made possible by our innovations in DNA nanotechnology. To actualize this vision, we seek ~$2M to create a world-class *Nucleic Acid Memory Institute*. The Institute will reside in the Micron School of Materials Science & Engineering at Boise State and ultimately be housed in the Micron Center for Materials Research, which is under construction. *En route* to Idaho's first NSF Engineering Research Center, or a national equivalent, the Institute will serve as a public-private partnership between Boise State, Micron, and the SRC. Because the SRC is the world's leading industrial research consortium, with IBM, Intel, Micron, Microsoft, Raytheon, and Twist Biosciences as members, the research team will be connected to a world-class network that has invested ~$2B in research. As a result, the *Institute* will function as the innovation nexus for emerging NAM technologies in the US. With support from IGEM-HERC, the *NAM Institute* will meet critical innovation, economic, and workforce development needs in Idaho. It will do this by combining research, development, and education (RD&E) in a Vertically Integrated Project (VIP).

To expedite our vision of Idaho becoming a global leader in NAM, five tasks will be met over the life of the IGEM-HERC: **TASK 1** – Create improved algorithms for coding information into data strands. **TASK 2** – Create a high-throughput, integrated analytical engine to design and select data strands using quantitative metrics based on an in-house, evolutionary algorithm. **TASK 3** – Create a cellular factory for manufacturing DNA scaffolds using a rapid design, build, and test cycle of genomes. **TASK 4** – Design and fabricate NAM storage nodes using the DNA scaffolds. **TASK 5** – Read and write arbitrary files into NAM storage nodes using super-resolution microscopy.

PROJECT START DATE: 7/1/18		PROJECT END DATE: 6/30/21	
NAME OF INSTITUTION: Boise State University		DEPARTMENT: Micron School of Materials Science and Engineering	
ADDRESS: 1910 University Dr., Boise, Idaho 83725			
E-MAIL ADDRESS: osp@boisestate.edu		PHONE NUMBER: 208-426-4420	
	NAME:	TITLE:	SIGNATURE:
PROJECT DIRECTOR/PRINCIPAL INVESTIGATOR	William L. Hughes	Associate Dean & Associate Professor	Not required
CO-PRINCIPAL INVESTIGATOR	Tim Andersen, Professor; Wan Kuang, Associate Professor; Elton Graugnard, Assistant Professor; Eric Hayden, Assistant Professor		Not required
NAME OF PARTNERING COMPANY: Micron Technology and the Semiconductor Research Corporation.		COMPANY REPRESENTATIVE NAME: Gurtej Sandhu at Micron, Steve Kramer at Micron, and Victor Zhirnov at the Semiconductor Research Corporation.	
	NAME:	SIGNATURE:	
Authorized Organizational Representative	Matt Smith	Matt G. Smith Digitally signed by Matt G. Smith DN: cn=Matt G. Smith, o=Boise State University, ou=Office of Sponsored Programs, email=mattsmith2@boisestate.edu, c=US Date: 2018.04.02 16:07:38 -06'00'	

Nucleic Acid Memory

IDAHO PUBLIC INSTITUTION	Boise State University
PRINCIPAL INVESTIGATOR	Will Hughes
PROJECT OBJECTIVE	Establish Idaho as a global leader in nucleic acid memory (NAM)
AMOUNT REQUESTED	$1,999,366

The rapid proliferation of cloud computing and the emergence of big data for massive social, scientific, and financial records is creating an information storage crisis[1,2]. In 2016, the digital universe produced 16 ZB (1 ZB = 1 trillion GB) of data. In 2025 it will create 163 ZB[1]. These data, once generated, cascade through the information lifecycle — from primary storage media in the form of hard disks and solid-state drives to archival media such as tape. To reveal the economic impact, a center storing 1 EB (1 EB = 1 billion GB) of data on magnetic tape would draw hundreds of megawatts of power and demand $1B over 10 years to build and maintain[3]. While this level of investment spurs innovations in density, stability, and energy efficiency, electronic and magnetic memory are fast approaching their physical and economic finish lines; affirmed by the end of the International Technology Roadmap for Semiconductors (ITRS)[4,5]. As envisioned by the new Semiconductor Synthetic Biology Roadmap and Consortium[6], DNA-based massive information storage is a fresh start for memory manufacturing in the US. As a member of this consortium and contributor to the roadmap, we "*stimulate non-traditional thinking about the issues facing the semiconductor industry, concentrating on synergies between synthetic biology & semiconductor technology.*[6]" According to our study[2] with Micron, Harvard, and the Semiconductor Research Corporation (SRC), DNA has a retention time that ranges from thousands to millions of years, 1 kg of DNA can store the projected digital universe in 2040, and DNA's energy of operation is 100 million times less than current electronic memory (**Table 1**). As a result, nucleic acid memory (NAM) has become a global conversation[3,7], a national investment[8,9], an industrial opportunity, and a local strength in ID[2,10]. In spite of this, there is a large gap to read, write, and edit NAM[8].

Why IGEM HERC

To capitalize on this opportunity, which has been facilitated by the PI and his team through a decade of strategic action/impact, Idaho is positioned to invest locally so that we can compete globally. The leadership and innovation of our research team has brought us to the threshold of becoming a *global* leader in the research, development, and education (RD&E) of nucleic acid memory. To secure our position, postdoctoral support and key infrastructure is vital to accelerate the rate and raise the impact of our science, workforce development, and intellectual property. With support from the Idaho Global Entrepreneurial Mission (IGEM) and the State Board of Education Higher Education Research Council (HERC), we will pioneer the first technology platform that reads, writes, and edits massive amounts of data using DNA, which will transform the digital universe. *En route* to this goal, our team is actively submitting proposals to the joint NSF/SRC partnership called *Semiconductor Synthetic Biology for Information Processing & Storage Technologies*[9]. This is a strategic step to secure Idaho's first NSF Engineering Research Center or national equivalent — both of which will provide a step-function in the amount of research funding, infrastructure, and intellectual capital available to the team — enabling a platform for long-term industry partnerships, the catalyzation of a new memory market based on NAM, and a semiconductor synthetic biology (SemiSynBio) workforce trained in Idaho, *for Idaho*.

Table 1. *Comparison between memory technologies and DNA as a baseline for Nucleic Acid Memory products*[1].

Memory (type)	Retention (years)	ON Power (W / GB)	A. Density (bit / cm^2)	V. Density (bit / cm^3)	Latency (µs / bit)	Error Rate
Flash	10	0.01 – 0.04	10G	10P	100	1E-15
Hard Disk	> 10	0.04	100G	10T	3K- 5K	1E-15
Magnetic Tape	30	0.004	1G – 10G	N/A	60 – 200	1E-18 – 1E-21
Cellular DNA	> 100	< 100p	10Z	10Z	< 100	1E-8 – 1E-9

Vision

Our vision is to pioneer a digital data storage paradigm in Idaho by designing, building, and testing accessible, editable, and non-volatile nucleic acid memory (NAM) technologies that are inspired by DNA circuits and made possible by our innovations in DNA nanotechnology. To actualize this vision, we seek ~$2M to create a world-class *Nucleic Acid Memory Institute*. The Institute will report to the VP of Research & Economic Development and be housed into the Micron Center for Materials Research, which is under construction. *En route* to Idaho's 1st NSF Engineering Research Center, or a national equivalent, the Institute will serve as a public-private partnership between Boise State, Micron, and the SRC. Because the SRC is the world's leading industrial research consortium, with IBM, Intel, Micron, Microsoft, and Twist Biosciences as members, the research team will be connected to a world-class network that has invested ~$2B in research over the past 30 years. As a result, the *Institute* will function as the innovation nexus for emerging NAM technologies in the United States. With support from IGEM-HERC, the *NAM Institute* will meet critical innovation, economic, and workforce development needs in Idaho.[8] It will do this by combining research, development, and education (RD&E) in a Vertically Integrated Project (VIP); defined and outlined in the *Workforce Development* section of this proposal.

Preliminary Results

In preparation for IGEM-HERC, we have established a very strong foundation for NAM: (**1**) encoded arbitrary files into DNA data strands[11-14], (**2**) created an evolutionary algorithm and thermodynamic metric for selecting data strands[15,16,25], (**3**) improved the stability and selectivity of data strands[17], (**4**) manufactured storage nodes, which are DNA breadboards that localize data strands[10,18], (**5**) deposited storage nodes onto wafers engineered by Micron, and (**6**) resolved data strands on storage nodes below the diffraction limit of light[19]. IGEM-HERC support will amplify and integrate these results in the design, build, and test of multiple NAM platforms (**Fig 1**).

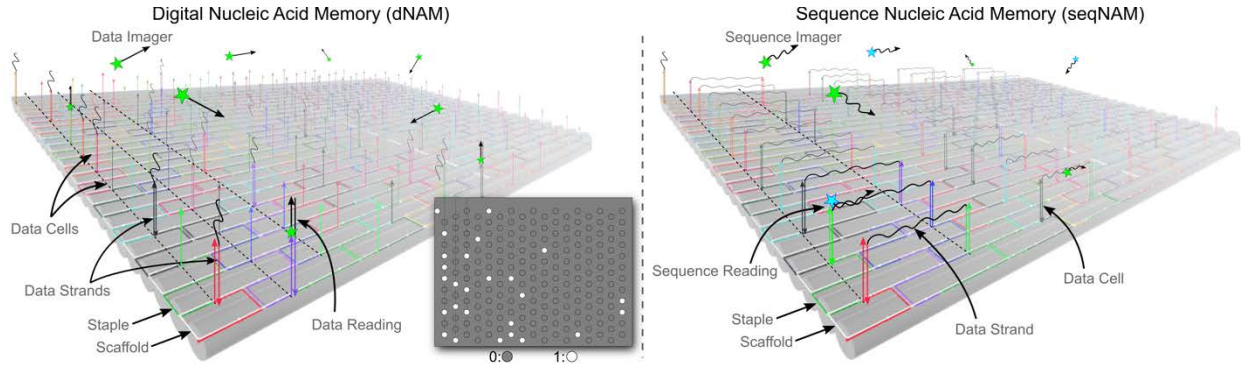

Fig 1. Example nucleic acid memory platforms. Binary dNAM storage node (left) and seqNAM (right) consist of storage nodes, which are DNA breadboards that localize data strands to specific sites. Localization is enabled by extending the structural staple strands of the breadboards to create addressable data cells. For dNAM, data strands exhibit unique sequences that serve as binding sites for data imager strands in super-resolution microscopy (SRM). The presence, absence, and identity of a data strand's docking sequence defines the state of each data cell. The spatially encoded binary information is shown in the inset. The resolution is ~7 nm for two-color SRM, which is readily achievable[19]. For seqNAM, two data cells arrange data strands in addressable locations. The sequences of these data strands are read by multi-color SRM using a library of sequence imager strands to perform sequencing.

Resource Commitment

The strategic mission of Boise State's Division of Research and Economic Development is to "*grow in select areas of research defined as those with the greatest potential for distinction, and societal, cultural and economic benefit*.[20]" In support of this mission, Micron has invested $40M into materials research at Boise State since 2003.[9] Since its start in 2012, the Materials Science & Engineering PhD program has become the single largest Science, Technology, Engineering, and Mathematics (STEM) PhD program in Idaho. Micron's recent $25M gift to create a world-class Center for Materials Research provides a foundation, both in terms of infrastructure and people, for Idaho to become a global leader in nucleic acid memory via the *NAM Institute*.[8] As described in the letter from Dr. Gurtej Sandhu, Director of Advanced Technology Development at Micron, the *NAM Institute* will be the centerpiece of the Micron Center for Materials Research building, delivering signature research, development, and education in support of a new memory industry. With the *Institute* as a distinct RD&E model within the new building, the essential infrastructure needed to pursue and secure a large, federally-funded research center will be realized in Idaho.

Specific Project Plan

The integration of deep expertise in DNA-inspired nanotechnology, photonics, computational science and the biological sciences, with overlapping interests in the semiconductor industry, provides the technical foundation to disrupt the memory market. To expedite our vision of Idaho becoming a global leader in NAM, five key tasks will be met over the life of the IGEM-HERC:

TASK 1 (WRITE) – Create efficient algorithms for coding information into data strands (**Fig 1**). Error correction strategies will account for DNA insertions, deletions, and substitutions, as well as screen for biological sequences to ensure that the data has no genetic function.

TASK 2 (SEQUENCES) – Create a high-throughput, integrated analytical engine to design and select data strands (**Fig 1**) using quantitative metrics based on an in-house, algorithm[11-14].

TASK 3 (SCAFFOLDS) **–** Create synthetic biological factories for manufacturing DNA scaffolds (**Fig 1**) using rapid design-build-test cycles of genomes. Genome size and structure will be engineered.

TASK 4 (FABRICATION) **–** Design and fabricate NAM storage platforms (**Fig 1**) using the DNA scaffolds, and validate the functionality of genome scaffolds using atomic force microscopy.

TASK 5 (READING) – Read arbitrary data files into NAM storage nodes using super-resolution microscopy. Realize sub-nanometer imaging resolution to enable high areal density data storage.

Project Team

The research team, described below, is well positioned to actualize *nucleic acid memory*.

Will Hughes (*PI*) is a founding faculty and professor of the Micron School of Materials Science & Engineering. He also serves as the cofounder and Associate Dean of the College of Innovation + Design, as well as the Head of Boise State's Vertically Integrated Projects (VIP) program[21]. At the forefront of NAM, his theoretical framework is motivating investments[8,9]. He significantly improved DNA reaction performance[17,22,23], creating the world's highest performing circuit[22].

Elton Graugnard (co-*PI*) is a founding faculty member and Assistant Professor of the Micron School of Materials Science & Engineering. He is also a recipient of the NSF CAREER Award. As part of an NSF Scalable NanoManufacturing grant with Hughes and Kuang, he co-invented a defect metrology technique for characterizing DNA masks[19]. He also created the first DNA machine to perform work in human serum with Hughes[24]. Graugnard will lead NAM fabrication.

Wan Kuang (*co-PI*) is an Associate Professor of Electrical & Computer Engineering. He is also a recipient of the NSF CAREER Award. He developed super-resolution microscopy techniques for defect characterization of DNA-based lithographic arrays in collaboration with Graugnard and Hughes[19]. He also serves as a visiting professor at Western Digital, providing technical depth aligned with semiconductor industry interests. Kuang will read NAM using advanced optics.

Timothy Andersen (*co-PI*) is a Professor of Computer Science. With expertise in bioinformatics, biologically inspired learning algorithms, and computing mechanisms such as artificial neural networks and genetic algorithms, he will lead the development of a biologically inspired coding scheme that compensates for DNA defects during encoding and sequencing events.

Eric Hayden (*co-PI*) is an Assistant Professor of Biological Sciences. His research expertise in synthetic biology, functional genomics, and biochemistry provides the foundation to manufacture robust genomic substrates for NAM.

Steve Kramer (*Advisor*) is a Principal Engineer within the Micron Research & Development group. He also serves as the University liaison for emerging technologies at Micron.

Advisory Committee

With strong support from the SRC and Micron, the advisory committee, described below, is well positioned to guide the research team and help establish the *Nucleic Acid Memory Institute*.

Gurtej Sandhu (*Chair*) is a Senior Fellow and Director of Advanced Technology Development at Micron, the 7th most prolific inventor in the world, and the recipient of the Andy Grove Award. He is also the Chair of the Micron School of Materials Science & Engineering Advisory Board.

Victor Zhirnov (co-*Chair*) is the Chief Scientist at the SRC, the world's leading industrial research consortium. He also serves as the founding Director of the Semiconductor Synthetic Biology (SemiSynBio) Roadmap and Consortium. His core responsibilities include assessment of emerging solutions for future information and communication technologies.

Bernard Yurke (*Member*) has made significant contributions in low-temperature physics, quantum optics, liquid crystals, biophysics, and DNA nanotechnology[17,23-30]. His pioneering work on toehold-mediated strand displacement is an enabling technology for NAM. Yurke will advise the team on the theoretical framework and technical challenges of encoding, synthesizing, patterning, and reading NAM. He serves as the scientific mentor for the PI on his NIH K25Career Award.

Potential Economic Impact

At an aspirational level, the potential economic impact of a *NAM Institute* is the seeding of a new global industry in Idaho. At the most basic level, it is the sustained funding that comes with a world-class research program, such as securing an NSF Semiconductor Synthetic Biology for Information Processing & Storage Technologies (SemiSynBio, $1.5M) and/or IARPA Molecular Information Storage (MIST, $4M) grants — with an achievable goal of securing Idaho's first Engineering Research Center (ERC, ~$3M–$4.25M/year for up to 10 years).

In preparation for this moment, the PI and his team have already secured ~$10M in external funding on foundational projects — highlighting their track record of securing external funding. It is this funding that has positioned the research team at the leading edge of nucleic acid

memory with Micron, SRC, and the State of Idaho as the primary stakeholders in advancing NAM from laboratory innovations to industrial integration. In doing so, Boise State is on the ground floor in what could be the most promising memory technology since flash memory.

With memory technology and consumer demands approaching their crossroads[2], startup companies, such as Twist Scientific and Catalog DNA, are working toward DNA-based digital storage solutions. Anticipating DNA as the medium to sustain the growth of the semiconductor industry, our partners, Micron Technology and the SRC, are also investing in NAM as the next-generation storage solution. According to Dr. Gurtej Sandhu[7], "*The rising cost of data storage will drive alternate solutions, and DNA storage is one of the more promising*". And with ~$6B in sales during the fourth quarter of 2017 alone, the potential economic impact to Idaho becoming the global leader in NAM includes the opportunity to create a new memory market.

Workforce Development

Building on the PI's leadership of the VIP program at Boise State[21], which is part of an international consortium of 23 universities supported by the Helmsley Charitable Trust[31], the *NAM Institute* will train a new cadre of students that work along the interface of semiconductor manufacturing and synthetic biology. Vertically Integrated Projects unite undergraduate students, graduate students, post-doctoral fellows, and faculty in a team-based setting. Within this context, VIP students earn academic course credit for their participation in design and discovery efforts that support faculty and post-doctoral fellows with large-scale projects, such as the *NAM Institute*. VIP teams are: (1) *multidisciplinary* – drawing students from all disciplines; (2) *vertically integrated* – maintaining a mix of freshman to faculty; and (3) *long term* – students may participate for the duration of their education. Providing course credit incentivizes participation, while aligning the needs of freshman *to* faculty *to* funding agencies *to* industry partners makes the program a vehicle for economic impact and workforce development in Idaho.

Criteria for Measuring Success

Listed below are specific, objective, measurable, and realistic performance metrics to gauge project success and economic impact. CURRENT values reflect the average performance prior to IGEM support, and PROPOSED values reflect the anticipated range because of IGEM support.

CENTER METRIC	CURRENT	PROPOSED
Idaho's 1st NSF Engineering Research Center (*or equivalent*)	0	1
FUNDING METRICS	**CURRENT**	**PROPOSED**
External funding per year (*starting after year 1*)	$200k	$1M
INTELLECTUAL PROPERTY	**CURRENT**	**PROPOSED**
NAM-related patents per year (*starting as soon as possible*)	0	3 – 5
SCIENTIFIC METRICS	**CURRENT**	**PROPOSED**
NAM-related publications per year (*starting after year 1*)	1	3 – 5
EDUCATIONAL METRICS	**CURRENT**	**PROPOSED**
Students enrolled in VIP per year	0	10 – 20

Budget Justification

With leading visionaries in the NAM field supported by R1 universities, such as University of Washington, MIT, and Harvard, this budget is designed to accelerate the pace of innovation and infrastructure capacity building needed to position Idaho as a global leader in nucleic acid memory, a field we coined. Thus, this project is expected to hire three postdoctoral fellows for three years with nationally competitive salaries. The project will also hire three PhD students. Working with the PI's team, the fellows and PhD students will execute Tasks 1-5 of the project plan. The project will also hire a program manager to facilitate the establishment of the NAM Institute and to manage the transition to a NSF-funded center. Salaries include an annual 3% increase for inflation. Fringe benefits are calculated via standard rates. To maximize the impact of the budget, the PIs will forgo summer salaries (typically 1 month), allowing over $180k to be invested into the consumable and capital expenses of the project.

A key component to our NAM technology vision is the construction of an advanced super-resolution microscope coupled with automated microfluidics for control of the NAM platforms during reading data with sub-5 nm resolution. $450,000 in capital equipment is budgeted for this microscope, based on quotations for sub-components of the custom system. Construction of this microscope will occur in tandem with the research over the three years of the project. A feedback loop will serve to inform the microscope design and construction based on progress within each Task of the project. To fund materials and supplies for the VIP students, $75,000 is budgeted, which will allow students to test high-risk and high-reward ideas and approaches to NAM. Other direct costs include DNA and consumables ($50,000/year) to fabricate and characterize NAM products. Standard maintenance of state-of-the-art lab facilities and lab user fees ($20,000/year) is included to ensure consistent operation. Fees for three PhD students are $86,931.

Institutional Commitment

The NAM Institute will report to the Vice President of Research & Economic Development. It will physically reside in the Micron School of Materials Science & Engineering, which will provide administrative assistance. Will Hughes & Elton Graugnard will serve as the Director and co-Director. Institutional commitments include: (1) additional space in the future Micron Center for Materials Research, (2) 2 research faculty, and (3) 5 PhD students during the initial two years of the grant. This investment is convenient since the new Micron Center for Materials Research will be coming on board in Fall 2020 — preparing the *NAM Institute* to become an NSF Center.

Additional Institutional and Other Sector Support

Other sector support includes: (1) industrial perspective and project guidance from Micron Principal Engineer Steve Kramer, (2) research and management expertise from the SRC, (3) leveraging/dissemination opportunities by the SRC, (4) connection to the SRC global network to build public-public partnerships, and (5) an advisory board chaired by Micron and the SRC.

Appendix A – Facilities & Equipment

The combined and integrated facilities include ~5,000 square feet of laboratory space within the College of Engineering and the College of Arts & Sciences. The space is equipped to encode, synthesize, characterize, and decode nucleic acid memory (NAM). In addition, the research team has access to the Microfabrication Laboratory, and the Microscopy and Characterization Suite.

A.1 Encoding / Decoding Nucleic Acid Memory

A central component of the proposed research is a biologically inspired algorithm, which must encode and decode information while avoiding creating biologically pertinent sequences and sequences with repeating nucleotides. Computer resources and software include a:

- 16-node GPU/CPU cluster hosted by INL. Each node consists of 32 AMD Opteron 6128 eight-core CPUs, for a total of 256 CPU cores with 2.0 GHz in parallel environment for EtherNet and Infiniband. Five compute nodes have dual T-2050 GPU cards, and three compute nodes with GTX680 GPU cards. Each GPU has 448 cores.
- 32-node CPU/GPU cluster acquired through a NSF MRI grant (Award # 1229709)
- 146-node Beowulf parallel computation cluster

A.2 Synthesizing DNA Scaffolds for Nucleic Acid Memory

To develop a pipeline for rapid design and assembly of scaffolds made for NAM, a 2,000 square foot molecular biology laboratory includes:

- Standard and real-time PCR Machines (BioRad C1000, Roche LC96)
- Centrifuges (Micro and floor models)
- Incubators/shakers for bacterial culture
- Electrophoresis apparatus (PAGE and Agarose)
- A robotic liquid handling workstation (Eppendorf epMotion)
- Freezer space -20°C and -80°C

A.3 Synthesizing Nucleic Acid Memory

Major equipment for synthesizing nucleic acid memory is located in the 1,200 square foot W.M. Keck Laboratory for nanoEngineering. This laboratory has DNA-based nanotechnology research for over a decade and includes:

- A Nuaire biological safety cabinet
- 4 Eppendorf Nexus Gradient thermal cyclers
- A ThermoFisher NanoDrop UV/Vis photometer, Eppendorf compact UV photometer, ProteinSimple quantitative Western Blot imaging system, 2 Varian Eclipse fluorescence spectrophotometers, Cary 5000 absorption spectrometer; and Horiba Fluorolog-3 fluorescence spectrophotometer
- 2 chemical fume hoods
- Eppendorf thermally-controlled high speed centrifuge, Labconco DNA centrifugal vacuum concentrator centrifuge, and multiple microcentrifuges
- Multiple gel electrophoresis units (agarose and polyacrylamide)
- An Eppendorf 5075 programmable automated pipetting system
- An autoclave, digital mixer, pH meter, several gel casters, several optical microscopes, and a fluorescent microscope
- 2 refrigerators, 2 freezers, a New Brunswick Scientific U360 -80°C ultra-low freezer
- A Mettler Toledo analytical balance
- A conductivity meter
- A Whatman electroelution system

A.4 Characterizing Nucleic Acid Memory

Atomic force microscopy will be used to confirm the structural integrity of the nucleic acid memory designs and the site-specific patterning of information strands. Three atomic force microscopes (AFM) housed in Boise State's Surface Science Laboratory are available for imaging. A fourth AFM (purchased through a NSF MRI award, DMR-1727026) will be installed in early April 2018, which will enable high-resolution characterization in controlled environments. The Surface Science Laboratory was designed to accommodate low noise, stable temperature environments essential for optimal imaging conditions, and have staff experienced in imaging DNA nanostructures and training students to do the same. Additional details on the instrumentation and facilities in support of physical characterization are provided below:

- Low noise imaging environment occupying 450 square feet
    - Concrete floor isolated from building
    - Ballasts for lighting located outside of the laboratory
    - Acoustic insulation in the walls
    - Static dissipative flooring
    - Large acoustic door
- Bruker Dimension Icon/FastScan Bio AFM
    - 64-bit Nanoscope V Controller
    - High speed XYZ closed loop scanning
    - 8 simultaneous real-time data channels (5k x 5k resolution)
    - Thermal stage (-35°C to +250°C)
    - PF-QNM, PF-KPFM, PF-TUNA, and SCM modules
    - MFM, nanolithography, and nanomanipulation capabilities
    - 8" wafer, biological, and multisample chucks

- Bruker Multimode 8 AFM with Nanoscope V controller with thermal stage and fluid cell
    - 32-bit Nanoscope V Controller
    - EVLR vertical engage scanner and ScanAsyst-HR probe holder
    - Herzan TS-140 active vibration isolation table
    - 8 simultaneous real-time data channels (5k x 5k resolution)
    - Thermal stage (room temperature to +50°C)
    - PF-QNM, PF-KPFM, PF-TUNA, SCM, and SECPM modules
    - Fluid and EC-AFM cells
- Veeco Dimension 3100 AFM
    - Nanoscope IV controller
    - X-Y-Z closed loop scanner
    - Hysitron TS 75 triboscope nanoindentation system
    - Multiple imaging modules
- Herzan 3-Axis vibration accelerometer system

A.5 Reading / Sequencing Nucleic Acid Memory

At the heart of this proposal is the ability to read the information encoded into nucleic acid memory. To do so, DNA-PAINT exploits the intrinsic transient nature of hybridizing short fluorophore-labeled DNA with complementary strands extending from DNA breadboards via super-resolution fluorescence microscopy. The major equipment to address this task is located in the Advanced Microscopy Laboratory, specifically designed to minimize noise. The 530 square foot state-of-the-art room consists of an acoustically isolated floor, ceiling and wall, as well as a fabric-based HVAC system to diffuse air flow. The laboratory houses the following equipment:

- Nikon Ti-U fluorescent microscope with stage-up for external optical coupling
- Coherent Chameleon 100 fs 4 W Ti:Sapphire mode-lock laser (80 MHz repetition rate)

- Coherent Mira optical parametric oscillators
- Si APD detector; Hamamatsu Photomultiplier tubes
- Solid-state CW lasers for fluorescent microscopy by Coherent, Big Sky Research, and others at 405, 450, 488, 520, 580, 630, and 670 nm
- uper-resolution microscope using TIRF
- 2 Princeton Instruments 512x512 EMCCDs
- PCO 5M sCMOS
- Mad City Labs X-Y-Z piezo stage and X-Y microdrive stage
- 2 Princeton Instruments Acton spectrometers
- Photon-counting avalanche photodiode
- Perkin Elmer photon-counting photomultiplier

A.6 General Computer Systems and Software

The team has multiple workstations in PI laboratories and offices, the postdoctoral researcher's office, senior personnel offices and the dedicated student office space. These computer systems are connected to a 3 TB university-maintained file storage and backup server network. Pertinent computer systems and software available to the research team include:

- Dell PowerEdge server with 4x 12-core Opteron processors, 128 GB DDR3 RAM
- Amber11, CHARMM, and GROMACS molecular simulators
- NAMD, VMD, and LAMMPS for molecular dynamics
- Custom 3D finite difference time-domain simulator
- University site licenses for Mathematica, Matlab, LabVIEW, and SolidWorks, Ansys
- Multiple licenses for OriginPro

Appendix B – Biographical Sketches

Listed below are the biographical sketches for:

- Will Hughes
- Elton Graugnard
- Wan Kuang
- Timothy Andersen
- Eric Hayden
- Stephen J. Kramer

WILLIAM L. HUGHES, PH.D.

PROFESSIONAL PREPARATION

INSTITUTION	LOCATION	MAJOR	DEGREE/YEAR
Virginia Tech	Blacksburg, VA	Materials Science & Engineering	B.S. 2001
Georgia Tech	Atlanta, GA	Materials Science & Engineering	Ph.D. 2006
National Academy of Engineering	Washington, D.C.	Center for the Advancement of Scholarship on Engineering Education Postdoctoral Fellow	Postdoc 2006

APPOINTMENTS

PERIOD	APPOINTMENT	INSTITUTION & LOCATION
2016 – Present	Founding Faculty & Associate Professor, Micron School of Materials Science & Engineering	Boise State University, Boise, ID
2015 – Present	Cofounder & Associate Dean, College of Innovation + Design	Boise State University, Boise, ID
2015 – Present	Head, Vertically Integrated Projects Program	Boise State University, Boise, ID
2017 – Present	Board Member, BLUUM	BLUUM, Boise, ID
2016 – Present	Board Member, Clinical Innovation + Design	Saint Luke's Health Partners, Boise, ID
2013 – Present	Board Member, Center for Bioengineering Innovation	Northern Arizona University, Flagstaff, AZ
2012 – 2016	Associate Professor, Department of Materials Science & Engineering	Boise State University, Boise, ID
2008 – 2012	Assistant Professor, Department of Materials Science & Engineering	Boise State University, Boise, ID
2006 – 2008	Assistant Professor, Materials Science & Engineering	Cal Poly, San Luis Obispo, CA
2005 – 2006	Student & Teacher Enhancement Partnership, National Science Foundation	Georgia Tech, Atlanta, GA

SELECT PRODUCTS

1. V. Zhirnov, R.M. Zadegan, G.S. Sandhu, G.M. Church, W.L. Hughes, "Nucleic Acid Memory," *Nature Materials*, 15, 366 (2016). http://www.nature.com/nmat/journal/v15/n4/full/nmat4594.html
2. R.M. Zadegan, E.G. Lindau, W.P. Klein, W.B. Knowlton, J. Lee, E. Graugnard, B. Yurke, W. Kuang, W.L. Hughes, "Twisting of DNA Origami from Intercalators," *Scientific Reports* 7, 7382 (2017). https://www.nature.com/articles/s41598-017-07796-3
3. C. Green, K. Schutt, N. Morris, W.L. Hughes, W. Kuang, E. Graugnard, "Metrology of DNA Arrays by Super-Resolution Microscopy," *Nanoscale* 9, 10205 (2017). https://doi.org/10.1039/C7NR00928C
4. X. Olson, S. Kotani, B. Yurke, E. Graugnard, W.L. Hughes, "Kinetics of DNA Strand Displacement Systems with Locked Nucleic Acids," *Journal of Physical Chemistry B* 121, 2594 (2017). http://pubs.acs.org/doi/abs/10.1021/acs.jpcb.7b01198
5. X. Olson, S. Kotani, J.E. Padilla, N. Hallstrom, S. Goltry, J. Lee, B. Yurke, W.L. Hughes, E. Graugnard, "Availability: A Metric for Nucleic Acid Strand Displacement Systems," *ACS Synthetic Biology* (2016). http://pubs.acs.org/doi/abs/10.1021/acssynbio.5b00231
6. S. Takabayashi, W.P. Klein, C. Onodera, B. Rapp, J. Flores-Estrada, E. Lindau, L. Snowball, J.T. Sam, J.E. Padilla, J. Lee, W.B. Knowlton, E. Graugnard, B. Yurke, W. Kuang, W.L. Hughes, "High precision and high yield fabrication of dense nanoparticle arrays onto DNA origami at statistically

independent binding sites," *Nanoscale* 6, 13928 (2014). http://pubs.rsc.org/en/content/articlelanding/2014/nr/c4nr03069a

SYNERGISTIC ACTIVITIES

Cofounder of the College of Innovation + Design (CID) at Boise State: CID is about nurturing new ideas – born out of the best faculty, student, and community input to ensure the growth and value of a Boise State education. From new cross-disciplinary majors to new courses designed to build skills employers demand to re-imagining the future of a university, CID is looking to incubate the most innovative and exciting ideas facing Boise State and higher education today.

Expanded the Vertically Integrated Project (VIP) Program at Boise State from Georgia Tech: VIP is an education program that operates in a research and development context. VIP teams earn academic credit for their participation in design/discovery efforts that assist faculty and graduate students with research and development issues in their areas of interest and expertise. VIP teams are: (I) multidisciplinary – drawing students from all disciplines on campus; (II) vertically-integrated – maintaining a healthy mix of freshman through postdoctoral fellows each semester; and (III) long-term – each undergraduate and graduate student may participate in a project for the duration of their studies.

Semiconductor Synthetic Biology (SemiSynBio) Member: The mission of the Semiconductor Synthetic Biology (SemiSynBio) Roadmap is to guide research that can accelerate technology development in the United States. The overall goal of this initiative is to enable the United States to lead in the emerging industry at the confluence of semiconductor technology and synthetic biology.

Function Accelerated nanomaterial Engineering Center Member: A university-based consortium that is supported by the Semiconductor Research Corporation through their Semiconductor Technology Advanced Research network (STARnet).

National Academy of Engineering Post-doctoral Fellow: Created and incorporated service-learning into the Materials Engineering Department at Cal Poly, San Luis Obispo which: (I) decreased the attrition rate from 38.64% to 2.22%, (II) altered self-perception of students' multiple intelligences and learning style preferences, and (III) increased the moral reasoning ability of freshman engineering students.

Current Support

TITLE	SPONSOR	AMOUNT	PERIOD	MONTHS
Low Cost Diagnosis of Disease using Synthetic DNA Reactions	National Institutes of Health/DHHS	$685,790.00	9/30/2011-8/31/2018	5.5 months academic year 3.0 months summer
SNM: Atomically Precise, Defect Free, DNA Masks with Embedded Metrology	National Science Foundation	$1,499,918.00	3/1/2014-2/28/2019	0.36 academic year
EAGER Germination: Aligning Stakeholders and Structures to Enable Risk Taking (ASSERT)	National Science Foundation	$99,992.00	4/1/2016-3/31/2018	0.41 academic year
EAGER: Germination Renewal: Piloting a Center for Transformative Research at Boise State University	National Science Foundation	$299,929.00	9/1/2017-8/31/2019	1.0/1.80 months academic year

Biographical Sketch: Elton D. Graugnard

Assistant Professor, Micron School of Materials Science & Engineering
Boise State University, Boise, ID 83725-2090

Professional Preparation

Centenary College of Louisiana	Shreveport, LA,	Physics	B.S. 1996
Purdue University	West Lafayette, IN	Physics	M.S. 2000
Purdue University	West Lafayette, IN	Physics	Ph.D. 2000
University of Illinois	Urbana-Champaign, IL	Materials Science & Engr.	2000-2002
Georgia Institute of Technology	Atlanta, GA	Materials Science & Engr.	2003-2006

Appointments

2013 – Present:	Assistant Professor	*Boise State University*	*Materials Science & Engr*
2009 – 2013:	Assistant Research Professor	*Boise State University*	*Materials Science & Engr*
2007 – 2009:	Assistant Professor	*Rollins College*	*Physics*
2006 – 2007:	Adjunct Assistant Professor	*Providence College*	*Engr-Physics-Systems*

Publications

1. Brittany L. Cannon, Lance K. Patten, Donald L. Kellis, Paul H. Davis, Jeunghoon Lee, Elton Graugnard, Bernard Yurke, and William B. Knowlton, "Large Davydov Splitting and Strong Fluorescence Suppression: An Investigation of Exciton Delocalization in DNA-Templated Holliday Junction Dye Aggregates," *Journal of Physical Chemistry A* **122**, 2086 (2018).
2. A.U. Mane, S. Letourneau**, D.J. Mandia, J. Liu, J.A. Libera, Y. Lei, Q. Peng, E. Graugnard, J.W. Elam, "Atomic layer deposition of molybdenum disulfide films using MoF6 and H2S," *Journal of Vacuum Science & Technology A* **36** 01A125 (2018).
3. R.M. Zadegan, E.G. Lindau, W.P. Klein, W.B. Knowlton, J. Lee, E. Graugnard, B. Yurke, W. Kuang, W.L. Hughes, "Twisting of DNA Origami from Intercalators," *Scientific Reports* 7, 7382 (2017).
4. P.H. Davis, K. Robles*, K. Livingston*, S. Johns*, V.A. Ravi, E. Graugnard, M.F. Hurley, "Phase separation in boron-doped Ti-6Al-4V for biomedical applications: scanning Kelvin probe force microscopy investigation of micro-galvanic couples and corrosion initiation," *JOM* **69** 1446-1454 (2017).
5. C. Green, K. Schutt, N. Morris, W.L. Hughes, W. Kuang, E. Graugnard, "Metrology of DNA Arrays by Super-Resolution Microscopy," *Nanoscale* **9**, 10205 (2017).
6. B. Cannon, D. Kellis, E. Graugnard, J. Lee, P.H. Davis, B. Yurke, W.B. Knowlton, "Coherent Exciton Delocalization in a Two-State DNA-Templated Dye Aggregate System," *Journal of Physical Chemistry A* **121**, 6905 (2017).
7. X. Olson, S. Kotani, B. Yurke, E. Graugnard, W.L. Hughes, "Kinetics of DNA Strand Displacement Systems with Locked Nucleic Acids," *Journal of Physical Chemistry B* **121**, 2594 (2017).
8. X. Olson, S. Kotani, J.E. Padilla, N. Hallstrom, S. Goltry, J. Lee, B. Yurke, W.L. Hughes, E. Graugnard, "Availability: A Metric for Nucleic Acid Strand Displacement Systems," *ACS Synthetic Biology* **6**, 84 (2017).

9. E. Krueger, J. Shim, A. Fathizadeh, A.N. Chang**, B. Subei**, K.M. Yocham*, P.H. Davis, E. Graugnard, F. Khalili-Araghi, R. Bashir, D. Estrada, D. Fologea, "Modelling and Analysis of Intercalant Effects on Circular DNA Conformation," *ACS Nano* **10** 8910-8917 (2016).
10. S. Goltry, N. Hallstrom, T. Clark, W. Kuang, J. Lee, C. Jorcyk, W.B. Knowlton, B. Yurke, W.L. Hughes, E. Graugnard, "DNA Topology Influences Molecular Machine Lifetime in Human Serum," *Nanoscale* **7**, 10382 (2015).

Synergistic Activities

1. Recipient: NSF CAREER grant for atomic layer deposition of 2D materials, NSF INSPIRE Grant for DNA-Based Quantum Coherence; W.M. Keck Foundation Award and NSF Nano-Biosensing grant for the development of DNA-based reaction networks for disease detection
2. Invented techniques for DNA functionalized noble metal nanoparticle-based colorimetric detection of biomarkers, DNA dye-based colorimetric detection, and DNA optical metrology, (provisionals filed with USPTO, patents pending)

Current Support

TITLE	SPONSOR	AMOUNT	PERIOD	MONTHS
Rapid Colorimetric Detection of Biomarkers via Catalytic Disassembly of Gold Nanoparticle Aggregates	National Science Foundation	$303,413.00	7/1/2017-6/30/2020	0.33 months summer
INSPIRE: Excitonic Quantum Coherence - A Path to Quantum Computing	National Science Foundation	$749,741.00	7/1/2016-6/30/2020	0.25 summer months
MRI: Acquisition of a Controlled Environment Atomic Force Microscope for Nanoelectrical Characterization	National Science Foundation	$624,000.00	9/1/2017-8/31/2019	0 months
Atomic Layer Deposition for Scalable Synthesis of Atomic-Layered Transition Metal Dichalcogenides	National Science Foundation	$500,000.00	8/1/2018-7/31/2023	0.2 months summer
Synthesis and Characterization of Molybdenum Disulfide by Atomic Layer Deposition	UChicago Argonne, LLC/US Department of Energy	$23,997.00	12/5/2017-5/31/2018	0 months
Synthesis and Characterization of Gallium Phosphide by Atomic Layer Deposition	Magic Leap, Inc	$177,743.00	4/10/2017-4/9/2018	1.0 month summer

BIOGRAPHICAL SKETCH: WAN KUANG

Associate Professor, Department of Electrical and Computer Engineering
Boise State University, Boise, ID 83725-2075

a. Professional Preparation

• Chongqing Univ. of Post and Telecom Electrical Engineering	BSEE	1997
• Chongqing Univ. of Post and Telecom Electrical Engineering	MSEE	2000
• University of Southern California Electrical Engineering	Ph.D.	2005

b. Professional Experience

- 2011-Now, Associate Professor, Boise State University
- 2005-2011, Assistant Professor, Boise State University
- 2001-2005, Research Assistant, University of Southern California
- 2000-2001, Teaching Assistant, University of Southern California
- 1997-2000, Research Assistant, Chongqing University of Post and Telecom, China

c. Publications

1) Christopher M. Green,a Kelly Schutt,a Noah Morris,b Reza M. Zadegan,a William L. Hughes,a Wan Kuang and Elton Graugnard, *Metrology of DNA arrays by super-resolution microscopy*, Nanoscale **9**, 10205-10211 (2017)
2) Sadao Takabayashi, William P. Klein, Craig Onodera, Blake Rapp, Elias Lindau, Lejmarc Snowball, Juan Flores-Estrada, Joseph Tyler Sam, Jeunghoon Lee, William B. Knowlton, Elton Graugnard, Bernard Yurke, Wan Kuang, and William L. Hughes, *High Precision, High Yield Fabrication of Nanoparticle Arrays via DNA Origami Nanotube Directed Self-Assembly*, Nanoscale **6**, 13928-13938 (2014).
3) K Zhu, V Saxena, X Wu, W Kuang, *Design considerations for traveling-wave modulator-based CMOS photonic transmitters*, IEEE Transactions on Circuits and Systems II: Express Briefs **62**(4), (2015)
4) R. Schreiber, N. Luong, Z. Fan, A. Kuzyk, P. C. Nickels, T. Zhang, D. Smith, B. Yurke, W. Kuang, A. Govorov, and T. Liedl, *Chiral plasmonic DNA nanostructures with switchable circular dichroism*, Nature Communications **4**, 2948 (2013)
5) W. P. Klein, C. N. Schmidt, B. Rapp, S. Takabayashi, W. B. Knowlton, J. Lee, B. Yurke, W. L. Hughes, E. Graugnard, and W. Kuang, *Multiscaffold DNA origami nanoparticle waveguides*, Nano Letters **13**(8), 3850 (2013)
6) Ngoc Luong, Cheng-Wen Cheng, Min-Hsiung Shih, and Wan Kuang, *Phase matching for surface plasmon enhanced second harmonic generation in a gold grating slab*, Applied Physics Letters **100**, 181107 (2012)
7) Elton Graugnard, Donald L. Kellis, Hieu Bui, Stephanie Barnes, Wan Kuang, Jeunghoon Lee, William L. Hughes, William B. Knowlton, and Bernard Yurke, *DNA-controlled excitonic switches*, Nano Letters **12**(4), 2217 (2012).
8) Alex English, Cheng-Wen Cheng, Lloyd Lowe II, Min-Hsiung Shih, Wan Kuang, *Hydrodydamic Modeling of Surface Plasmon Enhanced Photon Induced Current in a Gold Grating*, Applied Physics Letters **99**, 191113 (2011)

9) B. Yurke and W. Kuang, *Passive linear nanoscale optical and molecular electronics device synthesis from nanoparticles*, Physical Review A **81**, 033814 (2010).
10) W. Kuang, A. English, Z.-C. Chang, M.-H. Shih, W. B. Knowlton, J. Lee, W. L. Hughes, and B. Yurke, *Cavity resonant mode in a metal film perforated with two-dimensional triangular lattice hole arrays*, Optics Communications **283**, 4090-4093 (2010).

d. Synergistic Activities

- Assistant Editor, JOSA B
- Journal and conference reviewer: Photonics Technology Letters, Optics Communications, Optics Letters, IEEE Transactions on Nanotechnology, IEEE Journal of Lightwave Technology, IEEE International Conference on Communication Systems, Inland Northwest Research Alliance symposium
- Boise State University residential college faculty coordinator, Honor college advising board member
- OSA Frontier in Optics conference, session chair
- Professional membership: OSA, APS, SPIE

e. Current Support

TITLE	SPONSOR	AMOUNT	PERIOD	MONTHS
SNM: Atomically Precise, Defect Free, DNA Masks with Embedded Metrology	National Science Foundation	$1,499,918.00	3/1/2014-2/28/2019	0.4 months summer
Time-of-flight Spectroscopic Reflectometer	Idaho Department of Commerce	$260,435.00	4/3/2017-6/30/2018	0.9 months summer

TIM ANDERSEN, PH.D.

PROFESSIONAL PREPARATION

INSTITUTION	LOCATION	MAJOR	DEGREE & YEAR
Brigham Young University	Provo, Utah	Computer Science	B.S., 1992
Brigham Young University	Provo, Utah	Computer Science	M.S., 1995
Brigham Young University	Provo, Utah	Computer Science	Ph.D., 1999

APPOINTMENTS

PERIOD	APPOINTMENT	INSTITUTION & LOCATION
2013–Present	Professor, Department of Computer Science	Boise State University, Boise ID
2013–2017	Department Chair, Department of Computer Science	Boise State University, Boise ID
2007 - 2014	Associate Professor, Department of Computer Science	Boise State University, Boise ID
2001 - 2007	Assistant Professor, Department of Computer Science	Boise State University, Boise ID
1999 - 2001	Chief Scientist	IArchives, Orem, Utah

PRODUCTS

PROJECT-RELATED

1. King, Matthew; Long, Thomas; Andersen, Timothy; and McDougal, Owen M., "Genetic Algorithm Managed Peptide Mutant Screening: Optimizing Peptide Ligands for Targeted Receptor Binding", *J. Chem. Inf. Model.*, 56(12), 2378-2387 (2016). Cover.

2. Phillips, Paul Daniel; Andersen, Timothy; and McDougal, Owen M., "Assessing the Utility and Limitations of High Throughput Virtual Screening", *AIMS Molecular Science*, 3(2), 238-245 (2016).

3. King, Matthew D.; Phillips, Paul; Katz, Michael; Lew, Sarah; Bradburn, Sarah; Turner, Matthew W.; Andersen, Tim; McDougal, Owen M., "Computational Exploration of a Protein Receptor Binding Space with Student Proposed Ligands", *Biochem. Mol. Biol. Educ.*, 44(1), 63-67 (2016).

4. Long, T., O. McDougal, and **T. Andersen.** "GAMPMS: Genetic algorithm managed peptide mutant screening." *Journal of Computational Chemistry*, 05/2015; 36(17). doi:10.1002/jcc.23928

5. Bullock, C., N Cornia, R B Jacob, A Remm, T Peavey, K Weekes, C Mallory, J T Oxford, O M McDougal, **T Andersen** (2013). "DockoMatic 2.0: High Throughput Inverse Virtual Screening and Homology Modeling", J. Chem. Inf. Model. 53, 2161-2170.

OTHER SIGNIFICANT PRODUCTS

1. Budnikova, M., J Habig, D Lobo, N Cornia, M Levin, **T Andersen**, Design of a flexible component gathering algorithm for converting cell-based models to graph representations for use in evolutionary search, BMC Bioinformatics, 15:178, June 10, 2014.

2. **Andersen, T.,** R. Newman and T. Otter, (2009) “Shape Homeostasis in Virtual Embryos”, Artificial Life, Vol. 15, No. 2, Pages 161-183, MIT Press.

3. Hampikian, G., and **T. Andersen**, (2007) “Absent Sequences”, Proceedings of the Pacific Symposium on Biocomputing 12:355-366.

4. **Andersen, T**., R. Newman and T. Otter, (2006) “Development of Virtual Embryos with Emergent Self-Repair”, Proceedings of the AAAI Fall 2006 Symposium on Developmental Systems (Arlington, VA), pp. 16-23.

Synergistic Activities

Dr. Andersen’s lab has developed TAPP—a GUI application for manual and automatic classification and annotation of text documents.

Dr. Andersen’s lab developed ProtCalc—a web based application that allows users to enter multiple protein sequences, calculates several properties of the entered sequences, and displays the sequences in a spreadsheet-like interface that allows users to sort and rank the proteins on any selected criteria (http://trac.boisestate.edu/protcalc/).

Dr. Andersen’s lab has contributed to Gamera—an open-source platform for document recognition research. Specifically, Dr. Andersen’s lab contributed the Tsai moment-preserving thresholding algorithm, gabor filtering, the White Rohrer thresholding algorithms, and several others.

Dr. Andersen’s lab has developed DockOMatic—a GUI application for automating creation, distribution, and management of ligand-receptor docking jobs on a Beowulf cluster.

Current Support

Title	Sponsor	Amount	Period	Months
CS 10K: IDoCode: A Sustainable Model for Computer Science in Idaho High Schools	National Science Foundation	$1,046,143.00	3/1/2014-8/31/2018	0.4/.05/0.5 months summer
Computer Science at Boise State - An Investment in Idaho's Future	Idaho State Board of Education	$2,100,001.00	7/1/2015-6/30/2018	0 months
IUSE/PFE:RED: Software Hatchery; An Ecosystem for Nurturing the Next Generation of Computer Science Professionals	National Science Foundation	$2,000,000.00	7/1/2016-6/30/2021	1.5/1.75 months summer
Stream500: A new Benchmark and Infrastructure for Streaming Analytics	National Science Foundation	$119,544.00	8/1/2016-7/31/2018	0 months

Eric J. Hayden

Department of Biological Sciences, Boise State University, Boise, ID 83725
Phone: (208) 426-4625 email: erichayden@boisestate.edu

Professional Preparation

Linfield College, McMinnville, OR	Chemistry	BS 2002
Portland State University, Portland, OR	Biochemistry	PhD 2008
University of Zurich, Zurich, Switzerland	Evolutionary Biology	2009-2012
Stanford, CA	Bioengineering	2012-2013

Appointments

2013-Present	Assistant Professor, Biological Sciences, Boise State Univ., Boise, ID
2012-2013	Postdoctoral fellow, Bioengineering, Stanford University, Palo Alto CA
2009-2011	Postdoctoral researcher, Evolutionary Biology and Environmental Studies, University of Zurich, Zurich, Switzerland
2003-2008	Graduate assistant, Portland State University, Portland, OR
summer 2006	NSF/CESRI Research Fellow, Ruhr University, Bochum Germany and Collegium Budapest, Budapest, Hungary

Products – related

1. Hayden, E. J., **Ferrada, E. & Wagner, A. Cryptic genetic variation promotes rapid evolutionary adaptation in an RNA enzyme. *Nature* 474, 92–95 (2011).
2. Hayden, E. J. & Wagner, A. Environmental change exposes beneficial epistatic interactions in a catalytic RNA. *Proc. R. Soc. B* 279, 3418–3425 (2012).
3. Hayden, E. J., Weikert, C. & Wagner, A. Directional selection causes decanalization in a group I ribozyme. *PLoS ONE* 7, e45351 (2012).
4. Hayden, E. J., **Bendixsen, D. P., and Wagner, A. (2015) Intramolecular phenotypic capacitance in a modular RNA molecule. *PNAS* 112, 12444–12449.
5. Hayden, E. J., **Bratulic, **S., Konig, I., Ferrada, E. & Wagner, A. The effects of stabilizing and directional selection on phenotypic and genotypic variation in a population of RNA enzymes. *J. Mol. Evol.* 78:101–108 (2014).

Products – other

6. **Vaidya, N. et al. Spontaneous network formation among cooperative RNA replicators. *Nature* 491, 72–77 (2012).
7. Hayden, E. J., von Kiedrowski, G. & Lehman, N. Systems Chemistry on Ribozyme Self-Construction: Evidence for Anabolic Autocatalysis in a Recombination Network. *Angew. Chem.* 120, 8552–8556 (2008).
8. Hayden, E. J. & Lehman, N. Self-Assembly of a Group I Intron from Inactive Oligonucleotide Fragments. Chemistry & Biology 13, 909–918 (2006).
9. *Draper, W. E., Hayden, E. J. & Lehman, N. Mechanisms of covalent self-assembly of the Azoarcus ribozyme from four fragment oligonucleotides. *Nucleic Acids Res.* 36, 520–531 (2008).
10. Hayden, E. J., Empirical analysis of RNA robustness and evolution using high-throughput sequencing of ribozyme reactions. *Methods* 106, 97–104 (2016)

Synergistic Activities

- Organized the Origins of Life node in a physical tree of life exhibit constructed from real logs in the Zurich main train station (*Darwin Year '09*). Provided English explanation to passers by.
- Trained over 100 graduate students in basics of scientific computing through Software Carpentry workshops.
- Disseminated results through the popular magazine Wired, in article by Keim, B. "Cryptic mutations could be evolution's hidden fuel" [online] Available: http://www.wired.com/wiredscience/2011/06/cryptic-variation/
- Participated in Bio-inspired Maker Showcase at Trailhead, Boise Idaho.
- Organized Bioengineering labs for TRIO/Upward Bound STEM Summer Camp at Boise State, 2014. The camp is for first generation college-bound students to engage in STEM activities.

Current Support

TITLE	SPONSOR	AMOUNT	PERIOD	MONTHS
RII Track-4: Investigating Evolutionary Innovations through Metagenomics	National Science Foundation	$130,772.00	9/1/2017-8/31/2019	3.0 months summer
An Empirical Examination of the Evolution of Innovation	National Science Foundation	$500,166.00	8/1/2014-7/31/2018	2.0 months summer
RNA "Sea-Scapes": Fitness Landscapes with a Changing Environment	National Aeronautics & Space Administration	$214,122.00	9/27/2017-9/26/2020	3.0 months summer

STEPHEN J. KRAMER, PH.D.

PROFESSIONAL PREPARATION

INSTITUTION	LOCATION	MAJOR	DEGREE & YEAR
College of Idaho	Caldwell, ID	Chemistry	B.S.
UCLA	Westwood, Los Angeles, CA	Materials science and engineering	M.S. 1994

PROFESSIONAL APPOINTMENTS (partial LIST)

PERIOD	APPOINTMENT	INSTITUTION & LOCATION
1997 – Present	Manager and coordinator of external, university research related to emerging memory technology	Micron Technology Inc., Boise ID
1994 – 1997	Visiting researcher in sol-gel science	Nippon Sheet Glass Co., Itami City, Japan

SELECT PRODUCTS

1. W.I. Kinney, W. Kula, S.J. Kramer, “Cellules de mémoire, structures de dispositif à semi-conducteurs, systèmes de mémoire et procédés de fabrication,” Patent application number: EP2862173 (2015).
2. N. Sinha, S.J. Kramer, G.S. Sandhu, “Apparatus for contamination removal using magnetic particles,” Patent application number: US20140373880 (2014)
3. N. Sinha, S.J. Kramer, G.S. Sandhu, “Method for contamination removal using magnetic particles,” Patent application number: US8845812 (2014).
4. C.M. Wai, H. Ohde, S.J. Kramer, “Compositions comprising supercritical carbon dioxide and metallic compounds,” Patent application number: US8912238 (2014).
5. S.J. Kramer, G.S. Sandhu, “Spin torque transfer memory cell structures and methods,” Patent application number: WO2012036733 (2012).
6. T.M. Taylo, S.J. Kramer, “Process for enhancing solubility and reaction rates in supercritical fluids,” Patent application number: US8329595 (2012).
7. C.M. Wai, H. Ohde, S.J. Kramer, “Formation of insulator oxide films with acid or base catalyzed hydrolysis of alkoxides in supercritical carbon dioxide,” Patent application number: US8241708 (2012)
8. S.J. Kramer, “Apparatus for conditioning chemical-mechanical polishing pads,” Patent application number: US7563157 (2009).
9. S.J. Kramer, S. Meikle “Method and apparatus for uniformly planarizing a microelectronic substrate,” Patent application number: US6652363 (2003).
10. S.J. Kramer, M.J. Joslyn “Method and apparatus for forming and using planarizing pads for mechanical and chemical-mechanical planarization of microelectronic substrates,” Patent application number: US6592443 (2003).

SYNERGISTIC ACTIVITIES

Over fifty patents related to semiconductor technology: Steve Kramer manages and coordinates external, university research related to emerging memory technology. He joined Micron in 1997 as CMP engineer and worked to develop and implement new slurry and pad materials, as well as side projects in advanced deposition using supercritical fluid technology. This foray into deposition brought him to the Advanced Technology group where he now manages university projects funded by Micron relating to emerging memory. Steve maintains an active role within Micron analyzing strategic IP, cooperative research, and novel technology to help steer Micron's technological future. Steve holds over fifty patents related to semiconductor technology and has authored various collaborative research papers.

Appendix C – Letters of Support

Listed below are letters of support from:

- The Semiconductor Research Corporation
- Micron Technology
- The Office of Research & Economic Development at Boise State University
- The College of Engineering at Boise State University
- The Micron School of Materials Science & Engineering

Semiconductor Research Corporation

To: Idaho Global Entrepreneurial Mission Initiative March 31, 2018

Dear Sir/Madam,

We are happy to endorse the project entitled "*Nucleic Acid Memory*" at the Boise State University.

About myself: I am Chief Scientist at the Semiconductor Research Corporation (SRC), the world's leading industrial research consortium which has invested about $2 billion in cutting-edge, university semiconductor research. My responsibility at SRC includes the assessment of emerging solutions for future information and communication technologies. I also have served as the Chair of the International Technology Working Group/Chapter on Emerging Research Devices for the International Technology Roadmap for Semiconductors (ITRS). I hold a Ph.D. in Physics and have published over 100 peer-reviewed papers.

The proposed research is of direct interest for SRC and its member companies, such as Microsoft, Micron, IBM, Intel and others. The focus areas of the proposed research activities, are key to the development of future memory/storage technologies. The current projections for the total stored information suggest that by 2040 the amount of documented data and thus global memory demand at 3×10^{24} bits (lower bound), which will likely exceed the projected silicon supply in 2040. Therefore, new information storage technologies will be needed for zetta-scale big data deployments within two decades. Nucleic Acid Memory, with a volumetric density 1,000,000 times greater than Flash, is an attractive alternative to silicon-based memory.

SRC is currently running an exploratory research program in Semiconductor Synthetic Biology (SemiSynBio) whose primary goal is to explore new solutions for semiconductor and IT industry stemming from biology. The topics of SemiSynBio have also attracted considerable interest in Government Agencies such as NIST, NSF, IARPA, ONR and others. In 2018, SRC and NIST with a support from member companies will publish the 1st edition of the SemiSynBio Roadmap to guide long-term research that can accelerate technology development. The overall goal of the SemiSynBio initiative is to enable the United States to lead in the emerging industry at the confluence of semiconductor technology and synthetic biology.

I first became familiar with Dr. Will Hughes, the PI of this proposal, in 2013, when SRC and Micron initiated a fundamental study on using DNA in future storage technologies, and Dr. Gurtej Sandhu at Micron invited Dr. Hughes to join this effort. Since then we had extended interactions on a number of research topics. I was immediately impressed both by the depth and breadth of his knowledge, his creativity and by his very unique vision for the potential of DNA for future information processing technologies.

Dr. Hughes has made fundamental contributions to this study, in particular, he extended the concept of DNA memory/storage to a more general class of Nucleic Acid Memories (NAM). He also strengthened the study team by engaging Prof. George Church at Harvard in this project. The study resulted in important new understanding of the potential of Nucleic Acid polymers for the future data storage technologies. The findings have been published in Nature Materials in April 2016, spurring further investments into our community and bridging the bio/physics of NAM.

Based on the success of this work, Dr. Hughes received a $200,000 grant from the Semiconductor Research Corporation

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for further research of NAM. He also became a member of the SemiSynBio Roadmap committee, of which I am Chair, and his participation provides important input for strategic R&D planning in NAM and other SemiSynBio topics.

In 2018 the National Science Foundation (NSF) and Semiconductor Research Corporation have formed an industry-government partnership to fund research on the SemiSynBio topics. Also, in March 2018 the Intelligence Advanced Research Projects Activity (IARPA) has announced Molecular Information Storage (MIST) initiative that was developed with programmatic support from the SemiSynBio Roadmap Committee. The objective of this initiative is to develop deployable NAM storage technologies that can eventually scale into the exabyte regime and beyond. This proposal is well aligned with the above initiatives, establishing the necessary foundation to compete on a national scale, and has a potential for strengthening future economic developments in the State of Idaho.

In conclusion, I strongly support the proposal on "*Nucleic Acid Memory*" at Boise State University. This unique endeavor will certainly prove to be beneficial for this distinguished group but most importantly will bring the State of Idaho in a unique position for contributing to the creation of emerging data storage technologies that are locally relevant and globally significant. As someone who understands the technical details, well beyond what is shared in the proposal, I speak with confidence that the intellectual property by Dr. Hughes and his research team are worth pursuing in Idaho. Finally, I wish to note that if they are successful with their application, SRC will assist this initiative by providing research and management expertise towards building the NAM Institute, seeking leverage opportunities and disseminating the results of this work to distinguished academic and industrial groups. In addition, I will serve alongside Dr. Gurtej Sandhu as the co-chair of their external Advisory Board, to help connect the PI and his research team to the SRC global network in support of them building vital public-private partnerships specific to "*Nucleic Acid Memory"*.

Sincerely yours,

Victor Zhirnov

March 30, 2018

Dear IGEM HERC reviewers,

I am writing to endorse and outline specific commitments for the collaboration between Micron Technology, Inc. and Boise State for the Idaho Global Entrepreneurial Mission (IGEM) and the State Board of Education Higher Education Research Council (HERC) proposal entitled "*Nucleic Acid Memory*."

Micron is a long-time supporter of Boise State as evidenced by more than $40 million in gifts to support both program development and infrastructure. Recently, Micron made a $13 million gift to the College of Engineering to catalyze a new Ph.D. program in Materials Science and Engineering; the program was launched in fall 2012. Micron has since invested an additional $25 million into the Materials Science and Engineering program to build a state-of-the-art research building to house the new Micron School of Materials Science & Engineering. These investments are in large part to encourage the type of groundbreaking research that Will Hughes and his team are performing at Boise State, as demonstrated by prestigious and highly-competitive accolades such as their W.M. Keck Foundation award, NIH K25 Career award, NSF Career awards, NSF Scalable NanoManufacturing award, NSF EAGER awards, and Semiconductor Research Corporation (SRC) FAME (Function Accelerated nanoMaterial Engineering) award, as well as their growing list of internationally recognized journals.

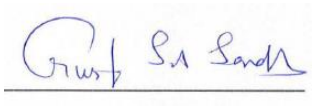
Our current $1.5 million NSF-supported scalable nanomanufacturing grant, that is led by Dr. Hughes (PI) and is in collaboration with Harvard University, is depositing and characterizing DNA masks onto silicon wafers manufactured by Micron. Preliminary results from the project have seeded two additional investments into Dr. Hughes research program from the Micron Foundation ($100k) and the Semiconductor Research Corporation (SRC, $200k). From these investments, Dr. Hughes and his team experimentally validated DNA as a viable memory material for archival storage. Their research is timely because DNA-based massive information storage has been targeted by the SRC Semiconductor Synthetic Biology (SemiSynBio) Consortium – which includes industry leaders such as IBM, Intel, Micron, and Microsoft; academic leaders such as Boise State, Georgia Tech, UCLA, and University of Washington; and federal agencies such as DoD, ONR, NIST, and NSF. With IGEM HERC investment, we fully anticipate that Dr. Hughes and his team will become nationally competitive for outsized research dollars, including but not limited to the joint NSF/SRC SemiSynBio initiative and a future NSF Engineering Research Center.

Micron, Boise State, and the SRC anticipate that as the semiconductor industry confronts technical challenges in scalability, energy consumption, and space, emerging memory technologies such as NAM will gain in appeal over standard solutions. According to our joint publication in Nature Materials, led by Dr. Hughes, NAM has information retention times that range from thousands to millions of years, and a volumetric density 10^3 times greater than and an energy of operation 10^8 times less than NAND flash—a memory industry standard. Therefore, NAM is of sincere interest to Micron and we strongly support Dr. Hughes' proposal to establish a *NAM Institute* at Boise State University.

In support of the *NAM Institute*, Micron will commit to the following assign a Micron principal engineer, Steve Kramer, as a non-paid co-PI for this project, and to have him collaborate with the research team. Kramer comes from the Micron Research & Development group and is the University liaison for emerging technologies at Micron; and (3) I will chair the *NAM Institute* Advisory Board to provide guidance on the alignment of the *NAM Institute* with long-range trends in the semiconductor industry. I will also serve as a conduit to Micron's executive leadership team, which will become increasingly important as Boise State pursues an NSF Engineering Research Center (ERC) on Nucleic Acid Memory.

It should be noted that Micron's investment in Boise State over the last 15+ years has helped address the workforce and technical expertise needs of the region's high-tech economy and has spawned a new generation of research within the Micron School of Materials Science & Engineering. The vision of Micron's leadership over the years has brought us to this exciting, yet critical juncture in which we — all the stakeholders of Boise State — have an opportunity to capitalize on our investment. By establishing the *NAM Institute* through the IGEM-HERC, Boise State, with Micron and the SRC as committed partners, will help guide the commercial microelectronics industry in the future. And by positioning the *NAM Institute* as the centerpiece of the Micron Center for Materials Research, it will have the infrastructure support needed to transition from the IGEM HERC to a federally-funded center. As Senior Fellow and Director of Technology Development at Micron, I will stay engaged for ensuring that the research team has the industry-context and commitment they need to be successful. Please feel free to contact me if you have any questions.

Sincerely,



Gurtej S. Sandhu

Fellow IEEE
Senior Fellow and Senior Director
Technology Development R&D
Micron Technology Inc., MS 1-715
8000 S Federal Way, PO Box 6
Boise ID 83707-0006 USA

BOISE STATE UNIVERSITY
VICE PRESIDENT FOR RESEARCH
AND ECONOMIC DEVELOPMENT

April 2, 2018

Dear Dr. Hughes:

As you know, Boise State is an emerging metropolitan research university of distinction with a history of meeting the needs of local and regional partners. The university has a particularly strong partnership with Micron Technology, which is centered in our School of Materials Science & Engineering. In particular, your research team has worked closely with Micron to help them enhance their research flexibility and maintain their leading edge in the global memory market by exploring emerging trends, including nucleic acid memory (NAM). Micron's commitments to your DNA based research, which include personnel and materials, is significant and reflects the importance of innovation in maintaining a competitive edge in the semiconductor industry. As an institutional priority, your group's partnership with Micron serves as a model of where research and academics combine with workforce development and training to create new avenues for economic development. Thus, the Division of Research and Economic Development strongly supports your proposal to the HERC Idaho Global Entrepreneurial Mission program.

To support and ensure the success of your team's efforts, the Division of Research and Economic Development will provide:

1. Returned F&A costs from externally funded grants related to the NAM Institute for the duration of the award in support of sustainability and to enable the team to seed new research activities in support of nucleic acid memory and *en route* to an NSF Engineering Research Center or national equivalent.
2. Continued financial support for two research faculty positions dedicated to your team.
3. One person-month of support from personnel in the Office of Research Development for research growth.
4. Dedicated support from the Office of Technology Transfer for intellectual property and business development of one to two marketable NAM technologies per year.
5. Support for securing external federal funding through representation in Washington DC.

In addition, our office will leverage other existing Boise State programs, such as the Vertically Integrated Projects program within the College of Innovation and Design and initiatives in STEM, to ensure full university commitment to and participation in your team's success.

Best regards,

Dr. Mark Rudin
Vice President for Research and Economic Development

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Phone (208) 426-5732 Fax (208) 426-2155 MarkRudin@boisestate.edu research.boisestate.edu

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING
Office of the Dean

March 29, 2018

Dear IGEM HERC Representatives,

As the Dean of the College of Engineering, I want to convey my support of Dr. Will Hughes' proposal entitled, "Nucleic Acid Memory." Prior to Boise State, I served as director of the Division of Chemical, Bioengineering, Environmental, and Transport Systems (CBET) in the Directorate for Engineering at the National Science Foundation. While the division director, I witnessed the evolution of DNA nanotechnology from fundamental basic research to targeted efforts to apply the technology to help many of the challenges impacting mankind, from health to next-generation digital data storage systems. Dr. Hughes' research in DNA nanotechnology is a prime example of how high-risk investments can lead to high-reward research outcomes. With support from the National Science Foundation, Micron Technology, and the Semiconductor Research Corporation, Dr. Hughes and team has shown that DNA is a very compelling alternative to electronic memory – a technology he has coined nucleic acid memory (NAM).

In support of this transformative research and the potential for the State of Idaho and Boise State University to become the global leaders in NAM, the College of Engineering will provide the following commitments:

1. Staff to support marketing, accounting and budgeting, information technology, and the human resource needs of the NAM Institute.
2. An agile committee of College of Engineering staff and faculty solely focused on identifying and addressing administrative barriers toward the NAM Institute evolving into an NSF-funded center.
3. As needed additional dedicated laboratory space in the Micron Center for Materials Research (which is slated to open fall 2020) and infrastructure support needed to successfully target NSF Engineering Research Centers, Science and Technology Centers, or Materials Research Science and Engineering Centers

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Phone (208) 426-1153 Fax (208) 426-4466 coen.boisestate.edu

In short, IGEM HERC support will significantly raise the research profile of Boise State University while fostering the long-term industry partnerships needed to be considered for NSF center support. This project has the commitment of the administration and staff within the College of Engineering to ensure the team has the resources needed to successfully harness the potential of their proposed IGEM HERC.

Sincerely,

JoAnn S. Lighty
Dean, College of Engineering
Professor, Mechanical and Biomedical Engineering

1910 University Drive Boise, Idaho 83725-2100
Phone (208) 426-1153 Fax (208) 426-4466 coen.boisestate.edu

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING
Micron School of Materials Science and Engineering

March 22, 2018

Dr. Will Hughes
Micron School of Materials Science and Engineering
Boise State University
1910 University Drive
Boise, ID 83725-2090

Dear Dr. Hughes:

The Micron School of Materials Science and Engineering is pleased to provide support for your proposal to the Higher Education Research Council's Idaho Global Entrepreneurial Mission Initiate Grants program. This is a solid proposal for the formation of a Nucleic Acid Memory Institute within the Micron School of Materials Science and Engineering at Boise State University will build upon the recent growth of our program and will continue our trajectory toward becoming a global leader in the field of nucleic acid memory.

The Micron School of Materials Science and Engineering will provide the following resources to support your team's research:

- Research space in the future Micron Center for Materials Research, currently breaking ground in April 2018 and expected to open in spring of 2020.
- PI and co-PI graduate assistantship funding for doctoral students engaged in the program. In particular, each PI will receive funds to bring on board a doctoral student for the students' first two years, throughout the course of the grant.
- Administrative assistance to support related purchasing, traveling, and hiring.

We look forward to working with you and your team on this project and other innovative research projects.

Sincerely,

Janet Callahan

Dr. Janet Callahan, Chair and Professor
Micron School of Materials Science and Engineering
janetcallahan@boisestate.edu

Appendix D – References

Listed below are the references for the proposal entitled *Nucleic Acid Memory*.

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SUMMARY PROPOSAL BUDGET

Name of Institution: Boise State University

Name of Project Director: Will Hughes

A. PERSONNEL COST (Faculty, Staff, Visiting Professors, Post-Doctoral Associates, Graduate/Undergraduate Students, Other)

Name/ Title	Salary/Rate of Pay	Fringe	Dollar Amount Requested
Post-Doctoral Associates (3); 12 months each/year	$55,000-$60,000	40%-41%	735,551
PhD-Level Graduate Student (3); 12 months each/year	$27,000 each	7% plus health insurance	290,884
Project Manager/Engineer Chad Watson; 4 months/year	$79,804	35%	111,000

% OF TOTAL BUDGET:	57%	SUBTOTAL:	$1,137,435

B. EQUIPMENT: (List each item with a cost in excess of $1000.00.)

Item/Description	Dollar Amount Requested
Laser scanner for imaging and precise quantitation of DNA	
System for amplification and quantification of pristine and degraded DNA	
Quantitation and quality control platform for DNA	
Combined thermal cycler and fluorometer that detects target DNA molecules	
System to dry DNA for transportation and storage	
Non-destructive optical quantification system	
Adjustable UV intensity source to create defects in DNA	
Precision multi-channel pipettes for low error material transfer and mixing	
Dedicated centrifuge to minimize cross-contamination	
SUBTOTAL:	$450,000

C. TRAVEL:

Dates of Travel (from/to)	No. of Persons	Total Days	Transportation	Lodging	Per Diem	Dollar Amount Requested
Details To Be Determined (IGEM, FNANO, NSF, IARPA)						40,000
SUBTOTAL:						$40,000

D. Participant Support Costs:

	Dollar Amount Requested
1. Stipends	
2. Other	
SUBTOTAL:	N/A

E. Other Direct Costs:	Dollar Amount Requested
1. Materials and Supplies: DNA & VIP ($70,000-$80,000/yr) and other laboratory consumables to fabricate and characterize NAM products	225,000
2. PhD Graduate Student Tuition and Fees for 3 students	86,931
3. Maintenance of Laser Lab; AFM Lab; IML Lab: Standard maintenance of state-of-the-art lab facilities is included to ensure consistent operation	60,000
4. Computer Services	
5. Subcontracts	
6. Other (specify nature & breakdown if over $1000)	
SUBTOTAL:	$371,931
F. Total Costs: (Add subtotals, sections A through E) TOTAL:	$1,999,336
G. Amount Requested: TOTAL:	$1,999,336
Project Director's Signature: Not Required	Date:

INSTITUTIONAL AND OTHER SECTOR SUPPORT

A. INSTITUTIONAL / OTHER SECTOR DOLLARS

Source / Description — Amount

Materials Science & Engr. Dept.:

Doctoral graduate assistantships for PIs & Co-PIs: Stipends, fringe, health insurance & tuition over the project period.

College of Engineering:

Dedicated lab space within the new Micron Center for Materials Research.

Support from the college research staff for infrastructure, equipment development, IT needs, and grant writers.

Division of Research & Economic Development:

Returned F&A costs from externally funded grants related to the NAM Institute for the duration of the award in support of sustainability and to enable the team to seed new research activities in support of nucleic acid memory and en route to an NSF Engineering Research Center or national equivalent.

Dedicated support from the Office of Technology Transfer for intellectual property and business development of one to two marketable NAM technologies per year.

Support for securing external federal funding through representation in Washington DC.

B. FACULTY / STAFF POSITIONS Description

Division of Research & Economic Development:

Continued financial support for two research faculty positions dedicated to your team.

One person-month of support from personnel in the Office of Research Development for research growth

Materials Science & Engr. Dept.:

Support for PhD-level Surface Science Lab Manager.

Dedicated office staff for administrative support.