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PI/PD Name: Keith A Nelson

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Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

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☐ Asian
☐ Black or African American
☐ Native Hawaiian or Other Pacific Islander
☒ White

Disability Status:
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Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

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TITLE OF PROPOSED PROJECT **CDI-Type II: Advanced Materials, Modern Optics, Real Experimentation, Virtual Research Group**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **2,247,216**	**48** months	**10/01/09**	

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PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
Spectroscopy Laboratory/Chemistry	**77 Massachusetts Avenue** **Room 6-235** **Cambridge, MA 021394307** **United States**
PI/PD FAX NUMBER **617-253-7030**	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME **Keith A Nelson**	**PhD**	**1981**	**617-253-1423**	**kanelson@mit.edu**
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the Authorized Organizational Representative or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), nondiscrimination, and flood hazard insurance (when applicable) as set forth in the NSF Proposal & Award Policies & Procedures Guide, Part I: the Grant Proposal Guide (GPG) (NSF 08-1). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

Conflict of Interest Certification

In addition, if the applicant institution employs more than fifty persons, by electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.A; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be dislosed to NSF.

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Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

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The following certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

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The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

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Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:

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(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF Grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME		

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER

*SUBMISSION OF SOCIAL SECURITY NUMBERS IS VOLUNTARY AND WILL NOT AFFECT THE ORGANIZATION'S ELIGIBILITY FOR AN AWARD. HOWEVER, THEY ARE AN INTEGRAL PART OF THE INFORMATION SYSTEM AND ASSIST IN PROCESSING THE PROPOSAL. SSN SOLICITED UNDER NSF ACT OF 1950, AS AMENDED.

CDI-Type II: Advanced Materials, Modern Optics,
Real Experimentation, Virtual Research Group

Keith A. Nelson
Department of Chemistry and Harrison Spectroscopy Laboratory, MIT

Primary CDI Theme: Virtual Organizations
Relevant CDI Theme: Understanding Complexity in Natural, Built, and Social Systems

An ambitious project is proposed to make cutting-edge research apparatus and analysis tools directly available to remote users including domestic and foreign universities, four-year colleges, high schools, and industrial partners. An existing outreach program run by the P.I.'s research group in the MIT Department of Chemistry in a dedicated laboratory within the MIT Harrison Spectroscopy Laboratory, presently set up for Boston area high school and four-year college students, will be expanded and made remotely accessible to a "virtual research group" that will enormously broaden and diversify access to the practice of modern optics, spectroscopy, and metrology of advanced materials, with an emphasis on energy-related research, and that will actively engage students in the research and the underlying fundamental science. The initial members of the virtual research group will include students, faculty, and staff members in the Departments of Chemistry and Mechanical Engineering at MIT, in the Department of Chemistry at Wheaton College (a four-year college in Massachusetts), in physics classes in a Boston area public high school (likely Somerville High School), in the Instituto de Física and the Instituto de Química at Universidad Autónoma de México (UNAM), the premier Physics and Chemistry Departments in Mexico, and at Advanced Metrology Systems (AMS), a company that manufactures a photoacoustic metrology instrument based on technology developed in the P.I.'s research group and used in the present outreach project. This far-reaching exercise in computational thinking will enable transformative front-line research in advanced materials with energy-related applications and will demonstrate a paradigm-shifting diversification of access to and participation in such research and in related education of high school through university students in its underlying fundamental principles. The project will demonstrate that remote access to some of the most sophisticated experimental equipment used in modern spectroscopy and metrology of advanced materials, mostly homebuilt one-of-a-kind apparatus rather than just commercial pieces of equipment, is entirely feasible with proper cyberinfrastructure and collaboration.

The main intellectual merit of the project will consist of the interdisciplinary research conducted on complex materials including candidates for thermoelectric applications, in which the transport of thermal energy (a property most often measured and calculated for Engineering applications and studied in Mechanical Engineering, Materials Science and Engineering, and Electrical Engineering Departments) and the microscopic contributions to it through short-wavelength acoustic phonons and through optic phonon-polaritons (whose properties are most often measured and calculated in Physics and Chemistry Departments) will be determined, and in the demonstration and assessment of a new paradigm for remote access to modern scientific experimentation by virtual communities including many who remain strongly underrepresented.

The broader impact of the project is inextricably intertwined with the intellectual merit, both in the value to society of the energy-related measurements to be performed and in the extraordinarily broad representation within the virtual research group that will be established, which we hope will become a new paradigm for low-barrier-to-entry participation in scientific research and education that helps surmount present barriers based on resources, gender, ethnicity, and national origin. The initial group of virtual research group members is intended to demonstrate the feasibility of outside use by individuals in a wide range of institutions. Once this is established, we plan to broaden access to any similar institutions and to individuals who are following their own interests.

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For font size and page formatting specifications, see GPG section II.C.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

Project Description

List of Participants

Principle Investigator: Nelson, Keith A., Professor, Department of Chemistry and Harrison Spectroscopy Laboratory, Massachusetts Institute of Technology

The P.I. has focused throughout his career on the development and use of modern time-resolved spectroscopic methods for new understanding of and optical control over complex material behavior. He has developed novel methods for optical generation, control, and measurement of acoustic waves, lattice vibrations (optic phonons and phonon-polaritons), and collective electronic excitations (excitons, biexcitons, etc.). The P.I. also has devoted his efforts to the introduction of modern experimental methods into the undergraduate curriculum in the MIT Department of Chemistry and into an outreach program for Boston area high school students. The P.I. received the MIT Class of 1960 Award for Innovation in Education for integration of research and teaching.

Other Senior Personnel

Chen, Gang, Warren and Towneley Rohsenow Professor, Department of Mechanical Engineering, Massachusetts Institute of Technology

Professor Chen has conducted extensive research and education in the area of thermal transport and the contributions of acoustic phonons and optic phonon-polaritons to it. Advanced material candidates for thermoelectric applications including solar energy conversion are topics of current interest. Professors Chen and Nelson currently collaborate in energy-related research on thermal transport in thermoelectric materials.

Bailey, Philip H., Senior Project Manager, Center for Educational Computing Initiatives, Massachusetts Institute of Technology

Philip Bailey has extensive experience in implementation, distribution, maintenance, and assessment of software and cyberinfrastructure in the MIT iLab Project which enables remote access to MIT educational materials including electronics apparatus. The iLab Project has served thousands of students inside and outside of MIT. Although the proposed project will involve far more sophisticated instrumentation, the cyberinfrastructure for remote access will be similar to that presently used in the iLab Project.

Muller, Laura J., Chair, Department of Chemistry, Wheaton College

Professor Muller has led curriculum development in her department and has been active in guiding undergraduate research. She conducted research in the P.I.'s laboratory as part of her University of Texas graduate thesis research on the acoustic properties of viscoelastic liquids undergoing liquid-glass transitions.

Moore, Christopher J. L., President and CEO, Advanced Metrology Systems (AMS)

AMS manufactures a photoacoustic instrument based on technology developed in the P.I.'s lab for optical generation and measurement of acoustic waves in bulk and thin film samples. The instrument is used in the microelectronics fabrication industry for rapid noncontact measurement of metal film thickness and uniformity. The same measurement method is used in the MIT outreach lab, which includes donated AMS instrumentation as well as a homebuilt setup.

Romero-Rochin, Victor, Instituto de Física, Universidad Nacional Autónoma de México

Professo Romero is a theoretical chemical physicist who has worked extensively on modeling of time-resolved spectroscopy of molecules and materials. He has collaborated with the P.I. on optical generation and measurement of phonon-polaritons in ferroelectric crystals. He has introduced modern experimental methods into the undergraduate curriculum in his department.

Peon, Jorge, Instituto de Química, Universidad Nacional Autónoma de México (UNAM)

Professor Peon is an experimental physical chemist who directs an ultrafast spectroscopy laboratory at UNAM, the only lab of its kind in Mexico. He has integrated research and teaching, using the research lab instrumentation for experiments in the undergraduate curriculum.

Description

Backgound: Outreach program in experimental modern optics and advanced materials

It's often said that being at MIT is like drinking from a firehose, and in some respects the outreach program, *The Lambda Project*, run out of my physical chemistry group fits that description [1]. It is a fairly intense program involving several afternoons at MIT in which high school students first are walked through the outreach lab and given a rather detailed description of the experimental measurement, its fundamental underpinnings, and the apparatus with which it is conducted; next they come in and conduct experiments, which involves some alignment of laser beams at the sample, looking for optical interference patterns and other key features, and then making measurements in which the crossed "excitation" laser pulses that generate those interference patterns are absorbed at the surface of a metal film on a silicon or glass substrate, giving rise to spatially periodic heating of the film and thereby launching surface acoustic waves whose wavelength and orientation match those of the interference pattern. "Probe" laser light is diffracted by the spatially periodic surface acoustic ripples, and the diffracted signal intensity shows time-dependent oscillations that directly reveal the acoustic frequency, the speed of sound, and the acoustic damping rate [2]. See Figure 1. The diffracted signal also reveals thermal diffusion in the sample as the heat deposited at the grating peaks gradually moves toward the unheated grating nulls. From their data the students can determine the film thickness, on the order of 10-100 nanometers, and other parameters including the thermal diffusion rate in some samples. Usually the students come to MIT once more to present their results, and in most cases they also present their results in their high school classes, in science fairs, or in other venues.

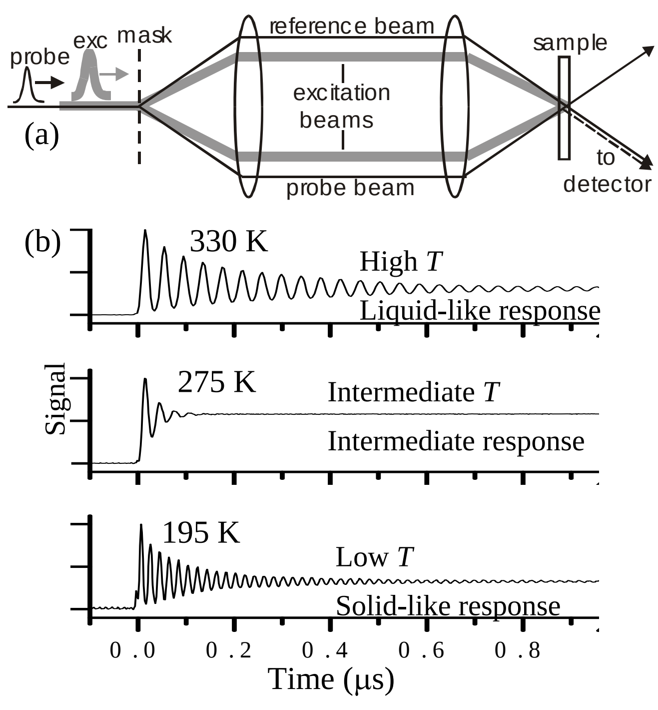

Fig. 1. (a) Transient grating photoacoustic measurement setup. Diffractive optic (phase mask) generates the excitation beams, which are crossed at the sample to heat it and generate a spatially periodic thermoelastic response. The probe and reference beams are used to monitor the time-dependent sample response through diffraction with optical heterodyne detection. Many mask patterns with different periods are etched onto a single glass substrate for rapid acoustic wavelength and frequency tuning. (b) Data recorded from bulk glycerol showing increased acoustic damping in the viscoelastic regime and showing increased acoustic frequency and speed as the sample is cooled from liquid to glass. On slower time scales, the signal decays back to zero through thermal diffusion which returns the sample to a spatially uniform state.

Why do high school students like coming in and figuring out what's going on in a "transient grating" "photoacoustic" measurement for characterization of thin metal films? At their stage, what they can learn well is limited to basic information about length and time scales - micron and nanometer thick films used in microelectronics and other applications, picosecond optical pulse durations, submicron light wavelengths, micron interference pattern fringe spacings, speed of light, speed of sound, and so on. Some students come away with a reasonable understanding of wave mechanics, in particular interference and diffraction which are key elements of the measurement. And there is a useful introduction to “advanced materials,” some fabrication methods, and some applications. Students get the idea qualitatively that sound speeds are higher in stiffer materials, so a relatively soft metal film on a relatively stiff substrate makes the sound travel more slowly than if there were no film at all, and the thicker the film, the slower the speed. But the first-principles quantitative relationship between film thickness and sound speed is complicated (involving analysis of thin film acoustic waveguide modes [3]) and we don’t try to lead them through it.

What excites these students is *real experimentation*. They figure out how the experiment works: the crossed pulses heat up the sample surface very suddenly in a spatially periodic pattern; the heated regions expand, and just like if you suddenly depress a comb into the surface of a liquid, the response is a spatially periodic sound wave; the probe light comes to the sample and is diffracted, just like it would be from any grating except that this grating pattern is time-dependent, with the ripple amplitude oscillating at the acoustic frequency. The students can try the experiment with different interference fringe spacings, yielding different acoustic wavelengths and therefore different acoustic frequencies, revealing the inverse relationship between those quantities just like in the familiar cases of piano and guitar strings. The students love aligning the optics and seeing the interference patterns form when the alignment is good. They enjoy depositing their own thin film samples, using apparatus in the MIT Center for Materials Science and Engineering (CMSE). They get a kick out of bringing in CDs or other “samples” and making measurements on them. They like seeing that our research is done using the same methods they have learned (producing results like those shown in Fig. 1b). The students are mostly from Boston public high schools, without any special background in science, and most of them are good but not extraordinary performers in school. Yet they voluntarily give up a few days of their time to come in and drink from the MIT firehose, and they seem to genuinely enjoy it and get something out of it. And they interact with MIT graduate students who they see as smart but not scary, and some of the students recognize that they could do this sort of thing if they decide they want to.

Why computational thinking for experimental science and outreach?

The experience of running the outreach lab led me to several questions. First, I always was frustrated that so few students, and only those from the local area, could participate in the program. All the experimental apparatus is or could be run by computer, just like the same measurements that are made in my research group. Why couldn’t they be run remotely so anyone, anywhere, could do them? And even the students who come to the outreach lab only conduct a very limited subset of the experiments that are done in my research lab. The students have no experience with lasers and it’s not practical to go through laser safety training which would use most or all of their time at MIT. The “real” research experiments that my graduate students and postdocs run are all under some degree of computer control. Why couldn’t anyone do those experiments remotely? And if they could, what about doing not just pedagogical measurements but real research, open to real researchers including students at various stages in their educations anywhere in the world? Why not industrial applications? The measurement conducted in the outreach lab has been fully commercialized for quality control in microelectronics fabrication. In fact there is a donated commercial instrument in the outreach lab, even though most or all of the project is done on a homebuilt breadboard version of the apparatus which is completely open to view and to hands-on adjustment of everything. But the industrial instrument with the usual bells and whistles costs over $1M, so only major microelectronics manufacturers can buy it. Plenty of small companies care about thin film properties including thickness, elastic modulus, thermal diffusivity, uniformity, delamination…all properties that can be determined through the measurement method [2].

One further question also bothered me. Quite a few years ago, I had the charming experience of having my computer infected by a malicious virus. I wanted to catch the person responsible and string him up, but to my surprise, my brilliant graduate student from Bulgaria had sympathy for whomever it was. He explained that as likely as not it was a very smart, bored-to-death Bulgarian 15-year-old. It may be wishful thinking, but I wonder whether the availability of real state-of-the-art lasers and challenging modern optics and spectroscopy measurements on advanced materials just might draw someone like that somewhere in the world out of ennui and into enthusiasm. In a small way, a project like the one I'm proposing is a remote call for engagement in a common human enterprise. Mine will be only one project, but I believe it should become a paradigm for broad public access to real science and technology. Some people, including a very smart, bored 15-year-old somewhere, will hear an irresistible call.

Expanded range of measurements for teaching, outreach, and research

The apparatus in our existing outreach lab is based on subnanosecond laser pulses that are short enough in duration to generate and monitor MHz-frequency acoustic waves. That is, the pulse duration is shorter than a single acoustic oscillation period, and individual oscillation cycles can be observed in the measurement. But a lot of important material behavior depends on other collective modes of higher frequency, including acoustic waves in the GHz frequency range (with nanometer rather than micron wavelengths) and including THz-frequency lattice vibrations, i.e. optic phonons and their admixtures with electromagnetic waves called optic phonon-polaritons All of these modes are particularly relevant to the movement of thermal energy through materials, since thermal energy is carried by material excitations that can move, and in most materials that means acoustic waves and phonon-polariton waves. This is an extremely important issue currently in the context of candidate materials for energy-related applications, especially thermoelectrics in which solar irradiation can give rise to a thermal gradient that leads to current flow through which solar energy can be captured and stored [4]. For this to work effectively, thermal conductivity has to be low so that the thermal gradient is maintained, even while electrical conductivity is fairly high. There is a great deal of current research aimed at design and fabrication of materials with this combination of properties. Success depends on poor phonon transport, and this can be achieved by introducing disorder which scatters acoustic waves whose wavelengths are comparable to the (nanometer) length scale of the disorder. But measurements of nanometer-wavelength acoustic waves, whose frequencies are in the roughly 50-500 GHz range, have been elusive. We recently developed a method in which timed sequences of femtosecond pulses are used to drive multiple-cycle acoustic waves, with each pulse launching a single cycle of the wave [5]. Figure 2 illustrates the approach. My research group and that of Professor Gang Chen in the MIT Mechanical Engineering Department are studying these materials collaboratively through the MIT Energy Initiative, and we are preparing a family of related samples (partially disordered crystalline solids such as PbTe/PbSe and Si/Ge based superlattices) for measurements of the sort depicted in Fig. 1 (through which thermal diffusivity and MHz-frequency acoustic properties will be determined) and Fig. 2 (through which GHz-frequency acoustic properties will be determind). The objective is direct determination of which acoustic modes contribute most effectively to thermal diffusion. Improved materials then can be fabricated in which disorder is introduced on length scales comparable to the acoustic wavelengths to optimally scatter the acoustic waves, reducing their propagation lengths and thus reducing their contributions to thermal transport. (Note that GHz-frequency acoustic propagation lengths in these materials will be far longer than the submicron propagation lengths in highly disordered silica glass, illustrated in Fig. 2.) Through this program of iterative sample design, fabrication, and measurement, improved thermoelectric materials for solar energy conversion will be produced.

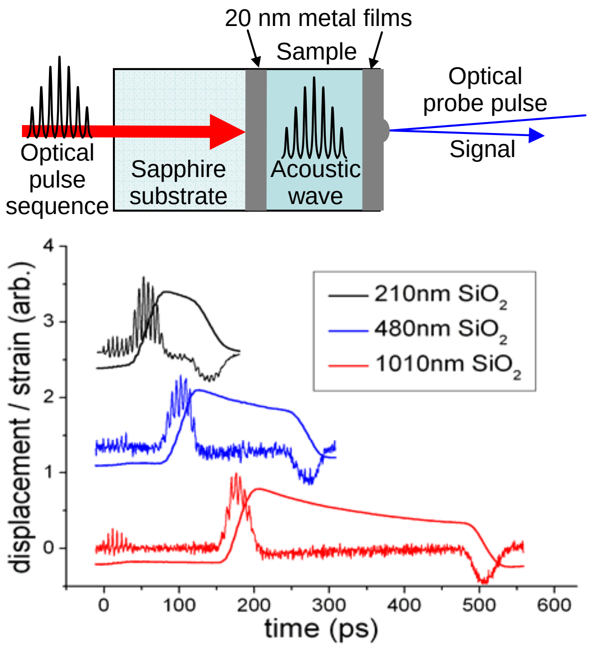

Figure 2. Direct optical measurement of GHz-frequency acoustic phonon transport. (a) Schematic illustration. A timed sequence of optical pulses generates the acoustic waves through repeated heating and thermal expansion of a metal film. The acoustic waves are detected after propagation through the sample and a second metal film. (b) Data showing 165-GHz acoustic waves after propagation through amorphous oxide layers of various thicknesses. As the glass layer thickness increases, so does the acoustic transit time through it and so does the attenuation of the high-frequency acoustic modulation, revealing the acoustic speed and the attenuation rate (i.e. acoustic phonon mean free path) which is due to acoustic wave scattering off of the intrinsic nanometer-scale structural disorder in the glass.

The measurements illustrated in Fig. 2 are conducted with subpicosecond duration laser pulses, far shorter than the subnanosecond duration pulses currently available. The outreach lab and an adjacent research lab were recently renovated, and there is a femtosecond laser system in the research lab on a laser table next to the wall between the two labs. A hole in the wall will permit entry of the femtosecond laser pulse into the outreach lab where a new laser table will house the experimental apparatus for GHz-frequency acoustic measurements. This will make these measurements possible for students coming to the outreach lab, since only a small fraction of the femtosecond laser power is needed. More importantly for present purposes, remote users will be able to conduct measurements on the new system as well as the existing system, greatly broadening the range of possible measurements.

With the femtosecond laser system, it will be possible to measure properties of optic phonons and phonon-polaritons [6] as well as acoustic phonons. Figure 3 illustrates optic phonon-polariton measurements conducted in the same manner as shown in Fig. 1a, using crossed excitation pulses to generate the polariton waves and using probe and reference pulses to measure the time-dependent oscillations. In this case phonon-polariton propagation (at light-like rather than acoustic speeds) has been monitored by moving the probing region away from the excitation region, and also by recording real-space images of the polariton waves (Fig. 3c).

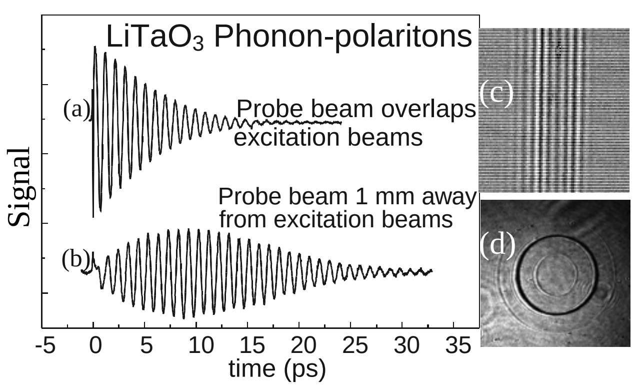

Figure 3. (a,b) Measurements of THz-frequency optic phonon-polariton waves in lithium tantalate crystal. The signal measured at the excitation region decays and at a nearby region grows in due to wave propagation from the excitation region to the nearby region. (c) Real-space image of the phonon-polariton waves recorded 1.3 ps after excitation by crossed pulses. The wavelength is 50 μm. (d) Image of acoustic waves in India ink, recorded 30 ns after excitation by a 150-μm diameter “ring” of light (dark circle).

What we will do and how it will work

The present outreach lab will be outfitted with apparatus for the full range of measurements illustrated in Figs. 1-3, including direct real-space imaging of acoustic waves (Fig. 3d) and phonon-polariton waves (Fig. 3c). The images can be recorded at various times after wave generation and played back to show illustrative "movies" of wave propagation [7].

The measurements will be used for high school and four-year college outreach, for university-level teaching in Science and Engineering departments at MIT and elsewhere, for industrial metrology, and for fundamental and applied research. Knowledgeable partners are already in place for the establishment of a "virtual research group" of remote users. In addition to those listed on the first page of this section, we expect to work with one of the Boston area high schools whose students have participated in our present outreach program. A physics teacher at Somerville High School has been the Laboratory Manager for the outreach program for the past several years, and this school is a likely candidate for initial partnership.

There is extensive precedent at MIT for enabling of remote access to educational materials, including the Open CourseWare (OCW) program [8] and the Center for Educational Computing Initiatives (CEDI) "iLabs" program for remote access to laboratory apparatus [9]. The CECI experience, although based on far simpler experimental apparatus than ours, is directly relevant to our objectives, and the CECI staff will play a central role in establishing the cyberinfrastructure for the project. The MIT iLabs project has developed open source middleware based on web services to support the deployment of online lab experiments. This middleware provides flexible authentication, authorization, storage and scheduling services. It also provides administrative services that separate the responsibility for administering users and their experiments' results from the job of administering a lab server. In broad terms, the iLab Shared Architecture (ISA) divides an online lab into three distinct parts: the lab client, the Service Broker and the lab server. The lab client is the user's interface to the iLab while the lab server connects to the lab hardware and manages the execution of user submitted experiments. The ISA specifies that lab clients and lab servers contain only lab-specific functionality. Unlike more limited internet-accessible lab efforts [10] with ad hoc systems that are closely tailored to particular instrumentation, the ISA infrastructure provides a unifying software framework that can support access to a wide variety of online labs. The proposed project will represent a paradigm shift demonstrating that state-of-the-art, unique experimental apparatus, not just standard instruments, can be accessed and used remotely. Although that will present new technical challenges, most of the supporting cyberinfrastructure developed for iLabs will be applicable directly or with minor modifications. The CECI staff also has extensive experience in assessment of remote user productivity and satisfaction, and this too will be essential for iterative refinement of the online environment.

In addition to a CECI staff member, a Laboratory Manager will be hired to set up and manage the experimental apparatus and the collaborations with outside users. Since samples and various experimental details will be changed for different users, and since a wide range of users with different backgrounds and objectives will be served, it will be essential to have a skilled scientist with a strong interest in teaching, outreach, and research as a full-time participant.

The virtual research group that we will establish will be expanded broadly once successful operation by the initial set of collaborators is under way. The proposed project will demonstrate that advanced research with specialized, homebuilt instrumentation can be made accessible to an extremely broad remote user base, resulting in greatly increased public participation in the scientific enterprise. Just as public access to scientific and technical information has expanded dramatically over the last 10-20 years, public participation in science and technology will expand similarly during the next 10-20 years. We hope to play a leading role in that transformative change.

References Cited

1. "Opening lab doors to high school students: Keys to a successful engagement," R.M. Slayton and K.A. Nelson, *Physics Education* **40**, 347-354 (2005).
2. "Optical generation and characterization of acoustic waves in thin films: Fundamentals and applications," J.A. Rogers, A.A. Maznev, M.J. Banet, and K.A. Nelson, *Annual Review of Material Science* **30**, 117-157 (2000).
3. "Study of Lamb acoustic waveguide modes in unsupported polyimide thin films using real-time impulsive stimulated thermal scattering," J.A. Rogers and K.A. Nelson, *Journal of Applied Physics* **75**, 1534-1556 (1994).
4. "Recent Trends in Thermoelectric Materials Research. Semiconductor and Semimetals," T.M. Tritt, Ed., 69-71, Academic Press, San Diego, 2001.
5. "Generation of ultrahigh-frequency tunable acoustic waves," J.D. Choi, T. Feurer, M. Yamaguchi, B. Paxton, and K.A. Nelson, *Applied Physics Letters* **87**, 081907 (2005).
6. "Terahertz Polaritonics," T. Feurer, N.S. Stoyanov, D.W. Ward, J.C. Vaughan, E.R. Statz, and K.A. Nelson, *Annual Review of Materials Research* **37**, 317-350 (2007).
7. Phonon-polariton movies can be viewed at the following website.
http://scripts.mit.edu/~nelsongroup/www/index.php?option=com_content&task=view&id=20&Itemid=38
Please enjoy them!
8. The MIT Open CourseWare program is described in detail on the website.
http://ocw.mit.edu/OcwWeb/web/home/home/index.htm
9. "The iLab Shared Architecture: A Web Services Infrastructure to Build Communities of Internet Accessible Laboratories", V.J. Harward, J.A. del Alamo, S.R. Lerman, P.H. Bailey, J. Carpenter, K. DeLong, C. Felknor, J. Hardison, B. Harrison, I. Jabbour, P.D. Long, T. Mao, L. Naamani, J. Northridge, M. Schulz, D. Talavera, C. Varadharajan, S. Wang, K. Yehia, R. Zbib, and D. Zych, *Proc. of the IEEE* **96** (6), 931-950 (June 2008).
10. "Hands-on, simulated, and remote laboratories: A comparative literature review," J. Ma and J.V. Nickerson, *ACM Comput. Surv*. **38** (3), 1-24 (September 2006), and references therein.

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Professional Preparation

Stanford University, B.S. Chemistry	April 1976
Stanford University, Ph.D. Chemistry	September 1981
UCLA, Postdoctoral Scholar	October 1981-June 1982

Appointments Held

Professor of Chemistry, MIT	1992-present
Associate Professor of Chemistry, MIT	1987-1992
Assistant Professor of Chemistry, MIT	1982-1987

Five Publications/Patents Related to Present Proposal

1. "Optical generation and characterization of acoustic waves in thin films: Fundamentals and applications," J.A. Rogers, A.A. Maznev, M.J. Banet, and K.A. Nelson, *Annual Review of Material Science* **30**, 117-157 (2000).
2. "Generation of ultrahigh-frequency tunable acoustic waves," J.D. Choi, T. Feurer, M. Yamaguchi, B. Paxton, and K.A. Nelson, *Applied Physics Letters* **87**, 081907 (2005).
3. "Terahertz Polaritonics," T. Feurer, N.S. Stoyanov, D.W. Ward, J.C. Vaughan, E.R. Statz, and K.A. Nelson, *Annual Review of Materials Research* **37**, 317-350 (2007).
4. "Opening lab doors to high school students: Keys to a successful engagement," R.M. Slayton and K.A. Nelson, *Physics Education* **40**, 347-354 (2005).
5. "Measurement of material properties with optically induced phonons," A. Duggal, J.A. Rogers, and K.A. Nelson, *United States Patent* 5,633,711, filed December 5, 1994.

Five Other Significant Publications/Patents

6. "Thermal conductivity of nanoparticle suspensions in insulating media measured with a transient optical grating and a hotwire," A. Schmidt, M. Chiesa, D. Torchinsky, J. Johnson, K.A. Nelson, and G. Chen, *Applied Physics Letters* **92**, 244107 (2008).
7. "Study of Lamb acoustic waveguide modes in unsupported polyimide thin films using real-time impulsive stimulated thermal scattering," J.A. Rogers and K.A. Nelson, *Journal of Applied Physics* **75**, 1534-1556 (1994).
8. "Spatiotemporal coherent control of lattice vibrational waves," T. Feurer, J.C. Vaughan, and K.A. Nelson, *Science* **299**, 374-377 (2003).
9. "High power THz generation, THz nonlinear optics, and THz nonlinear spectroscopy," J. Hebling, K.-L. Yeh, M.C. Hoffmann, and K.A. Nelson, *IEEE Journal of Selected Topics in Quantum Electronics* **14**, 345-353 (2008).
10. "Characterization of materials with optically shaped acoustic waveforms," J.D. Beers, T. Feurer, K.A. Nelson, B. Paxton, and M. Yamaguchi, *United States Patent* 7,387,027, filed July 23, 2004.

Synergistic Activities

1. The P.I. conceived, planned, initiated, and has led for three years a pre-college outreach program that integrates his research with guided experimental work that inexperienced but interested young students undertake. He negotiated laboratory space, arranged for staff and experimental equipment, made contact with educators who bring students into the program, and engaged participation of Philips Advanced Metrology Systems for an industrial lab/career component and for donation of equipment whose commercial value totals over $0.3M. Students spend several afternoons at MIT and are introduced to academic and industrial research and career tracks. A strong effort is made to bring underrepresented minority students into the program. See http://nelson.mit.edu/outreach/outreach.html. A write-up of the program in *Physics Education* is indicated in publication #4 above.
2. The P.I. integrated modern spectroscopy research methods developed in his lab into the MIT undergraduate teaching laboratory. A pulsed laser spectroscopy system including heterodyned transient grating experiments for bulk and thin film study was incorporated as a regular, required component of the course. Many students consider it a high point of their undergraduate laboratory experience. The P.I. was recognized for this effort by the MIT Class of 1960 Innovation in Education Award.

3. The P.I. has developed several methods used widely in the time-resolved spectroscopy community and beyond, some of which have been commercialized through licensing or start-up company development. These include the discovery of impulsive stimulated Brillouin and Raman scattering, the latter a ubiquitous feature of ultrafast measurements of molecules and materials; methods for optical generation and measurement of acoustic wave generation that are tunable throughout nearly all frequencies (MHz-THz) that can be supported in condensed matter; the development of a method for thin film characterization based on optically excited surface acoustic waves, commercialized through a start-up company that was wholly acquired by Philips Analytical (the commercial instrument is used for metal film thickness measurement in the microelectronics fabrication industry); the initial use of femtosecond pulse shaping for ultrafast coherent spectroscopy and coherent control, and ongoing refinements; the design of an apparatus for programmable femtosecond pulse shaping, including both phase and amplitude profiles, that is used by most experimentalists conducting femtosecond coherent control, commercialized by Cambridge Research Instrumentation, Inc. (CRI); the development of terahertz "polaritonics," a platform for THz wave generation, control and guidance, readout and visualization; the development of spatioremporal femtosecond pulse shaping and its uses for THz control and fully phase-coherent nonlinear spectroscopy; the development of single-shot femtosecond spectroscopy, in which entire ultrafast time-dependent responses are recorded in just one laser shot, enabling measurements of irreversible solid-state processes.

Collaborators and Other Affiliations in Past 48 Months

a. Collaborators and co-Editors

Prof. Moungi Bawendi, MIT
Prof. Sandro DeSilvestri, Politecnico di Milano
Prof. Michael D. Fayer, Stanford University
Prof. Christ Glorieux, Catholic Univ. of Leuven
Prof. Yogendra M. Gupta, Washington State U
Prof. John Joannopoulos, MIT
Prof. Henry Kapteyn, U of Colorado at Boulder
Prof. Takayoshi Kobayashi, University of Tokyo
Prof. Tetsuro Kobayashi, Osaka University
Prof. Margaret M. Murnane, U Colo. Boulder
Prof. Tadashi Okada, Toyota Phys. and Chem. Research Institute, Japan
Prof. Richard Osgood, Columbia University
Prof. Hrvoje Petek, University of Pittsburgh
Prof. James F. Scott, Cambridge University
Prof. Mark Sherwin, UCSB
Prof. Mark Stockman, Georgia State University
Prof. Jean Toulouse, Lehigh University
Prof. Kevin Webb, Purdue University

b. Ph.D. Advisor Prof. Michael D. Fayer, Stanford University
Postdoctoral Advisor Prof. John McTague, University of California

c. Thesis Students Mentored and Postdoctoral Scholars Sponsored in Past 5 Years

Postdoctoral Associates (9)

Past:
Dr. Rebecca Slayton, Stanford University
Prof. Dr. Thomas Feurer, University of Berne, Switzerland
Dr. Thomas Hornung, University of Berne, Switzerland
Dr. Emmanuel Peronne, CNRS, France
Prof. Masashi Yamaguchi, Rensselaer Polytechnical Institute
Prof. Kenji Katayama, Chuo University
Dr. Thomas Pezeril, CNRS, France
Prof. Kenan Gundogdu, North Carolina State University

Present:
Dr. Matthias Hoffmann
Dr. Kung-Hsuan Lin

Thesis Students (27)

Past:
Michael Gleason, 2001
Gregory Wakeham, 2001
Rebecca Slayton, 2002
Nikolay Stoyanov, 2003
Jaime Beers Choi, 2005
David Ward, 2005
Peter Poulin, 2005
Joshua Vaughan, 2005
Darius Torchinsky, 2007
Ben Paxton, 2007
Eric Statz, 2008
Cynthia Bolme, 2008

Present:
Taeho Shin
Christoph Klieber
Ka-Lo Yeh
Katherine Stone
Daniel Turner
Gagan Saini
Johanna Wendlandt
Kit Werley
Harold Hwang
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Jeremy Johnson
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Professional Preparation

Huazhong University of Science and Technology, Power Engineering, China	B.S.	1984
Huazhong University of Science and Technology, Power Engineering, China	M.S.	1984
University of California, Berkeley, Mechanical Engineering Ph.D.,		1993
Visiting Postdoctoral Research Engineer, University of California, Berkeley		June 1993

Appointment Held

Professor, Mechanical Engineering Dept, MIT	July 2004-Present
Associate Professor, Mechanical Engineering Dept, MIT	July 2001-June 2004
Associate Professor, Mechanical Aerospace Engineering Dept., UCLA	July 1997-June 2001
Assistant Professor, Dept. Mech. Eng. & Materials Science, Duke Uni.	Sept 1993-June 1997
Research Assistant Professor, Duke University	July 1993-Aug 1993
Graduate Student Research Assistant, Uni. of California, Berkeley	June 1990-May 1993
Graduate Student Research Assistant, Uni. of California, Irvine	Oct 1989-May 1990
Lecturer, Huazhong Uni. of Science and Technology, China	May 1987 – Sept 1989

Five Publications

1. G. Chen, Nano-to-Macro Energy Transport, Oxford University Press, 2005.
2. G. Chen, “Micro/Nano Education in Mechanical Engineering,” Seminar on the Renewal of Mechanical Engineering Higher Education, Bandung, Indonesia, Nov. 8, 2008.
3. A. Schmidt, M. Chiesa, X.Y. Chen, and G. Chen, “An Optical Pump-Probe Technique for Measuring the Thermal Conductivity of Liquids,” Review of Scientific Instruments, Vol. 79, 064902 (1-5), 2008.
4. B. Poudel, Q. Hao, Y. Ma, Y.G. Lan, A. Minnich, B. Yu, X. Yan, D.Z. Wang, A. Muto, D. Vashaee, X.Y. Chen, J. Liu, M. S. Dresselhaus, G. Chen, and Z.F. Ren, “High Thermoelectric Performance of Nanostructured Bismuth Antimony Telluride Bulk Alloys,” Science, Vol. 320, pp. 634-638, May 2, 2008.
5. J. Y. Huang, S. Chen, Z.Q. Wang, K. Kempa, Y. M. Wang, S. H. Jo, G. Chen, M.S. Dresselhaus, and Z. F. Ren, “Superplastic Single-Walled Carbon Nanotubes,” Nature, Vol. 439, p. 281, 2006.

Five Other Significant Publications

6. C. Dames and G. Chen, “1ω, 2ω, and 3ω methods for Measurements of Thermal Properties,” Review of Scientific Instruments, Vol. 76, 124902/1-12, 2005.
7. T. Borca-Tasciuc and G. Chen, “Thin-Film Thermal Conductivity Measurement Techniques,” in Thermal Conductivity: Theory, Properties, and Applications, T.M. Tritt, Ed., Kluwar Press, New York, pp. 205-238, 2004.
8. J. Y. Huang, S. Chen, S. H. Jo, Z. Wang, G. Chen, M.S. Dresselhaus, and Z. F. Ren, “Atomic-Scale Imaging of Wall-by-Wall Breakdown and Concurrent Transport Measurements in Multiwall Carbon Nanotubes,” Physical Review Letters, 236802/1-4, 2005.
9. G. Chen, D. Borca-Tasciuc, R.G. Yang, “Nanoscale Heat Transfer,” Encyclopedia of Nanoscience and Nanotechnology, H.S. Nalwa, Ed., American Scientific Publishers, Vol. 7, pp. 429-459, 2004.
10. G. Chen, M.S. Dresselhaus, J.-P. Fleurial, and T. Caillat, “Recent Developments in Thermoelectric Materials,” International Materials Review, Vol. 48, pp. 45-66, 2003.

Synergistic Activities

(1) Published first textbook on nanoscale heat transfer and energy conversion. Currently working on another book on low-dimensional thermoelectrics
(2) Serve as chairman of the advisory board of ASME Nano Institute
(3)Attracted 25 undergraduate students into real research, including10 minority/underrepresented students

Collaborators in Projects and Papers

T. Caillat (JPL), B. Dunn (UCLA), G. Dresselhaus (MIT), M.S. Dresselhaus (MIT); J.-P. Fleurial (JPL), C. Grigoropoulos (UCBerkeley), R. Gronsky (UC Berkeley), M.S. Goorksy (UCLA), C.-M. Ho (UCLA), J.Y. Huang (Sandia National Lab), C.J. Kim (UCLA), J. Meyer (Naval Research Lab), H. Lyon (Hi-Z), S. Mao (UCBerkeley), S.S. Pei (U of Houston), Z.F. Ren (BostonCollege), T. Sands (Purdue), A. Shakouri (UCSanta Cruz), J. Snyder (Caltech), A. Stacy (UCBerkeley), F. Stoddart (UCLA), A. Tobin (UCLA), K.L. Wang (UCLA); X. Xu (Purdue), X. Zhang (UCBerkeley).

Graduate Students and Post-Docs Supervised

Graduated: V. Berube, D.-Z. A. Chen, C. Dames, D. Borca-Tasciuc, T. Borca-Tasciuc, J. Cybulski, F. Hashemi, W.L. Liu, A. Narayanaswamy, A. Schmidt, D. Song, B. Yang, R.G. Yang, A. Liao, A. Shah, X.Y. Yu, Post-Docs: R. Kumar, D.K. Qing, S. Volz, T. Zeng

Advisors: Ph.D. Thesis: Chang-Lin Tien; M.S. Thesis: Shang-Mo Chen.

Biographical Sketch for Philip H. Bailey

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Professional Preparation

1979-1981	Lowell Institute School at M.I.T.	Certificate of Electronic Technology Advanced Micro-processor Programming
1970-1973	The Film School at The Orson Wells	

Appointments Held

1996-	Senior Project Manager	Center for Educational Computing Initiatives (MIT)
1992-1996	Senior Software Engineer	Center for Educational Computing Initiatives (MIT)
1990-1992	Senior Software Engineer	Bell Atlantic Software Systems
1988-1990	Software Engineer	Mirror Systems
1979-1988	Production Engineer	Honeywell – Honeywell Bull
1975-1978	Head Producer	City of Somerville, MA Municipal/Educational Cable

Publications Relevant to Present Proposal

1. Harward, V.J.; del Alamo, J.A.; Lerman, S.R.; Bailey, P.H.; Carpenter, J.; DeLong, K.; Felknor, C.; Hardison, J.; Harrison, B.; Jabbour, I.; Long, P.D.; Tingting Mao; Naamani, L.; Northridge, J.; Schulz, M.; Talavera, D.; Varadharajan, C.; Shaomin Wang; Yehia, K.; Zbib, R.; Zych, D., "The iLab Shared Architecture: A Web Services Infrastructure to Build Communities of Internet Accessible Laboratories," Proceedings of the IEEE , vol.96, no.6, pp.931-950, June 2008. URL:https://wikis.mit.edu/confluence/download/attachments/9406186/iLab_IEEE_published.pdf?version=1
2. Bailey, Philip H.; White, Ray, "The iLab Project and LabVIEW". NI Week. August 5, 2008. Austin, Tx.
3. Hardison, J., DeLong, K., Bailey, P., Harward, V.J., "Deploying Interactive Remote Labs Using the iLab Shared Architecture," Frontiers in Education (FIE) Conference, Saratoga Springs, New York, October 22-25, 2008. URL:https://wikis.mit.edu/confluence/download/attachments/9406186/FIE2008-paper-final.pdf?version=1
4. del Alamo, J. A., P. Bailey, J. Hardison, V. Judson Harward, S. R. Lerman, and P. D. Long, "MIT iLabs." Sloan-C Inernational Conference on Asynchronous Learning Networks, Orlando, Florida, November 17-19, 2005. URL:https://wikis.mit.edu/confluence/download/attachments/9406186/RC-111+del+Alamo+Sloan-C+2005.pdf?version=1
5. Bailey, Philip H, The iLabs Shared Architecture and the Future of Web-based Laboratory Experiments, Workshop on Internet Accessible Laboratory Experiments in Chemical Engineering Education, University of Cambridge, July 8, 2005.

Other Significant Publications

1. Freed, Geoff, M. Rothberg, T. Wlodkowski, Making Educational Software and Web Sites Accessable: Design Guidelines Including Math and Science Solutions, The CPB/WGBH National Center for Accessible Media (2003)
2. Harward, Judson, M. Meehan, *et al.*, The AthenaMuse® 2.1 Documentation, AthenaMuse Software Consortium, Technical Report, Center for Educational Computing Initiatives, M.I.T. (1995); updated to version 2.2 (1996).

Synergistic Activities

Responsible for the implementation and distribution of the iLab Project software. As part of this initiative I have presented at conferences and workshops in Australia, China, England, Nigeria, Uganda and the United States.

Software architect of TEALsim, a toolkit for the creation of 3D simulations. Partially funded by NSF grant DUE #0618558. TEALsim was originally designed to visualize electro-magnetic simulations, additional modules have been created for Newtonian physics and an interactive viewer for Protein Database (PDB) models. TEALsim has been modified to visualize real-time data generated by an iLab experiment.

Software architect for the Physics Interactive Video Tutor (PIVoT), PIVoT provides a unique 24-hour-a-day opportunity for students to conduct "virtual office hours" with renowned MIT Physics Professor Walter Lewin, using streaming digital video and the Internet. PIVoT also features an on-line textbook, FAQs, physics simulations, and practice problems. Additional features include a search engine and a "Personal Tutor," an intelligent agent that provides individualized help based on each user's clicks through the web site. Worked with the National Center for Accessible Media on NSF grant HRD-9906159, using PIVoT as the base project for the research into guidelines for creating accessible science and math web sites, *see publication above.*

. Project Manager for Networked Multimedia Information Services (NMIS), grant: NRC-9307548 and Dual-Use Education and Funding (DUET), grant NSF #9528439 (1995-1997). The NMIS & DUET projects were designed as a collection of experiments and research studies that explored the new frontier of Internet delivered multimedia.

Collaborators and Other Affiliations in Past 48 Months

Jesus A. del Alamo (MIT), Kayode P. Ayodele(Obafemi Awolowo University, Ile-Ife, Nigeria),Warwick Bailey (University of Cambridge and Icodeon, Ltd), Miri Barak (Haifa University), John Belcher(MIT), Vijay Choudhary (MIT),Clark Colton(MIT) Kimberly deLong (MIT), Yehudit J. Dori **(**Technion), Peter Dourmashkin(MIT), James Hardison (MIT), Kunle Kehinde (Obafemi Awolowo University/Texas Southern University), Phillip D. Long(University of Queensland), Andrew McKinney(MIT), Janet Murray **(**Georgia Tech), Mark Schulz(University of Queensland), Anders Selmer (University of Cambridge), Charuleka Varadharajan (MIT), Ray White(University of Queensland), Rabih Zbib (MIT), D. Zych (MIT)

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Professional Preparation

Bard College, A.B. Mathematics	May 1990
University of Texas at Austin, Ph.D. Chemical Physics	June 1995

Appointments Held

Chair, Department of Chemistry, Wheaton College	2007-present
Associate Professor, Wheaton College	2003 – present
Resident Supervisor, The Jackson Laboratory Summer Student Program	2008 (summer)
Assistant Professor, Wheaton College	1998 - 2003
Visiting Scholar, Massachusetts Institute of Technology	2002 (spring)
Adjunct Assistant Professor, Boston College	1995 - 1998
Visiting Scientist, Massachusetts Institute of Technology	1993 - 1995

Publications/Patents Relevant to Present Proposal

L. J. Muller , "Strategies for Undergraduate Student Faculty-Research Collaboration Learned Through the Involvement of a Student with Diagnosed Learning Disabilities," *Journal of College Science Teaching* **36**, 26 (2006).

D. Harwell, B.Cruickshank, L. Muller, N. Pienta, and K. Robbins, Essential Study Partner for *Chemistry, 7e*, New York: McGraw-Hill, June 2001. (CD-ROM) Principal author for "chapters" on Bonding, Periodic Trends, and Acid-Base Chemistry.Y. Yang, L. J. Muller, and K. A. Nelson, "Relaxational Dynamics and Strength in Supercooled Liquids From Impulsive Stimulated Scattering," in Materials Research Society Symposium Proceedings **407** (1996).

M. Berg, D. VandenBout, and L. J. Muller, "Raman Echo Studies of Attractive and Repulsive Forces in the Coupling of Solvents to Vibrational Motion," in Proceedings of the Workshop on Ultrafast Reaction Dynamics and Solvent Effects, edited by Y. Gaudel, and P. J. Rossky, 1997.

L. J. Muller, D.VandenBout, and M. Berg, "Ultrafast Raman Echo Studies of Composition Fluctuations in a $CH_3I/CDCl_3$ Mixture," *Journal of Chemical Physics* **99**, 810 (1993).

Other Significant Publications

L. A. Deschesnes, J. Barrett, L. J. Muller, J. T. Fourkas and U. Mohanty, "Inhibition of Bubble Coalescence in Aqueous Solutions," *Journal of Physical Chemistry B* **102**, 5115 (1998).

L .A. Deschesnes, P. Zilaro*, L. J. Muller, J. T. Fourkas, and U. Mohanty, "Quantitative Measure of Hydrophobicity; Experiment and Theory'" *Journal of Physical Chemistry B* **101**, 5777 (1997).

M. Berg, L. J. Muller, and D. VandenBout, "Ultrafast Raman Echo Experiments in the Liquid Phase," in Optical Methods for Time and State Resolved Chemistry, SPIE Proceedings, 1628, 282 (1992).

D. VandenBout, L. J. Muller, and M. Berg, "Ultrafast Raman Echoes in Liquid Acetonitrile," *Physical Review Letters* **67**, 3700 (1991).

Synergistic Activities

1. The PI has been involved in major curricular changes in her department. She and a colleague re-envisioned the *Analytical Chemistry* sequence at Wheaton College. She is currently working on a similar re-design of the *Physical Chemistry* sequence. As department chair, she is spear-heading development of a new course sequence, including new and revamped courses, for all Chemistry majors. One major component of this new curriculum is a research requirement for all chemistry majors. In addition, she has been involved with the integration of writing instruction into all chemistry courses. Writing in her courses often focuses on the importance of science to society.

2. The PI has mentored eight undergraduate theses in chemistry. Seven of these students are in graduate school or have received a graduate degree in chemistry (six have earned a Ph.D. or are currently ABD). She has taken all of her research students to give posters or oral presentations at regional and national meetings. Last year, her undergraduate students gave oral presentations on their work at both the

Pittsburgh Conference on Analytical Chemistry and the American Chemical Society Annual Meeting in Boston.

3. The PI has developed a new course, *Art, Color and Chemistry*, for students who do not consider themselves scientists. An interesting component of this course is a laboratory research project for all students. She has spoken on this course (invited and submitted talks) at several conferences. She has also taken activities she developed for this course to workshops for high school teachers and to elementary school students through public schools and through Girl Scouting.

4. The PI has mentored both undergraduate students and advisors unfamiliar to working with undergraduate students while working with The Summer Student Program at The Jackson Laboratory. She worked with the Education Department at TJL to encourage collaboration between summer students outside the laboratory.

5. The PI is involved in several College-wide initiatives stemming from the AAC&U Project LEAP. Her efforts focus on putting an international context into science education. She has collaborated with the chemistry department at the University of Wollongong to advise Wheaton students studying there into appropriate courses, as well as to help them prepare for research opportunities while abroad. This spring, she will visit Ewha Univeristy in Seoul, the Alliance China Program in Shanghai, and the Chinese University of Hong Kong to set up similar programs.

Collaborators and Other Affiliations in Past 48 Months

a. Collaborators and co-Editors

Renate Woudhuysen Keller, Hamilton Kerr Institute, University of Cambridge
Jilleen Nadolny, University of Oslo
Unn Plahter, Kulturhistorisk Museum Oslo
Phoebe Dent Weil, Northern Lights Conservation
Sarah Belchetz-Swensen, Northern Lights Conservation
Diane Jolley, University of Wollongong

b. Ph.D. Advisor Prof. Keith Nelson, Massachusetts Institute of Technology
Prof. Mark Berg, University of South Carolina (now)

c. Thesis Students Mentored and Postdoctoral Scholars Sponsored in Past 5 Years

Undergraduate Thesis Students

Past: Miles Sweet '01 (Ph.D. (Organic Chemistry) University of Oxford (UK))
Shaelah Reidy '03 (Ph.D. (Analytical Chemistry) University of Michigan)
AnGayle Vasiliou '05 (Ph.D. student (Physical Chemistry) University of Colorado)
Sarah Stefan '05 (Ph.D. student (Analytical Chemistry) University of Florida)
Sarah Stollar '07 (MS student (Nursing) Emory University)

Present: Julia Dekermendjian '09
Caitlin Glover '09

Christopher J. L. Moore

Advanced metrology Systems LLC Tel: +1 508 647 8445
12 Michigan Drive Email: chris.moore@advanced metrologysystems.com
Natick, Massachusetts 01760

Professional Preparation

University of Waterloo BSc. Physics	1977
University of Waterloo MSc Physics	1979
University of Waterloo PhD Physics	1983

Positions Held

President and CEO Advanced Metrology Systems	2006 - present
Frontline/Marketing Manager Philips Analytical	2000-2006
Marketing/Technology Manager Waterloo Scientific	1985-2000
Adjunct Professor (Physics) University of Waterloo	1983-1985

Publications/Patents Relevant to Present Proposal

1. Non-Contact Metal Film Metrology Using Impulsive Stimulated Thermal Scattering. M. Gostein, M. Joffe, A.A. Maznev, M. Banet, C.J.L. Moore. Philips Analytical, 12 Michigan Drive, Natick, MA 01760, (508) 647-1100.
2. AEC-APC 2000. Non-contact Optical Measurement of Post-CMP Dishing and Erosion of High-Feature-Density Damascene Structures. M. Joffe, R. Surana, D. Bennett, M. Gostein, S. Mishra, A.A. Maznev, M. Banet, C. J. Moore, R. Lum, R. Bajaj Philips Analytical, 12 Michigan Drive, Natick, MA 01760. Applied Materials, 3111 Coronado Drive, Santa Clara, CA 95054. AEC/APC Symposium XII September 23-28, 2000.
3. "Anisotropic Elastic Properties of Low-k Dielectric Materials", A.A. Maznev, A. Mazurenko, G. Alper, C.J.L. Moore, M. Gostein,M.T. Schulberg, R. Humayun, A. Sengupta, and J.-N. Sun, MRS Symposium Proceedings Vol. 812 (Materials Research Society, 2004), p. F.5.9.1-6.
4. Optical testing techniques for new semiconductor processes and materials. A. reader, C. Moore, R. Brinker, J. Hennessy, Surface and Interface Analysis, Vol 31, Issue 10, pp 1000-1011

Other Significant Publications

1. Spatially resolved composition measurements of ternary epitaxial layers C J L Moore, J Hennessy *Semicond. Sci. Technol.* **7** A69-A72 1992

2. High Resolution Spatially Resolved And Spectrally Resolved Photoluminescence Mapping C.J.L Moore, Pages: 611-614

3. A New Approach to Composition Metrology. G.T. Merklin, J. Hoglund, H.C. Chang. A. Bonanno, CJL Moore, Future Fab International, Issue 24, Jan 2008.

4. Properties of Gallium Arsenide, C.J. Miner, **C.J.L. Moore**: 3rd edn., ed . by M.R. **Brozel**, G.E. Stillman. (INSPEC, London 1996) pp.320–332

5. Correlation Of Epitaxial Layer Measurements With Device Performance : Practicalities
Hennessy, J**.;** Moore, C.J.Integrated Optoelectronics, 1994., Proceedings of IEE/LEOS Summer Topical Meetings: Volume , Issue , 6-13 Jul 1994
Page(s):4_57 - 4_58

<u>Synergistic Activities</u>

Advanced Metrology Systems has donated two systems to universities in the past few years to be sued a test beds for research and student training. In addition we have ongoing research programs with both Sematech and IMEC for collaborative research in cutting edge semiconductor metrology.

We have co-operated with MIT in the past on measurement technology, sample measurements and data analysis.

Although opto-acoustic technology is becoming more important as a technique for on-line material property measurements it is still in its infancy as a technology. We see this proposal as a way to provides wider exposure of the technology and techniques for the next generation of scientists and engineers which will be important to our companies future success.

VICTOR ROMERO-ROCHIN

Instituto de Física.
Universidad Nacional Autonoma de Mexico
C.P. 01000, Mexico, D.F., Mexico

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Email: romero@fisica.unam.mx

Professional Preparation

Universidad Autonoma Metropolitana (Mexico), B.S. Physics	June 1982
Massachusetts Institute of Technology, Ph.D. Physics	August 1988
University of Chicago, Postdoctoral Associate	October 1988 - April 1990

Appointments Held

Investigador Titular "C" (Professor), Instituto de Física, UNAM	2002 - present
Investigador Titular "B" (Associate Professor), Instituto de Física, UNAM	1994 - 2002
Investigador Titular "A" (Assistant Professor), Instituto de Física, UNAM	1990 - 1994

Five Publications/Patents Relevant to Present Proposal

1. R. Martinez-Galicia and V. Romero-Rochin. "Molecular wavepacket interferometry and quantum entanglement," *Journal of Chemical Physics* **122**, 094101 (2005).
2. S. Ramos-Sanchez and V. Romero-Rochin , "Preparation and resolution of molecular states by coherent sequences of phase-locked ultrashort laser pulses," *Journal of Chemical Physics* **121**, 2117 (2004).
3. V. Romero-Rochin, R. Koehl, C.J. Brennan, and K.A. Nelson. "Anharmonic phonon-polariton excitation through impulsive stimulated Raman scattering and detection through wavevector overtone spectroscopy: Theory and comparison to experiments on lithium tantalite," *Journal of Chemical Physics* **111**, 3559 (1999)
4. V. Romero-Rochin and J.A. Cina, "Aspects of impulsive stimulated scattering from molecular systems," *Physical Review A* **50**, 763 (1994).
5. N. Scherer, R. Carlson, A. Matro, M. Du, A. Ruggiero, V. Romero-Rochin, J. Cina, G. Fleming, and S. Rice, "Fluorescence-detected wave packet interferometry: Time resolved molecular spectroscopy with sequences of femtosecond phase-locked pulses," *Journal of Chemical Physics* **95**, 1487 (1991).

Five Other Significant Publications

6. E.A.L. Henn, G.B. Seco, J.A. Seman, K.M.F. Magalhaes, Romero-Rochin, and V.S. Bagnato, "Global thermodynamic variables description for a confined gas undergoing Bose-Einstein condensation," *Nuclear Physics A* **790**, 800 (2007).
7. Victor Romero-Rochin, "Thermodynamics and phase transitions in a fluid confined in a harmonic trap," *Journal of Physical Chemistry B* **109**, 21364 (2005).
8. Victor Romero-Rochin, "Equation of state of an interacting Bose gas confined by a harmonic trap: the role of the "harmonic" pressure," *Physical Review Letters* **94**, 130601 1- 4 (2005).
9. S. Nilsen-Hofseth and V. Romero-Rochin, "Dispersion relation of guided-mode resonances and Bragg peaks in dielectric diffraction gratings," *Physical Review E* **64**, 036614 (2001).
10. R. Duarte-Zamorano and V. Romero-Rochin, "Analysis on the Cina-Harris proposal for the preparation and detection of chiral superposition states," *Journal of Chemical Physics* **114**, 9276 (2001).

Synergistic Activities

1. A serious problem in underdeveloped countries is the fact that physical sciences are taught much more as a theoretical endeavor rather than an experimental one. From the personal point of view of the P.I. this should be corrected. Besides their inherent value to understand Nature, physical sciences must have an impact in the development of the countries. Therefore, physical sciences must be taught in a hands-on experimental way. This should not be confused with the usual lab classes; these are already part of the curriculum, but they tend to be divorced from the usual classroom lectures. As part of this effort, the P.I. has devoted part of his teaching and research time to develop lecture classes that make use of illustrative experiments in the classroom; the enthusiasm and response of the students has shown the validity of this approach. The goal is to develop full semester classes for teaching science in this fashion. The perspective of being part of the project led by Prof. Nelson at MIT, in which students can have access to laboratory facilities at the forefront of science fits perfectly with our own efforts along these lines.

2. The P.I. was involved in a grant proposal that led to the establishment of a laboratory for ultrafast spectroscopy at UNAM. This lab is now a reality and research is currently performed with several graduate students involved. The director of this lab is Prof. Jorge Peon, who is also interested in Prof. Nelson initiative.

<u>Collaborators and Other Affiliations in Past 48 Months</u>

a. Collaborators and co-Editors

Prof. Vanderlei S. Bangato, University of Sao Paulo, Brazil.
Prof. Fernando del Rio, UAM, Mexico
Prof. Rosario Paredes, UNAM, Mexico

b. Ph.D. Advisor Prof. Irwin Oppenheim, MIT
Postdoctoral Advisor Prof. Jeffrey A. Cina, University of Oregon

c. Other Affiliations

Sabbatical Stay, Professor at Universidad Autonoma Metropolitana (Mexico) 2006

d. Thesis Students Mentored and Postdoctoral Scholars Sponsored in Past 5 Years

Postdoctoral Associates (1)
Present: Dr. Luis Olivares

Thesis Students (9)

Past:
Roberto P. Duarte, 2002
Jose G. Segovia, 2002
Sara Nilsen, 2003
Luisi E. Diaz, 2005
Ricardo Martinez, 2005
Ernesto Gonzalez, 2006

Present:
Nadia Sandoval
Luis M. Melendez
Alejandro Bautista

JORGE PEON

Institute of Chemistry
Universidad Nacional Autónoma de México (UNAM)
Distrito Federal, México

Tel: +52 55/56224508
Email: jpeon@unam.mx

Professional Preparation

Universidad Nacional Autónoma de México, B.S. Chemistry	June 1995
The Ohio State University, Ph.D. Chemistry	January 2001
Caltech, Postdoctoral Scholar	Feb0 2001-Oct 2003

Appointments Held

Professor of Chemistry, Universidad Nacional Autónoma de México	2003-present

Five Publications/Patents Relevant to Present Proposal

1.“Ultrafast Intersystem Crossing in 1-Nitronaphthalene. An Experimental and Computational Study”. Jimena S. Zugazagoitia, Cesar Xavier Almora-Diaz, Jorge Peon. *Journal of Physical Chemistry A* 2008, *112*, 358-365.
2. “Excited State Intramolecular Proton Transfer in Schiff Bases. Decay of the Locally Excited Enol State Observed by Femtosecond Resolved Fluorescence.” William Rodriguez-Córdoba, Jimena Saucedo-Zugazagoitia, Elisa Collado-Fregoso and Jorge Peon. *Journal of Physical Chemistry A,* 2007, *111*, 6241-6247.
3.“Singlet excited state dynamics of nitro-polycyclic aromatic hydrocarbons: Direct measurements by femtosecond fluorescence up-conversion.” Rodrigo Morales-Cueto, Mariana Esquivelzeta-Rabell, Jimena Saucedo-Zugazagoitia and Jorge Peon. *Journal of Physical Chemistry A*. 2007, *111*, 552-557.
4. “Femtosecond electron ejection in liquid acetonitrile: Evidence for cavity electrons and solvent anions” C. Xia, J. Peon and B. Kohler. *Journal of Chemical Physics* 2002, *117*, 8855-8866.
5. “Biological water: Femtosecond Dynamics of Macromolecular Hydration” S. K. Pal, J. Peon, B. Bagchi, and A. H. Zewail. *Journal of Physical Chemistry B.* 2002, *106*, 12376-12395.

Five Other Significant Publications

6. “Ultrafast decay and hydration dynamics of DNA bases and mimics. S. K. Pal, J. Peon and A. H. Zewail. *Chemical Physics Letters*, 2002, *363,* 57-63.
7. “Solvent reorganization controls the rate of proton transfer from neat alcohol solvents to singlet diphenylcarbene”. J. Peon, D. Polshakov, and B. Kohler. *Journal of the American Chemical Society*. 2002, *124,* 6428-6438.
8. “DNA/RNA nucleotides and nucleosides: direct measurement of excited-state lifetimes by femtosecond fluorescence up-conversion”. J. Peon and A. H. Zewail. *Chemical Physics Letters*, 2001, *348*, 255-262.
9. “DNA excited-state dynamics: Ultrafast internal conversion and vibrational cooling in a series of nucleosides. J.-M. L. Pecourt, J. Peon and B. Kohler. *Journal of the American Chemical Society,* 2001, *123*, 10370-10378.
10. “Ultrafast internal conversion of electronically excited RNA and DNA nucleosides in water”. J.-M. L. Pecourt, J. Peon and B. Kohler. *Journal of the American Chemical Society*, 2000, *122*, 9348-9349.

Synergistic Activities

1. Recently established the first experimental ultrafast spectroscopy research group in Mexico. Currently the group incorporates six graduate students pursuing Masters and Ph. D. degrees. This lab, although mainly intended for scientific research, also integrates some teaching activities for the Chemical Kinetics course at UNAM. Here, undergraduate students can get involved in simple pump-probe experiments as well as the respective data analysis. Directly tutored several Chemistry undergraduate students in research stays at the Institute of Chemistry-UNAM (total 8 since 2003). Most of these students have continued in graduate programs in the U.S. and in Europe. Developed course material for the Chemistry B. S curricula. at UNAM, which included numeric simulations of the kinetics of complex networks of reactions. Coordinated the first meeting in Optical Spectroscopy in México.

Collaborators and Other Affiliations in Past 48 Months

a. Collaborators and co-Editors

Prof. Hiram Beltran, Univ. Aut. Metropolitana
Prof. Ernesto Rivera, UNAM
Prof. Natalie Solladie, CRNS, France
Prof. Gabriel Cuevas, UNAM

b. Ph.D. Advisor Prof. Bern E. Kohler, The Ohio State University
Postdoctoral Advisor Prof. Ahmed H. Zewail. California Institute of Technology.

c. Thesis Students Mentored and Postdoctoral Scholars Sponsored in Past 5 Years

Thesis Students

Past:
Rodrigo Morales Cueto, 2008
Elisa Collado-Fregoso, 2008
Julio C. Armas-Perez 2007

Present:
Jimena S. Zugazagoitia
William Rodriguez-Cordoba
Eddy Francis Plaza-Medina
Elizabeth Gutierrez-Meza
Pedro Navarro-Perez

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION **Massachusetts Institute of Technology**	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Keith A Nelson**	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Keith A Nelson - P.I.**	0.00	0.00	4.00	$ 62,577	$
2. **Philip H Bailey, Jr. - Sr. Project Manager**	10.80	0.00	0.00	100,163	
3. **Gang Chen - Professor**	0.00	0.00	2.00	34,660	
4. **TBA Senior Lab Manager**	48.00	0.00	0.00	309,096	
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (4) TOTAL SENIOR PERSONNEL (1 - 6)	58.80	0.00	6.00	506,496	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0	
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	10.80	0.00	0.00	73,384	
3. (1) GRADUATE STUDENTS				121,420	
4. (1) UNDERGRADUATE STUDENTS				37,934	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				739,234	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				170,661	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				909,895	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **See itemization in budget justification** $ 168,000					
TOTAL EQUIPMENT				168,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				32,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				142,800	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				8,000	
3. CONSULTANT SERVICES				36,972	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				83,152	
6. OTHER				81,223	
TOTAL OTHER DIRECT COSTS				352,147	
H. TOTAL DIRECT COSTS (A THROUGH G)				1,462,042	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **F&A on MTDC Base (Rate: 68.0000, Base: 1154667)**					
TOTAL INDIRECT COSTS (F&A)				785,174	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				2,247,216	
K. RESIDUAL FUNDS				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 2,247,216	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME **Keith A Nelson**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION **Massachusetts Institute of Technology**	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Keith A Nelson**	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Keith A Nelson - P.I.**	0.00	0.00	4.00	$ **62,577**	$
2. **Philip H Bailey, Jr. - Sr. Project Manager**	10.80	0.00	0.00	**100,163**	
3. **Gang Chen - Professor**	0.00	0.00	2.00	**34,660**	
4. **TBA Senior Lab Manager**	48.00	0.00	0.00	**309,096**	
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**4**) TOTAL SENIOR PERSONNEL (1 - 6)	58.80	0.00	6.00	**506,496**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	**0**	
2. (**1**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	10.80	0.00	0.00	**73,384**	
3. (**1**) GRADUATE STUDENTS				**121,420**	
4. (**1**) UNDERGRADUATE STUDENTS				**37,934**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**739,234**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**170,661**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**909,895**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **$ 168,000**					
TOTAL EQUIPMENT				**168,000**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**32,000**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ **0** 2. TRAVEL **0** 3. SUBSISTENCE **0** 4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**142,800**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**8,000**	
3. CONSULTANT SERVICES				**36,972**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**83,152**	
6. OTHER				**81,223**	
TOTAL OTHER DIRECT COSTS				**352,147**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**1,462,042**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**785,174**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**2,247,216**	
K. RESIDUAL FUNDS				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **2,247,216**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME **Keith A Nelson**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

Budget Justification

Most of the budget will go toward personnel. A personnel-intensive effort will be needed to establish, assess, refine, and maintain the cyberinfrastructure that will support multiple outside users of the experimental apparatus and to work with outside users to coordinate their experimentation. A Senior Project Manager and a second staff member ("other professional" in the budget) from the MIT Center for Educational Computing Initiatives (CECI) will establish and oversee the cyberinfrastructure. We estimate that this will require 35% time and 30% for the Senior Project Manager and the second staff member, respectively, during two of the project years, when new cyberinfrastructure will be established (first for the existing experimental system and then for the femtosecond system), and 10% and 15% time respectively during the other two project years when cyberinfrastructure maintenance, assessment, and refinement will be the primary needs. An MIT undergraduate will be supported to test the cyberinfrastructure that is created. A Senior Laboratory Manager will be hired to work with the CECI staff members and to work collaboratively with outside users. This will be essential since even though the experimental apparatus will be controlled and data will be received remotely, many important details (e.g. what samples are put into place for measurement, whether or not a sample is housed in a cryostat, which measurement geometry is needed, etc.) will need the assistance of someone in the lab. The Lab Manager also will encourage outside use, advise and help educate outside student (and other) users, prepare instructional and pedagogical materials, collaborate in novel research and teaching efforts, and maximize system use and balance among different user groups and different objectives. An MIT graduate student will be supported (including tuition under "other" budget line G6) to work with the Lab Manager and the CECI Project Manager on setting up the femtosecond measurements with appropriate computer control over the apparatus and the data that are generated. Faculty summer salary and student participation at the collaborating 4-year college will be supported to set up online access ("subcontract" budget line G3), and the high school teacher summer salary will be provided ("consultant services" budget line G5).

Additional funds will go toward the experimental apparatus needed to complete the outreach lab for online access. The outreach lab already includes apparatus valued at more than $1/3 million for optical excitation and measurement of MHz-frequency acoustic waves. Immediately adjacent to the outreach lab is a Nelson Group research lab with additional equipment, including an amplified femtosecond laser system, that is valued at least another $1/3 million. A hole in the wall between the two rooms will allow entry of the femtosecond beam into the outreach lab. A new laser table will house apparatus for femtosecond laser excitation of GHz-frequency acoustic phonons, optic phonons, phonon-polaritons, and THz electromagnetic waves. It also will house a femtosecond laser machining setup. Approximately $168K of equipment and $143 K of materials and supplies (mostly optics including reflectors and lenses, polarizers and waveplates, nonlinear crystals, phase masks, and their mounts; electronics; software; maintenance) will be needed during the four-year grant period for initial establishment and ongoing refinements of the new experimental systems. The equipment items are as follows.

Computers(2)	6,000
Cryostat and temperature controller	35,000
Detection electronics: lock-in amplifier, photodetectors, diagnostic scope	20,000
Imaging CCD's (2) for acoustic and polariton waves	50,000
Laser table	15,000
Motorized delay stages (4, one extra long for temporal delay line)	30,000
Video cameras (4) for remote observation of apparatus, interference patterns, etc.	12,000

Funds will be needed for reporting of results in publications and at conferences (estimated 2 participants in 2 domestic conferences per year).

MIT's standard EB and F&A rates will apply and will be detailed in a full proposal.