THE SPECTROGRAPH

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George R. Harrison Spectroscopy Laboratory

Massachusetts Institute of Technology

IAP Events Highlight Spectroscopy

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* "Multidimensional Spectroscopy: Four Why's", a morning seminar, will explain the basis of multidimensional spectroscopy from its origins in NMR to recent developments in the infrared and visible spectral ranges. The presenters will be John Waugh, Robert Griffin, Joseph Loparo, and Keith Nelson.

* A course on "Optical Imaging, Scattering, and Interference for Biological Investigations", offered by Gabriel Popescu, will present the physical basis of microscopy, light scattering and interference for biomedical investigations.

* "Breakdown of the Born-Oppenheimer Approximation in Diatomic Molecules", a series of four lectures by Robert Field, will discuss various aspects of photofragmentation dynamics in diatomic molecules.

Details about these offerings will be found on pages 5, 6, and 7 and on the web at: http://web.mit.edu/spectroscopy/events/iap.html.

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Also in this issue

Awards

Nocera and Nelson Receive Awards

Two Spectroscopy Laboratory researchers, Professors Daniel Nocera and Keith Nelson, have been recognized for their research and educational accomplishments. Professor Nelson received the Class of 1960 Innovation in Education in June. Professor Nocera will receive the Igalgas Prize for Research and Technological Innovation in March.

Keith Nelson

photo by BACHRACH

Daniel Nocera

Nelson, a Chemistry professor at MIT, was cited for his dedication to excellence in teaching, his innovative education efforts toward integration of research and education, and his outreach to high school students and other non-MIT undergraduates. The award recognizes his development of the Lambda Project, which offers students and educators at both high school and undergraduate levels the opportunity to learn about and apply cutting-edge optical measurement techniques to characterization of advanced materials. Participants are additionally encouraged to interact with working scientists in both industrial and laboratory settings to learn more about scientific careers and forge new relationships.

The MIT Class of 1960 Endowment for Innovation in Education was established in 1985 in honor of their 25th reunion. The annual income from the endowment is awarded by MIT's Provost, without restriction as to school or department, to faculty members involved in developing innovative instructional programs at either the undergraduate or graduate level. Faculty recipients are known as Class of 1960 Fellows, and receive grants for periods of one to three years. Dr. Nelson's award is for the three year period 2004 - 2006.

Nocera, also an MIT Chemistry Professor, will be recognized for his accomplishments in molecular chemistry for the production of renewable energy, which have contributed to results in the development of the first photocatalytic cycle for the production of hydrogen.

The Italgas Prize was instituted in 1987 by the Premio Italgas company to mark the 150th anniversary of the Company's founding, with the aim of promoting and creating added value in social and civilian development fields. The award will be presented in Italy in March.

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Commentary

Security, Scientific Inquiry and Spectroscopy - Finding the Right Balance

by Michael S. Feld

During the past three years the issue of national security has shaped the American government policy in dramatic ways, both at home and abroad. This has had major implications to virtually every aspect of our society, science and technology being no exception. An apparent conflict appears to have developed between enhancing the nation's security and advancing the scientific enterprise, which has for so many years been a central part of our culture and, at the same time, the driving force of the American economy. Our nation has always been a melting pot which attracts the best scientific minds from nations around the world. U.S. research universities have played a central role in this, attracting top notch graduate students and postdocs, as well as highly talented senior level researchers.

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The Spectroscopy Laboratory houses two laser research resource facilities. The MIT Laser Research Facility, supported by the National Science Foundation, provides shared facilities for core researchers to carry out basic laser research in the physical sciences. The MIT Laser Biomedical Research Center, a National Institutes of Health Biomedical Research Technology Center, is a resource center for laser biomedical studies. The LBRC supports core and collaborative research in technological research and development. In addition, it provides advanced laser instrumentation, along with technical and scientific support, free of charge to university, industrial, and medical researchers for publishable research projects. Call or write for further information or to receive our mailings.

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http://web.mit.edu/spectroscopy/www/

At MIT, for example, about two-thirds of the postdocs over the period 1990-2000 have been foreign, from a very wide range of countries. In the Spectroscopy Laboratory during this period we have had students and postdocs from China, Taiwan, India, Japan, Korea, Singapore, Russia, Germany, Mexico, Brazil, Greece, Argentina, Romania and Yugoslavia. These young scientists have had an enormous positive impact on our research accomplishments. Further, the benefits of having a truly international research milieu– scientific diversity- are immeasurable. Some of these researchers elect to stay in the US for further study and research. Some become permanent residents and US citizens. Others return to their home countries. Lasting bonds of mutual respect and friendship are established. This highlights the finest features of our country- in essence we create a core of scientific ambassadors who carry away their positive experiences and spread good will, thus strengthening our country and making it more secure.

Now this precious resource is being endangered. Heightened security measures, intended to prevent illegal transfer of sensitive technology, have slowed down significantly the visa issuing process at foreign embassies throughout the world. As a result, the number of visas issued to international students and highly trained workers has decreased by 25% since 2001 [1]. Scientific and educational institutions are experiencing a shortage of students and research staff, as the internal sources of such personnel are known to be insufficient.

Case Study

The Spectroscopy Laboratory has its own story to tell along these lines. In June 2003, one of our postdoctoral researchers, with a Ph.D. form the University of Central Florida, went to visit his family in his home country, Romania, and also to get an H1 visa stamp at the U.S. embassy in Bucharest. What seemed to be a mere visa formality turned into a nightmare. The U.S. embassy officer interviewer determined that there was a need for a special verification in Washington before the visa could be issued. And that was that. The researcher was told that he should go home and wait for a phone call from the embassy, which would be made when the verification process was completed. The phone call came in April 2004, ten months later!

During those ten long months, MIT and the Spectroscopy Laboratory tried in various ways to intervene to expedite the visa issuing process. With the help of MIT's International Scholars Office and their legal council, and our office of Government and Community Relations, we rallied in our colleague's behalf and tried to break what appeared to be a bureaucratic logjam. Letters of support were sent to the embassy. We enlisted the help of Michael E. Capuano, our local congressman, who wrote a wonderful letter of support to the State Department, but to no avail. Many months passed before our colleague was allowed to return to the U.S.

This could have been disastrous to our colleague's career. We did our best to keep him in the loop. We sent him the data he had taken prior to leaving for Romania, and set up a program in which he conducted extensive data analysis. And we held weekly PowerPoint telephone meetings, in which he would report on his progress and we would provide feedback. His absence also impacted adversely on our research activities, primarily sponsored by NIH. The research projects in which he was participating nearly came to a halt.

We fully support measures to safeguard our nation's security. But we must find a balance that does not impair the U.S. scientific enterprise. "Secure borders, open doors" [2] should become reality, as science is by nature an international endeavor. The international feature of U.S. research must not be damaged, lest we kill the goose that lays the golden eggs.

References

1. T. Price, "U.S. science still leads but others are gaining ground", OPN, 18, July 2004.

2. C. L. Powell, "Secure borders, open doors", The Wall Street Journal, April 21, 2004. ⊕

Research Report

Investigation of Cellular Structure and Dynamics Using Fourier Phase Microscopy

Gabriel Popescu, Kamran Badizadegan, Lauren Deflores, Ramachandra R. Dasari, and Michael S. Feld, Departments of Physics and Chemistry and Spectroscopy Laboratory, MIT

1. Introduction

Optical microscopy has been the most commonly used method of investigation in medicine and biology, and various related technologies have been developed over the past years [1]. Numerous biological samples, including live cells, are quite transparent under visible light illumination and behave essentially as phase objects. Techniques such as phase contrast [2] and Nomarski microscopy [3] provide contrast of nearly invisible samples by transforming the phase information into the intensity distribution and thus reveal structural details of biological systems. However, the information obtained with these techniques about the phase shift associated with the illuminating field is only qualitative. Retrieving quantitative phase information from transparent objects with high accuracy and low noise allows for novel applications in the biological investigation of structure and dynamics [4]. Both interferometric [5] and non-interferometric [6] techniques have been proposed for quantitative phase imaging of biological samples. Fourier phase microscopy (FPM) has been recently developed in our laboratory as an extremely low-noise phase imaging method [7]. Due to the sub-nanometer phase stability over extended periods of time, FPM is suitable for investigating biological structures, as well as their dynamics on time scales from seconds to a cell lifetime.

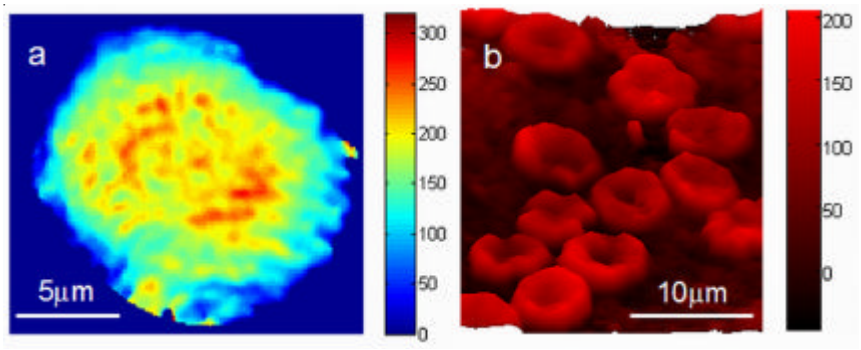

Figure 1. *FPM images obtained using a 40x microscope objective. a) Phase image of a HeLa cell undergoing mitosis; b) phase image of whole blood smear. The color bars represent optical path length in nm.*

2. Fourier Phase Microscopy (FPM)

The principle of FPM relies on the spatial decomposition of an arbitrary complex field V into its average and a spatially varying field, which can be controllably shifted in phase with respect to each other. The description of an arbitrary image as a (complicated) interference pattern has been recognized more than a century ago by Abbe, in the context of microscopy: "*The microscope image is the interference effect of a diffraction phenomenon*" [2]. The FPM method is described in more detail elsewhere [7]. An aerial image formed by a typical microscope at its output port is Fourier transformed onto the surface of a programmable phase modulator (PPM). The PPM is used to controllably shift the phase of the unscattered (zero spatial frequency) field with respect to the scattered (high-frequency component) in increments of $\pi/2$, as in typical phase shifting methods [8]. Upon recording 4 corresponding interferograms, the phase shifts associated with the sample can be evaluated quantitatively in each point of the field of view. Due to this specific geometry, the measurement is characterized by high stability, as will be shown. The technique has been successfully applied to measure the phase information of standard samples, such as plastic beads and phase gratings. In the following, the results in terms of quantifying both the structure and dynamics of living cells are presented.

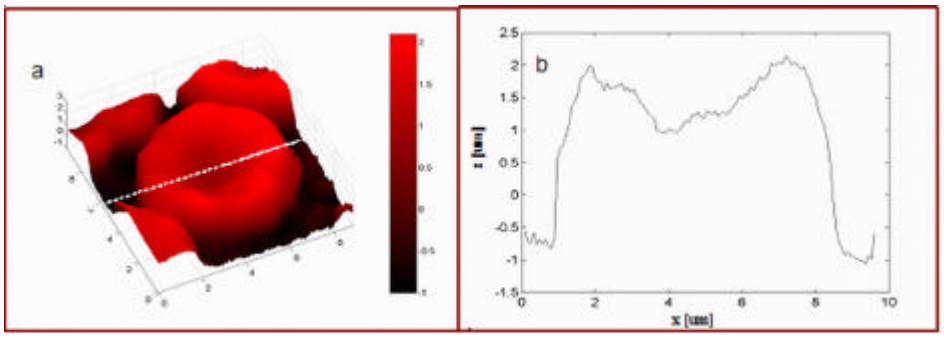

Figure 2. *a) FPM image of a red blood cell (the color bar represents thickness in microns). b) Thickness profile along the dotted line indicated in a.*

3. FPM cell structure investigation

FPM was applied to image live cells. HeLa cells (an epithelial cell line derived from a cervical neoplasm) were continuously monitored over periods of up to 12 hours at repetition rates of 4 frames/minute.

Figure 1a shows the color-coded quantitative phase image of a cell during the metaphase of mitosis, revealing the structure of separating chromatids. The cells were imaged in typical culture conditions (i.e. immersed in culture medium) and no preparation was performed prior to the measurement. Therefore, quantitative phase images could be reconstructed over extended observation periods,

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Investigation continued from page 3

allowing quantitative analysis of cellular dynamics such as shape change or growth. We note that the quantitative phase information is also suitable for automatic cell motility analysis. Figure 1b shows the pseudo-color quantitative phase image of a whole blood smear. The sample was prepared by sandwiching a small drop of fresh blood between two cover slips. The well-known discoid shape of red blood cells is recovered.

Analysis that takes into account the refractive index of hemoglobin with respect to plasma can easily provide 3D information about single red blood cells, as shown in Fig. 2. Similar information about red blood cells can be obtained by scanning electron and atomic force microscopy [9]. However, both of these techniques require extensive sample preparation and lengthy data acquisition, which prevents them from being used as live cell diagnostic tools. The FPM technique, on the other hand, works without cell preparation on live blood cells; therefore it may provide a high-throughput procedure for screening various abnormalities in red cells and other blood constituents.

4. FPM investigation of cell motility

Figure 3a shows the FPM image of a confluent monolayer of HeLa cells. The cells were imaged in typical culture conditions, without additional preparation.

Figure 3b shows the temporal optical path length fluctuations associated with an area in the field where there are no cells. The standard deviation of these fluctuations has a value of 0.15nm, which is equivalent to λ/5,500. This result demonstrates the remarkable path length sensitivity of the FPM and its potential for investigating long term time-varying processes, such as cellular transport.

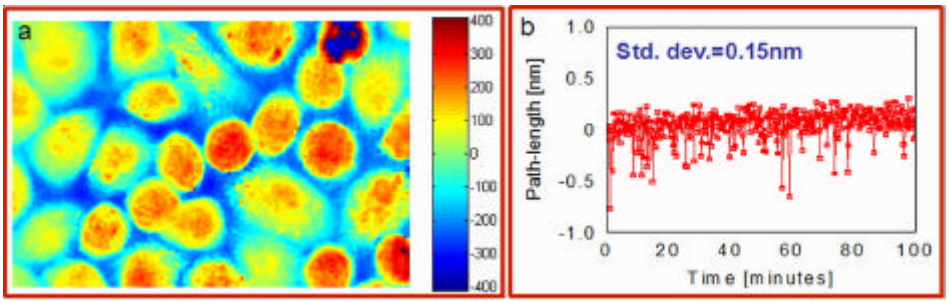

Figure 3. *a) FPM image of a confluent monolayer of cells (color bar represents path-length in nanometers). b) Optical path length temporal fluctuations in the absence of cells.*

The motility of both mitotic and non-mitotic cells has been investigated by statistically analyzing their center of mass displacements. It should be noted that, given the linear relationship between the phase shift through the cell and its non-aqueous content, the FPM data offers information about the actual center of mass of the cell. The information provided by phase-contrast or Nomarski/ DIC microscopes is qualitative in terms of the mass distribution of cell, thus the intensity-weighted centroid of a given cell does not necessarily overlap with its true center of mass. Thus, FPM should a low for a more accurate measurement of cellular motility.

The center of mass displacements have been used to calculate the mean squared displacements $\left\langle \Delta r(t)^2 \right\rangle$ associated with the two types of cells. A total of 15,000 cell steps has been recorded and the results in terms of mean squared displacements are summarized in Fig. 4. Remarkably, at long times, the mean squared displacement approaches a power law dependence. This behavior is more apparent for the non-mitotic cells, which appear to be characterized by a power law function with an exponent of 1.25. This result is a clear indication of the superdiffusive motion of the live cells. In addition, the mean squared displacement of the mitotic cells at long times is approximately a factor of 2 higher than that of the non-mitotic cells, which demonstrates the weaker interaction with the substrate during mitosis.

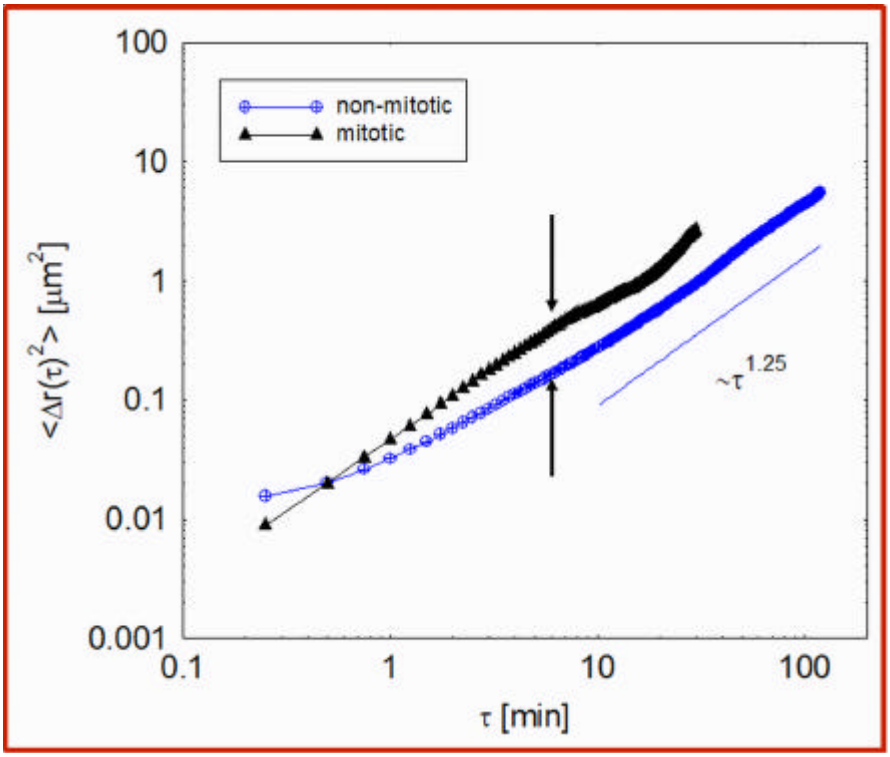

Figure 4. *Mean squared displacements associated with non-mitotic and mitotic cells, as indicated.*

Investigation continued from page 15

Independent Activities Period Program

G.R. Harrison Spectroscopy Laboratory
MIT

IAP Events Highlight Spectroscopy

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* A course on "Optical Imaging, Scattering, and Interference for Biological Investigations", offered by Gabriel Popescu, will present the physical basis of microscopy, light scattering and interference for biomedical investigations.
* "Breakdown of the Born-Oppenheimer Approximation in Diatomic Molecules", a series of four lectures by Robert Field, will discuss various aspects of photofragmentation dynamics in diatomic molecules. This offering will be joint with the MIT Chemistry Department.

Details about these offerings will be found on pages 5, 6, and 7 of this newsletter and on the web at: http://web.mit.edu/spectroscopy/events/iap.html.

MIT's Independent Activities period (IAP) is a special four week term at MIT that runs from the first week on January until the end of the month. IAP 2005 takes place from January 3 though January 28. IAP Offerings are distinguished by their variety, innovative spirit, and fusion of fun and learning.

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Breakdown of the Born-Oppenheimer Approximation in Diatomic Molecules

Sponsored by the MIT Department of Chemistry and the G.R. Harrison Spectroscopy Laboratory

Prof. Robert Field

January 3 - 7
9 AM - 10:30 AM, MIT Room 6-233

A lecture series on photofragmentation dynamics in diatomic molecules. The first lecture will introduce the terms in the Hamiltonian. Especially troublesome are the Born-Oppenheimer breakdown terms, that "cause" all intramolecular dynamics. Subsequent lectures include topics: perturbations, autoionization, predissociation, semiclassical calculations of vibrational overlap integrals, wavepacket dynamics, and the Landau-Zener picture of electron transitions induced by crossing potential curves.

No enrollment limit, no advance signup. Participants welcome at individual sessions of this series. Prereq: 5.61 or equivalent and an interest in molecular dynamics. Further information: Robert Field, MIT 6-219, 617-253-1489, rwfield@mit.edu or http://web.mit.edu/iap.

1. *January 3, Monday*
   Introduction to the spectroscopic effective Hammilton

2. *January 4, Tuesday*
   Spectroscopic pertubations, predissociations, and autoionization

3. *January 5, Wednesday*
   Semiclassical methods for calculating vibrational overlap integrals

4. *January 7, Friday*
   Wavepackets and Landau-Zener Picture

IAP 2005

Spectroscopy Laboratory Special Course

OPTICAL IMAGING, SCATTERING, AND INTERFERENCE FOR BIOLOGICAL INVESTIGATIONS

Gabriel Popescu

January 5 - 18, 2 PM – 3 PM, MIT Room 1-375

The theme of this course is the study of modern optical technologies based on microscopy, scattering, and interference for biomedical investigations. Optical fields will be described in the framework of linear system theory, and the use of Fourier transforms will be introduced as a powerful tool for describing their temporal and spatial fluctuations. This approach will provide common ground for formulating the various optic methodologies presented. A basic description of imaging systems will be developed with resolution, and contrast as key properties. Coherent imaging and various ways of improving contrast will be addressed. Various methods of microscopy will be considered, including bright field, dark field, Schlerein, confocal, OCT, phase contrast, DIC, Nomarsky, and quantitative phase imaging. Various models of scattering of light by inhomogeneous media will be formulated, and light scattering spectroscopy will be presented as a tool for early cancer diagnosis and other applications. The principles of interferometry will be presented, and particular geometries will be discussed. Both amplitude and phase-based techniques will be introduced. To provide focus, each student will be expected to write a paper on a particular optical methodology.

The course will build from the basic principles of optics, and thus will be accessible to a broad audience with interest in biomedical optics, but prior acquaintance with optics and EM theory will definitely help. Those interested should contact Gabriel Popescu (gpopescu@mit.edu).

1. *January 5, Wednesday*
   Introduction
2. *January 6, Thursday*
   Math toolbox: linear systems, convolutions, Fourier transforms, useful theorems
3. *January 7, Friday*
   Elements of optical microscopy: imaging systems, resolution, contrast, examples
4. *January 10, Monday*
   Bright field, dark field, Schlerein, phase contrast, DIC/ Nomarski, confocal, etc
5. *January 11, Tuesday*
   Light scattering techniques: light scattering in inhomogeneous media, single scattering, multiple scattering, diffusion model
6. *January 12, Wednesday*
   Light scattering spectroscopy and diagnostics of early cancer
7. *January 13, Thursday*
   Interferometric methods for diagnostics: field cross- correlations, cross-spectral densities; coherence time, area, interferometric geometries
8. *January 14, Friday*
   Michelson interferometry with polychromatic fields: optical gating, ODR- optical domain reflectometry, thickness/ refractive index measurements, OCT and applications
9. *January 17, Monday*
   Phase-based techniques of investigation: point measurements, harmonic, phase-referenced
10. *January 18, Tuesday*
    Quantitative phase microscopy: Fourier Phase Microscopy, applications for imaging cellular structure and dynamics

Independent Activities Period

G.R. Harrison Spectroscopy Laboratory
MIT

MULTIDIMENSIONAL SPECTROSCOPY: FOUR WHY'S

This symposium will explore the basis for coherent multidimensional spectroscopy from its origins in NMR, where it now plays a central role, to its more recent emergence in the IR and visible spectral ranges. The power of multidimensional spectroscopy will be illustrated through examples of important current areas that it has illuminated, and its prospects for further advances will be discussed.

Wednesday, January 19, 2005
9:00 - 11:30 AM

John Waugh
MIT Professor Emeritus
Multidimensional Spectroscopy — Why it started with NMR and (mostly) stays there.

Robert Griffin
MIT Francis Bitter Magnet Laboratory
Multidimensional NMR in rotating solids — Why high resolution?

Joseph Loparo
MIT Department of Chemistry
Two-dimensional IR spectroscopy: Observing coherent vibrations and hydrogen bond dynamics in water — Why two dimensions are better than one.

Keith Nelson
MIT Department of Chemistry
Multidimensional Spectroscopy — Why it is moving to the optical regime and has a glowing future there.

MIT Grier Room 34-401A

Poster session and buffet lunch to follow

PLEASE POST

Spectral Lines

by Stephen R. Wilk

Roy G. Biv - Red, Orange, Yellow, Green, Blue, Indigo, and Violet.

When I was very young, my father taught me the mnemonic often used to remember the colors of the rainbow, and their order – the name "Roy G. Biv". Red, Orange, Yellow, Green, Blue, Indigo, and Violet. It's easy to remember, also works for the colors of spectra generated by prisms and gratings (and almost works for the resistor color code), and comes in handy in many circumstances. But there's something troubling about it.

Why only seven colors? We can subdivide the spectrum into infinitely many colors. Even if we restrict ourselves to distinguishable colors, as with MacAdams' color ellipses, there are more than seven. Why not six? We could have the three "primary" colors of Red, Blue, and Yellow, along with their binary mixtures of Orange, Green, and Purple. But Purple isn't really Violet. (On the CIE Chromaticity Chart, Purple lies along the line joining the extremes of the spectral locus.) And what about Indigo? What *is* Indigo, anyway?

One explanation that I have heard is that seven is an ancient mystical number – there are Seven days of the Week, Seven Planets in the ancient astronomies, Seven Deadly Sins, and Seven Cardinal virtues. Of course there should be Seven Colors in the Rainbow. I have long suspected that there are seven colors only so that "Roy G. Biv" could have a pronounceable last name.

Did the ancient have a series of seven mystical colors? The evidence doesn't support it. There are virtually no color terms in the works of Homer, for instance. The sea is described as "wine dark", never as "blue". The goddess Athena is said to be "grey eyed", which many think ought to be what we call blue. This absence of color terminology lead the British Prime Minister William Gladstone to write a book in the 1800s suggesting that he ancient Greeks were color-blind!

The 13th century philosopher Roger Bacon thought that Aristotle believed there to be seven colors, but in fact Aristotle's view was more complex. He believed there were three primary colors – red, green, and blue – and that all others were mixtures of these. Most other Greek philosophers seemed to favor four primary

(c) Freefoto.com

colors, but this does not mean that any of them numbered the colors at three or four.

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Personality

Dr. Kamran Badizadegan

When Kamran Bazizadegan took the Cambridge exit off I-90 in the summer of 1985, he never thought that nearly two decades later he would still be looking for a place to park near 77 Mass Ave! Kamran came to MIT as an undergraduate student in the fall of 1985, and has remained affiliated with the Institute in various capacities ever since. He graduated with a bachelor's degree in chemical engineering before entering Harvard Medical School and the Harvard-MIT Division of Health Sciences and Technology (HST) as a medical student. Although he is a full-time Harvard faculty member, he continues to be active in the MIT community as a member of the HST faculty and a Visiting Scientist in the Spectroscopy laboratory.

Kamran was born and raised in Isfahan, Iran, and his encounter with America was originally more of an experiment that a lifelong plan. He grew up with the poetry of Khayyâm and Hâfez, that imprinted in him the philosophy that the most important responsibility in life is to learn, and the most important duty, to teach. Growing up in an ancient city, he sought comfort in hiking the path to the remains of the Zoroastrian fire temple of the Sassanian Dynasty; in listening for the calming sound of bells of the Cathedral of the Holy Savior down the street; and in taking strolls along the roads and bridges that had once rumbled under the troops of Genghis Khân, the caravans of Chinese and Dutch merchants, and the heavy machinery of the British Army. But the comfort of living in the crossroad of civilization was suddenly lost when these same roads once again rumbled under the footsteps of the millions who demonstrated in revolt against the regime of the Shah in 1979. He and other Iranian students faced a difficult period of years marked by a seemingly endless closure of access to higher education. Kamran, who had just graduated from high school in 1980, remained in Iran during this period, and was among the first students to enter college when the universities reopened in 1983. Nevertheless, after his first semester as a medical student at Tehran University, he

Kamran Badizadegan

decided to leave Iran to pursue the rest of his education abroad.

After graduating from medical school in 1993, Kamran did his residency in anatomic pathology at the Brigham and Women's Hospital, and his fellowship in

Badizadegan continued on page 10

Popescu, Kim, and Bhatia Win MIT 1K Entrepreneurship Competition

Gabriel Popescu

Gabriel Popescu, a postdoctoral researcher in the Spectroscopy Laboratory, teamed up with Jiny Kim, a second year Sloan MBA student and Akash Bhatia, a senior product manager for Bowstreet, to enter the MIT 1K Entrepreneurship Competition. On December 1, their PhiOptics business proposal of producing the next generation advanced optical microscopy was selected elected the winner of the "hardware" category. The underlying technology has been developed at the Spectroscopy Laboratory during the past two years. For details, see the research article on page 2.

According to the PhiOptics summary, optical microscopes only provide users with a 2D view of their sample. To obtain a 3D view, investigators are forced to use expensive and invasive electron or atomic force microscopes, which require extensive pre-preparation of the sample. The new instrument provides a composite hardware and software imaging extension that turns off-the-shelf optical microscopes into 3D imaging systems. The product has immediate applicability in the medical research and semi-conductor industries, a $3.5 billion market. ⊕

Spectral Lines continued from page 9

Bacon himself believed there to be five colors. Theodoric of Freibourg (circa 1310), who wrote a surprisingly modern treatise on the rainbow (correctly observing the path of refraction, reflection, and refraction in spherical drops) held that there were four colors, based on his observations. But his observations were mainly of white light multiple order interference, and his observed colors of red, yellow, green, and purple corresponds pretty well with those cases.

The first case of someone asserting that there are seven colors in the rainbow I can find is the work of Franciscus Maurolycus (1494-1575). His theory of the rainbow is modern in asserting that it is due to interference between rays travelling different paths. But he could have learned from Theodoric's work. Maurolycus has a light ray traversing an internal path in which the light ricochets seven times around the raindrop, finally coinciding with a ray that reflects a single time from the surface of the drop. As Carl Boyer puts it, in **The Rainbow: From Myth to Mathematics**: "Here, (Maurolycus) thought, was the secret of the rainbow's 45º radius. It is the angle at which externally reflected rays are reinforced by those internally reflected seven times or more; and, *mirabilu dictu*, seven is precisely the number of colors in the rainbow!" This gives the impression of tradition lying behind that number seven, but, aside from Bacon's mistaken assumption, no one prior to this seems to have numbered the colors as seven.

But afterwards, it was not unusual. Isaac Newton, in his classic **Opticks**, not only numbers them as seven, but even names them. His scheme is the first I know of in which "indigo" appears.

So here is where we get Roy G. Biv – it seems to have been thought to be traditional (and may have had some strength of tradition behind it, but nothing that has been documented), and was used by rainbow theorists until finally Newton fossilized it in his work, after which it had a considerable weight of authority. It would take a lot of guts to go against the authority of Newton himself.

And what is "indigo"? It's the color produced by the plant of that name, which was at one time used to dye denims into "blue jeans". On the basis of that knowledge, "indigo" would seem to be more like what we today call "blue", while Newton's "blue" would be the darker, almost invisible color terminating the short end of the spectrum.

References

This article draws heavily upon Boyer's book, cited above (Sagamore Press, 1959). Reprinted 1987 by Princeton University Press.

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Badizadegan continued from page 9

pediatric pathology at Children's Hospital. In 1997, he joined the faculty of Harvard Medical School as a pathologist at Children's Hospital and a cell biologist in Wayne Lencer's group in Enders GI Cell Biology laboratories. Kamran's work in this group was focused on characterizing the structure and function of plasma membrane microdomains (lipid rafts) in intestinal epithelia, and he continues to maintain a research interest in this field. Also in 1997, he agreed to replace his longtime pathology teacher, James Crawford, in Michael Feld's group as a clinical collaborator on the spectral diagnosis of gastrointestinal dysplasia. Since then, Kamran has remained affiliated with this group as a collaborator and consultant on various projects ranging from spectral diagnosis of neoplasia to testing the applications of various optical technologies in the study of cellular biology. In 2004, Kamran left Children's Hospital to join the MGH Pathology Department as the head of pediatric pathology and an attending in gastrointestinal pathology. In addition to his basic research, Kamran has maintained an active clinical practice and published on various topics in gastrointestinal pathology ranging from metabolic liver disease to allergic esophagitis. He has been fortunate to have various aspects of his research supported by various awards from the Howard Hughes Medical Institute, the Charles H. Hood Foundation, and the National Institutes of Health.

The HST Division has been a significant part of Kamran's service to the MIT and Harvard communities. In addition to serving on various committees, Kamran has been an active HST teaching faculty member. For several years, he was a core faculty for HST.120 (Gastrointestinal Pathophysiology). In 2003, he became the founding course director for HST.035 (Principles and Practice of Human Pathology). In addition, he is actively involved in clinical training of pathology residents and medical students at MGH.

Kamran's wife, Kim, is also an MIT graduate and a current faculty in Risk and Decision Analysis at Harvard. Their daughter, Deanna, is a seventh-grader in Oak Hill Middle School and a budding concert violist. Their son, Nima, is a fourth-grader in Memorial Spaulding School with an insatiable apatite for Star Wars! Kamran, Kim and the kids have all been caught playing Neopets when they are not supposed to!

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Lester Wolfe Workshop in Laser Biomedicine

Optical Methods for Managing Diabetes: Will Technology or Biology Succeed First?

Tuesday, November 16, 2004 4:00-6:00 PM

MIT Grier Room, * 34-401

50 Vassar Street * Cambridge, MA

Challenges and Opportunities in Managing Diabetes
David Nathan, Massachusetts General Hospital

Imaging Islet Cell Function - From Single Cells to Intact Islets
David Piston, Vanderbilt University

Diabetic Retinopathy, From Basic Science to Clinical Studies
Sven Bursell, Joslin Diabetes Center

Optical Methods for Noninvasive Blood Glucose Analysis
Mark Arnold, University of Iowa

Refreshments served at 3:30 PM

Sponsored by the G. R. Harrison Spectroscopy Laboratory, MIT, MGH Wellman Laboratories, the Harvard-MIT Division of Health Sciences and Technology, and the Center For the Integration of Medicine and Innovative Technology (CIMIT)

(On-line map available at: http://whereis.mit.edu/map-jpg?mapterms=34-401)

PLEASE POST

Seminar on

Modern Optics and Spectroscopy

Fall Semester 2004

October 12	**Daniel Grischkowsky**, Oklahoma State University*THz time domain spectroscopy of molecular vapors*
October 19	**Elfar Adalsteinsson**, MIT*Magnetic resonance spectroscopic imaging: Spatial encoding and applications to disease*
October 26	**Dewey Holten**, Washington University *Ultrafast electron transfer in photosynthetic reaction centers*
November 2	**Christoph Rose-Petruck**, Brown University*Ultravast (XAFS) measurement of solvated transition metal complexes*
November 9	**Louis Brus**, Columbia University *Rayleigh scattering from single carbon nanotubes*
November 16	**Michael Feld**, MIT*Spectral diagnosis*
November 23	**Lihong Wang**, Texas A&M University *Photonic imaging in biological tissue*
November 30	**Grace Chou**, MIT*Photoluminescence spectroscopy of DNA-wrapped carbon nanotubes*
December 7	**Dara Entekhabi**, Massachusetts Institute of Technology*Multispectral earth imaging for earth and environmental science*

TUESDAYS, 12:00 - 1:00 p.m., Grier Room (34-401)
Refreshments served following the seminar.

Sponsored by the George R. Harrison Spectroscopy Laboratory,
Department of Electrical Engineering and Computer Science, and School of Science, MIT

PLEASE POST

Research Report

Discharge-Flow Kinetics Measurements using Intra-Cavity Laser Absorption Spectroscopy

P. Sheehy and J.I. Steinfeld, Department of Chemistry and Spectroscopy Laboratory, MIT

Trace amounts of molecular free radicals play an integral role in the chemical properties of the atmosphere[1]. A principal objective of laboratory studies of free radicals is to obtain the spectroscopic and kinetic parameters necessary to understand their behavior in the atmosphere[2]. The high reactivity of free radicals and the difficulty in generating, and subsequently isolating the radical for analysis present significant challenges to their detection. Cavity enhanced spectroscopy offers an approach to compensate low intrinsic absorbance by placing the sample of interest within the cavity of a laser. In the IntraCavity Laser Absorption Spectroscopy (ICLAS) experiment, light from a lasing medium reflects through the absorbing sample as many as 10^5 times, amplifying the absorbance of a weak absorber to a much greater extent than in traditional multi-pass absorption cells. We have coupled our ICLAS system to a discharge-flow apparatus[3] and measured the formation kinetics of HNO from atomic hydrogen and nitric oxide as a test of Kinetics using Intra-Cavity Absorption Spectroscopy (KICAS). The results indicate that KICAS will be a promising method for carrying out kinetics measurements on weakly absorbing species.

A traveling-wave, ring configuration was utilized for these measurements (Figure 1a)[4]. The horizontally polarized output of an argon ion laser pump Ti:sapphire rod (AM) was situated between two spherical folding mirrors (FM1 and FM2). The pump beam was focused on the gain medium by means of a focusing lens (FL). A polarizer (P) and a Faraday rotator (FR) were inserted into the short arm of the cavity, between the first high reflector (HR1) and the crystal (AM). Two high reflectors (HR1 and HR2) are used to compensate for the rotation of polarized light induced by the Faraday rotator to ensure a uni-directional, traveling-wave. The height of the second high reflector (HR2) is adjustable to optimize the compensation. The distance between HR3 and the output coupler

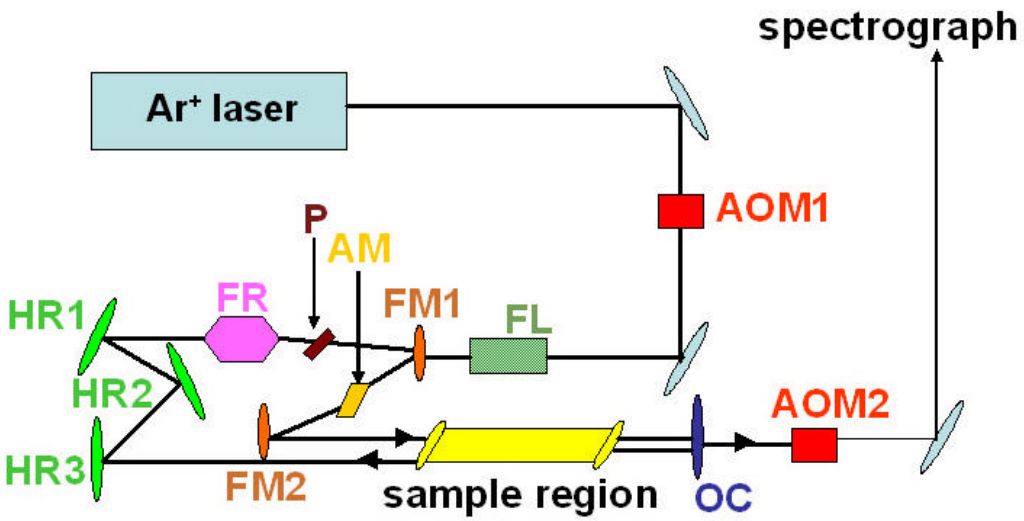

Figure 1. a) *Traveling-wave, ring configuration of the IntraCavity Laser Absorption Spectrometer.*

(OC) makes up the long arm of the cavity, including the sample cell. The generation time of the laser was controlled by two acousto-optic modulators (AOM1 and AOM2). The first gate, AOM1, directed the pump laser onto the gain medium, while the second gate, AOM2, directed the output of the laser to the spectrograph.

Nitrosyl hydride, HNO, was chosen to demonstrate the utility of the KICAS method for a variety of reasons – it is a key intermediate in a number of reactions relevant to the fields of astrophysics, combustion chemistry, and atmospheric chemistry[5-10]. HNO has a strong electronic transition within the spectral range of the Ti:sapphire-based ICLA Spectrometer. The molecule has a large absorption cross-section – requiring only trace amounts of HNO to conduct the necessary experiments. With an appropriate setup, a detection limit for HNO of ~10^7 molecules cm^{-3} is achievable.

The apparatus used for kinetic measurements is shown in Figure 1(b). Helium was used as the main carrier gas. Hydrogen atoms were injected through a side-arm inlet located at the rear of the flow tube. The excess reactant, NO, was injected through a moveable inlet. Nitric oxide was purified by passing the gas through a liquid nitrogen and pentane (LN_2/pentane) slush cooled to approximately 165 K.

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Discharge-Flow continued from page 13

Kinetic measurements of HNO were made using the (000)←(000) band of the $\tilde{A}^1A''\leftarrow \tilde{X}^1A'$ electronic transition, centered at 13,154.38 cm^{-1}. The $^RQ_0(8)$ line of the DK_a''=0 subband was used for monitoring HNO kinetics because of the lack of interference from other HNO lines and oxygen transitions, as well as sufficient oxygen at nearby frequencies to accurately calibrate the transition (Figure 2).

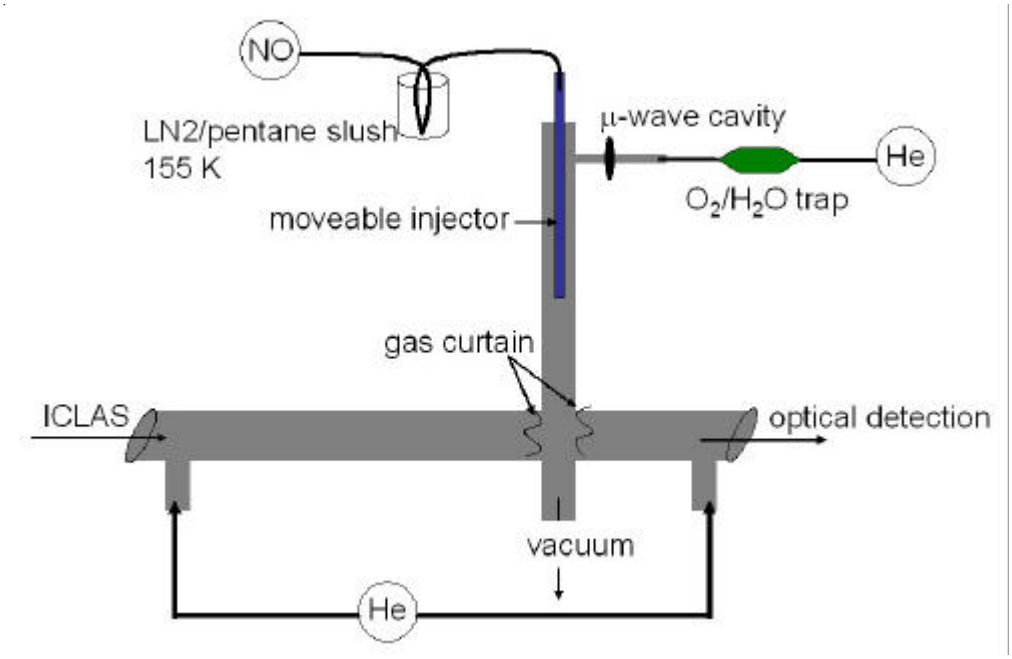

Figure 1. b) *Flow apparatus used for measuring HNO formation kinetics using an ICLA Spectrometer.*

Reactions relevant to HNO formation include:

$$H + NO \xrightarrow{M} HNO \qquad \text{(R1)}$$

$$H + H + M \xrightarrow{k_2} H_2 + M \qquad \text{(R2)}$$

$$HNO + H \xrightarrow{k_3} H_2 + NO \qquad \text{(R3)}$$

$$HNO + \text{wall} \rightarrow \text{decay} \qquad \text{(R4)}$$

The procedure used for determining the rate of reaction (R1) by KICAS is similar to that commonly used for low-pressure flow tubes[3]. Nitric oxide and helium were injected at a fixed rate, and their number densities were calculated assuming complete mixing in the region downstream of the injector. In each reaction, both NO and He carrier gas were present in several orders of magnitude greater than the estimated hydrogen atom concentration, creating pseudo-first-order conditions. The concentrations of the moveable injector was varied to generate a series of kinetic curves. The data were fit to the following expression:

$$[HNO]_t = \frac{k_{eff}[H]_o}{k_w - k_{eff}}\left(e^{-k_{eff}t} - e^{-k_w t}\right) \qquad (1)$$

where $k_{eff} = k_1[NO][M]$ (M = He), and $[H]_o$ is the initial concentration of atomic hydrogen in the flow tube in the absence of nitric oxide. The number densities calculated for [HNO] are in good agreement with expected values: the concentration of atomic hydrogen generated from the discharge was estimated to be between 10^9-10^{11} molecules cm^{-3} and the calculated number densities for $[HNO]_{max}$ varied between 3-5 x 10^9 molecules cm^{-3}.

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Discharge-Flow continued from page 14

Considering potential systematic errors in the measurement of gas flows, pressure, and detector signal, as well as uncertainties associate with Franck-Condon factors used to calculate the HNO number density, it is estimated that the rate constant can be determined with an accuracy of ± 20%.

A reaction rate constant of $(4.3 \pm 0.4) \times 10^{-32}$ cm^6 $molecule^{-2}$ s^{-1} at 295 K was measured for the reaction H+NO+M →HNO+M (M=He). The pressure and concentration range enabled by ICLAS detection has allowed us to limit reactive pathways that would inhibit the formation of HNO. The sensitivity of ICLAS, coupled with the versatility of the discharge flow technique has validated the KICAS methodology for measuring free radical kinetics.

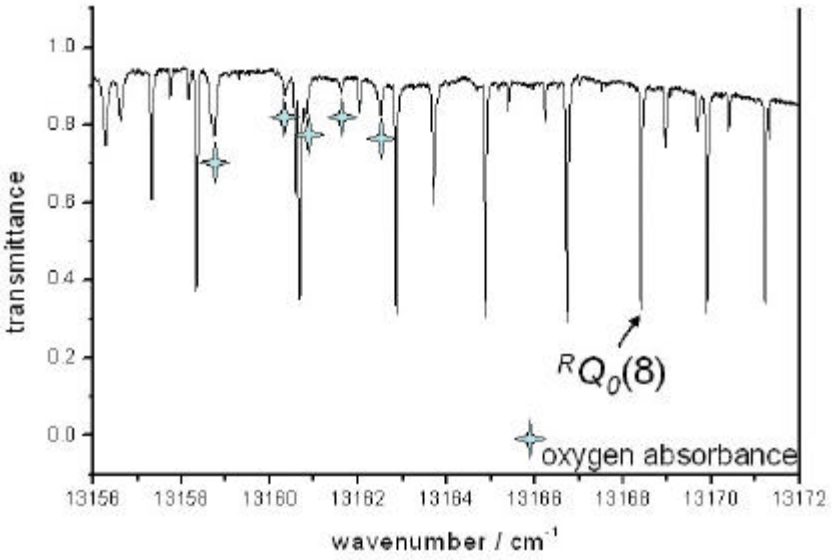

Figure 2. *ICLAS spectrum of HNO used for kinetics measurements. Transitions marked with a star are oxygen absorbance peaks that are used to frequency calibrate the spectrum.*

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Investigation continued from page 4

Such power law behavior suggests that the trajectory patterns obey self similar scaling properties. The superdiffusive nature of cell motion has been also observed in Hydra cells and the Tsalis statistics has been proposed to model such behavior [10]. To our knowledge, this is the first time that a statistical analysis has been performed on cells during different stages of their life cycle.

5. Summary

In summary, we have developed Fourier phase microscopy as an extremely sensitive quantitative phase imaging technique. The remarkably low noise characterizing the method is due to the fact that the two interfering fields traverse a common optical path. In addition, the Fourier processing is performed on a magnified microscope image of the sample, which further narrows the optical path of the interfering fields and also provides improved mechanical stability. The use of a low-coherence illumination field, as opposed to laser radiation, contributes to the sensitivity of the method, as fringes created by multiple reflections on various components are suppressed. We anticipate that FPM will become an important tool for quantifying cell growth, interaction/ synchronization, and membrane fluctuations.

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