CURRICULUM VITA

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PERSONAL INFORMATION

Date of Birth: February 3, 1954
Citizenship: USA
President of Chinese Cultural Association of Greater Philadelphia, 1999-2001, 2002-2004
Principal of Main Line Chinese School, 2001-2002

EDUCATION

Ph.D.	1984	Ohio State University, Columbus, Ohio Department of Physics
B.Sc.	1976	National Tsing-Hua University, Hsinchu, Taiwan, ROC Department of Physics

POSITIONS HELD

Professor	Dept. of Materials Science & Engineering Drexel University	9/1/03-present
Overseas Famous Teacher	Shanghai Second Polytechnic University	9/20/13-12/31/16
Visiting Professor	National Taiwan University, Taiwan	8/1/14-present
Visiting Professor (Sabbatical leave)	National Taiwan University, Taiwan	8/16/13-7/31/14
Visiting Expert	National Taiwan University, Taiwan	5/16/07-8/15/13
Visiting Professor (Sabbatical leave)	National Taiwan University, Taiwan	12/15/06-5/15/07
Associate Professor	Dept. of Materials Engineering Drexel University	9/1/96-8/31/03
Visiting Researcher (Sabbatical leave)	Catalytic Systems Division Johnson Matthey, Wayne, PA	7/1/98-3/31/99
Visiting Associate Professor	Dept. of Applied Chem. and Chem. Eng. Kagoshima University, Japan	6/97-8/97
Visiting Associate Professor	National Taiwan University, Taiwan	8/97
Visiting Summer Faculty	Naval Air Warfare Center, Warminster, PA	7/93-9/93
Assistant Professor	Dept. of Materials Engineering Drexel University	4/1/91-8/31/96
Research Scientist	Dept. of Materials Science & Engineering University of Washington, Seattle, WA	9/87-3/91
Visiting Researcher	Academia Sinica, Taipei, Taiwan	12/88-2/89
Postdoctoral Research Associate	Dept. of Physics, University of Washington	1985-1987
Postdoctoral Research Associate	Dept. of Physics, Ohio State University	1984-1985

AWARDS

1. Voted the Best Professor of Materials Engineering Department by the graduating class of 1996
2. The American Ceramic society 1999 Edward C. Henry Electronics Division Best Paper Award for "Electromechanical Behavior of PZT-Brass Unimorphs," *J. Am Ceram. Soc.* **82**[7], 1733-1740 (1999) by X. Li, W.Y. Shih, I. A. Aksay, and W.-H. Shih
3. Faculty Achievement Award for excellence in teaching at Drexel, Feb. 23, 2000
4. Professor of the Year, College of Engineering, Student Choice Awards, 2001
5. Winner of Best Senior Design Project in Department of Materials Engineering, Drexel University, M. P. Rossi, 2002
6. Winner of Best Senior Design Project in Department of Materials Engineering, Drexel University, Steve Szewczyk, 2003
7. Best Poster in Drexel Research Day, Undergraduate category, Robert Luchenta and W.-H. Shih, 2003
8. Inducted to Drexel 10^6 Club
9. Research Achievement Award, Drexel University 2004
10. Best Poster in 2004 Drexel Research Day, Graduate category in Emerging Technology, Hongyu Luo, C. Martorano, W. Y. Shih, and W.-H. Shih
11. Teaching Award, Department of Materials Science and Engineering, Drexel University 2004
12. 2^{nd} place best poster at the 4th annual poster contest for graduate students of the Philadelphia "Liberty Bell" Chapter of ASM International, 2005, Hui Li, W. Y. Shih, and W.-H. Shih
13. Best poster award at the 2005 Research Day, College of Engineering, Drexel University, Hakki O. Yegingil, Wan Y Shih, Waqas Anjum, Jeffrey Justin, Ari D Brooks, and Wei-Heng Shih
14. Travel Grant for Hakki O. Yegingil to attend 2005 MRS Fall Meeting
15. Koerner Fellowship awarded to Joe Capobianco, 2007
16. 1^{st} place best poster at the 7th annual poster contest for graduate students of the Philadelphia "Liberty Bell" Chapter of ASM International, 2008, Hakki Yegingil, W. Y. Shih, and W.-H. Shih
17. 3^{rd} best poster at the 7th annual poster contest for graduate students of the Philadelphia "Liberty Bell" Chapter of ASM International, 2008, Joseph Capobianco, W. Y. Shih, and W.-H. Shih
18. The senior design team, Giang Au, Rosemary Bastian, Thao Nguyen , and Zankhana Patel, with their project, "Optimization of Synthesis Process and Surface Modification of Non-toxic ZnSe Quantum Dots for In-vivo Imaging and Diagnosis Applications," was selected as the best senior design project of School of Biomedical Engineering, Science, and Health Systems in 2009
19. Student Xiaotong Gao won the Lee Smith Traveling Fellowship to China
20. Xiaotong Gao received the Excellent presentation award, 2010 Symposium on Piezoelectricity, Acoustic Waves, and Device Applications, Xiamen, China, Dec. 10-13, 2010
21. Outstanding Teaching Award, Department of Materials Science and Engineering, 2011, Drexel University
22. Giang Au's poster "Aqueous $Cd_{1-x}Pb_xS$ Quantum Dots for Near Infrared Imaging," is the winner of the poster award for graduate student in Biology and Biomedical category in

Drexel's Research Day 2011 competition.

23. Giang Au's poster "Assessing Breast Cancer Margin Using an Aqueous Quantum Dot (AQDs) Enabled Molecular Probe," is the winner of the poster award for graduate student in Biology and Biomedical category in Drexel's Research Day 2012 competition.
24. Drexel Teaching Excellence Award, 2012-2013, Cheng-Hsin (Johnson) Lu (advisor: Wei-Heng Shih) – Highly Commended
25. Shanghai Second Polytechnic University Overseas Famous Teacher, 2013-2018
26. 2013 Fellow of National Academy of Inventors
27. 2018 Drexel University College of Engineering Outstanding Innovation Award

RECOGNINITIONS

1. The paper, J.-P. McGovern, W. Y. Shih, R. Rest, M. Purohit, Y. Pandya, and W.-H. Shih, "Label-Free Flow-Enhanced Specific Detection of *Bacillus anthracis* Using a Piezoelectric Microcantilever Sensor," *The Analyst*, **133**, 649-654 (2008)**,** was featured in *Chemical Technology News* of the Royal Society of Chemistry in 3/08.
2. The paper, H. Li, W. Y. Shih, and W.-H. Shih, "Synthesis and Characterization of Aqueous Carboxyl-Capped CdS Quantum Dots for Bioapplications," *IECR*, **46**, 2013 (2007) in the ACS journal, Industrial & Engineering Chemistry Research, has been named one of the most-accessed articles in 2007 of that journal.
3. The paper, H. Li, W. Y. Shih, and W.-H. Shih, "Non-Heavy Metal ZnS Quantum Dots with Bright Blue Photoluminescence by a One-Step Aqueous Synthesis," *Nanotechnology*, **18**, 205604 (2007) was one of the most down-loaded articles for that journal in April, 2007.
4. The paper, H. Li, W.-H. Shih, W. Y. Shih, L. Chen, S.-J. Tseng, and S-C. Tang, "Transfection of Aqueous CdS Quantum Dots Using Polyethylenimine," Nanotechnology, **19**, 475101(2008) was downloaded more than 250 times in the first two weeks after its publication, among the top 10% most downloaded articles.
5. Organized International Symposium on Colloidal Ceramic Processing in the 2003 Annual Meeting of American Ceramic Society.
6. Editor of the book, Colloidal Ceramic Processing of Nano-, Micro-, and Macro-Particulate Systems : Proceedings of the symposium held at the 105th Annual Meeting of The American Ceramic Society, April 27-30, 2003, in Nashville, Tennessee, Ceramic Transactions, Volume 152
7. Chairman of Graduate Affairs Committee, 2000-present: Restructured the graduate program to be more research oriented. The number of domestic students and graduate students winning awards has increased steadily.
8. A news release about the portable piezoelectric finger (PEF) breast cancer detector can be found in physorg.com (http://www.physorg.com/news173004222.html) and in scribblewikiblog.com (http://www.scribblewikiblog.com/piezoelectric-fingers-key-in-new-breast-cancer-detector/).
9. The piezoelectric finger (PEF) breast cancer detector was reported in Technology Transfer Tactic, http://www.technologytransfertactics.com/content/2010/12/08/drexel-licenses-hand-held-breast-cancer-screening-device/
10. Associated Editor of Journal of the Ceramic Society of Japan, 2011
11. Editorial Board Member of the Journal-Nano Biomedicine and Engineering, 2010
12. Advisory Member of International Union of Advanced Materials (IUAM), 2011

13. The paper, Chun-Yi Hsieh, Meng-Lin Lu, Ju-Ying Chen, Yung-Ting Chen, Yang-Fang Chen, Wan Y Shih and Wei-Heng Shih, "Single ZnO nanowire–PZT optothermal field effect transistors," published in *Nanotechnology*, **23,** 355201 (2012), was featured online in nanotechweb.org, titled "Ferroelectricity and light control current in new transistors" at http://nanotechweb.org/cws/article/lab/50664
14. Editor of Journal of Nanomaterials special issue on Advanced Green Energy Nanomaterials for Optoelectronic Devices: Synthesis, Processing, Characterization, and Applications, in 2016

RESEARCH AREAS

1. Colloidal Coating: A Novel Ceramic Processing Approach

Aqueous colloidal processing has the advantages of controlling the interactions between particles and environmental friendliness. I have developed a colloidal coating method that modifies the surface of ceramic powders. The coating serves multiple functions. It can enhance the chemical and thermal stability of the powders, improve the consolidation and rheological properties of slurries, and lower the sintering temperatures of the green compacts. For example, silicon nitride and silicon carbide powders were coated by boehmite (AlOOH) via a sol-gel process. The coated powder suspensions were shown to have a significantly higher solids loading than the uncoated powder in water. Viscosity measurements and centrifugation showed that the coating changes the long-range interaction between the silicon nitride particles. Rheological studies indicate that the suspensions of coated powders have lower viscosity and wider linear viscoelastic region than that of uncoated powders. Furthermore, as the coating thickness increases, the shear modulus of boehmite-coated SiC gel decreases because the boehmite coating prevents the close contact of the SiC particles thereby reducing the van der Waals attraction interaction between the SiC particles. We have extended this part of research to the biomedical applications of nanometric hydroxyapatite coating for implant surface modifications. Additionally, we have also synthesized microporous and mesoporous nanostructured materials that are suitable for enzyme immobilization and absorbents for environmental wastes.

2. Low-Temperature Processing of Piezoelectric Ceramics with Enhanced Properties

Based on the coating approach, a low-temperature, direct sintering approach for high performance perovskite lead magnesium niobate-lead titanate (PMN-PT) solid solution ceramics was developed using $Mg(OH)_2$-coated Nb_2O_5 particles. The mixtures of $Mg(OH)_2$-coated Nb_2O_5, PbO particles, and lead titanate particles are compacted and sintered to near full density at temperatures lower than 1000ºC with superior dielectric and piezoelectric properties.

More recently, we developed a method to fabricate freestanding piezoelectric films with giant electric-field-enhanced piezoelectric response. The d_{31} piezoelectric coefficient for PMN-PT layers can be as high as 2000 pm/V, larger than that of commercial single crystalline PMN-PT bulk, at 10 kV/cm (or 20 V over the 20-micron film thickness). In contrast to single crystals, the polycrystalline freestanding films are easy to make and can be made into any size. They are also easy to be miniaturized. Together with researchers at University of Southern California, we have developed high-frequency ultrasound transducers for ultrasound imaging based on the

piezoelectric freestanding films. The freestanding films can be easily stacked to form multilayer actuators as well as multilayer capacitors. They are ideal for miniaturized sensors and actuators applications.

3. Aqueous Synthesis of Nanocrystalline Semiconductors: Quantum Dots

Quantum dots are semiconductor nanocrystals with superior photostability than traditional organic dyes. In our lab we have developed an environmentally friendly aqueous QD synthesis route to synthesize aqueous QDs (AQDs) such as CdS, ZnS, CdSe, and ZnSe with bright photoluminescence and high quantum yield ranging as high as 75% directly in water using mercaptopropionic acid (MPA). By partially replacing MPA with (3-Mercaptopropyl) trimethoxysilane (MPS) as the capping molecule, we were able to not only enhance the photoluminescence intensity but also the stability. The MPS-capped QDs can sustain UV exposure for more than 15 hours and daylight exposure for more than 50 days at room temperature. Near-infrared (NIR) QDs within the window (700-1000 nm), separated from the major absorption peaks of hemoglobin and water, has the potential to image tissues deeper than several mm under the surface. Due to higher coverage of the capping molecules, AQDs exhibited a better than 80% conjugation efficiency compared to 6% exhibited by quantum dots made in organic solvents and were also colloidally more stable. These qualities permit AQDs for practical applications such as breast cancer margin evaluation and immunohistochemical staining.

Biomedical application: Aqueous quantum dots (AQDs) for tumor margin assessment. Breast cancer is the second most common cancer in women in the United States, with an estimated 232,620 new cases in 2012. The majority of cases undergo breast conserving surgery (BCS), in which the surgeon attempts to excise the tumor along with a margin of normal tissue while conserving as much breast volume as possible. Surgeons currently have no rapid, reliable method to determine whether they have removed the entire tumor; they must wait from one to seven days to receive a pathology report. Consequently 15% to 60% of BCS patients in the US and Europe undergo these additional surgeries, taking a physical, emotional, and financial toll on patients and adding expenses for re-excision to healthcare expenses. Our solution is to develop the Aqueous Quantum Dots (AQD) system for intra-operative assessment of breast cancer surgical margins. It will provide the surgeon with rapid images visualizing the presence or absence of cancer cells on the surface of the surgical specimen, directing the surgeon to area(s) of the surgical cavity where additional tissue should be excised. The system will significantly reduce the number of additional surgeries, and reducing healthcare expenses.

4. Synthesis of Dispersed Hydroxyapatite Particles and Gels

Hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$, was synthesized using a sol-gel method. When sufficient amount of citric acid or sodium citrate was added to the precursor salts, a translucent suspension was formed, in contrast to the opaque suspension obtained without the citrate addition. Particle size analysis found that the size of the HA varied from 2.5 μm to 4 μm when the citrate concentration is below 0.8 M. Above 0.8 M of citrate, the particle size was 0.1 μm. In addition, the Ca/P ratio in the particles made with sodium citrate is higher than that without sodium citrate. The gelation behavior of the submicron HA particles was used for the fabrication of coatings on implant surface for bioactivity study.

5. Piezoelectric Plate Sensor (PEPS)

Piezoelectric Plate sensor (PEPS) is a new type of biosensors first developed in our laboratory. By immobilizing receptors specific to target antigens on the PEPS surface, binding of target antigens to the receptor on the sensor surface causes the PEPS resonance frequency to shift. *Real-time detection* of a target antigen is achieved by immersing a PEPS in the antigen containing liquid and monitoring the PEPS resonance frequency shift. We have developed highly piezoelectric lead magnesium niobate-lead titanate (PMN-PT) freestanding films with enhanced piezoelectric response which enabled us to pioneer an innovative and economical way of constructing PEPS by simple cutting without the need of tedious micromachining. PMN-PT PEPS 800 μm long exhibited unprecedented sensitivity in real-time quantification of cells, viruses, proteins, and DNA in various liquid environments including patient's sera using all-electrical measurements. Such high detection sensitivity permits robust detection of extremely low levels of proteins, enzymes, antibodies, and cells in sera several orders of magnitude better than commercial enzyme-linked immunosorbent assays (ELISA). Furthermore, PEPS can rapidly (< 30 min) detect double-stranded DNA at a concentration of 30 copies/ml in urine or serum and genetic signature of bacteria at 150 copies/ml in stool comparable to polymerase chain reaction (PCR) but without the need of isolation, concentration, and amplification. PEPS's enhanced detection sensitivity is directly linked to the elastic modulus change of the PMN-PT layer as a result of the target antigen binding to the sensor surface that causes the polarization domains in the PMN-PT layer to switch as well as the electromechanical coupling constant of the PMN-PT.

6. Piezoelectric Finger (PEF) for Soft-tissue Stiffness Detection/Imaging

Cancerous tissues and tumors are stiffer than surrounding tissues. Measurement of tissue stiffness could aid early tumor/cancer location. Ability to measure tumor stiffness under shear in the DC mode, which none of the current technology could achieve, could greatly improve the accuracy of tumor malignancy diagnosis. The PEF that we developed is an "electronic finger" capable of accurately and non-destructively measuring both the Young's modulus and shear modulus of tissues with gentle touches to the surface. A PEF can measure the Young's modulus and shear modulus variations in tissues with less than one-millimeter spatial resolution to a depth of up to several centimeters, offering great potential for in-vivo early detection of diseases such as breast cancer tumor. The ability of a PEF to probe the interfacial properties of hard inclusions by comparing the DC compression and shear tests stands to greatly aid tumor malignancy test accuracy. Preliminary results indicated that a PEF is capable of identifying and locating small malignant tumors (less than 3 mm) that were missed by mammography, ultrasound and a physician's palpation.

7. High Surface-Area Catalytic Oxides

High surface-area powders are a critical component in many catalytic systems. The thermal stability of these ceramic powders is essential to the performance of catalytic systems. We have been studying the synthesis of oxide nanoparticles such as ZrO_2, CeO_2, Al_2O_3, SiO_2, and MnO_x with the aim of maintaining high surface area at elevated temperatures. It was shown that impurities within the powders are a key factor in determining the thermal stability of oxide powders. Furthermore, synthesis conditions such as heat treatment temperature and time, as well as precursor concentration were shown to be controlling parameters in achieving high surface area. We discovered that the colloidal coating approach of precipitation an oxide in the presence of the

support oxide can enhance the surface area of the mixed oxides due to morphological change. Our study provides a basic understanding to the important industrial processes in obtaining thermally stable, high surface-area ceramic particles.

8. Size Effect in Nanoparticles

The crystalline structure of $BaTiO_3$ nanoparticles has been shown by many authors to depend on the size of the particles. However, the reason for the size dependence is not clear. We showed that the size effect of crystalline structure of $BaTiO_3$ is related to the depolarization effect of the small particles. The large depolarization energy prohibits the small particles from becoming polarized (the tetragonal structure) and causes the particles to remain as unpolarized (the cubic structure). The depolarization effect is demonstrated by coating the $BaTiO_3$ particles with Cu and that the tetragonality of the powders (c/a lattice constant ratio) is enhanced by the metal coating. After oxidation of the metal coating, the tetragonality of $BaTiO_3$ powders decreases. In addition, it is shown that particle clustering can stabilize the tetragonal structure down to a smaller particle size than individual $BaTiO_3$ particles due to the reduction of depolarization energy by clustering.

Size also plays an important role in the coating of particles. We found that nanoparticles were difficult to coat compare to micron-sized particles due to higher solubility of the small particle size. Size effect also plays an important role of the emission spectrum of quantum dots that we synthesized.

9. Conversion of Coal Wastes into Microporous and Mesoporous Materials

Annually, in the state of Pennsylvania alone, 8.4 million tons of fly ash, a coal combustion waste, is generated. Due to the increasingly tighter environmental regulations, the disposal of such a large amount of fly ash poses a challenge. In the past few years, we have chemically converted fly ash into zeolites which have a wide range of applications such as molecular sieves, catalysts, adsorbents, etc. Zeolites are crystalline forms of aluminosilicates and the fly ash is composed of mainly silica and alumina. Therefore, it is expected that fly ash can be converted to zeolites. This study represents a new approach in dealing with waste materials. It not only eliminates the disposal problem of coal wastes and more importantly turns the waste material into a useful one. We have found a fusion method that can convert a variety of ashes into zeolites with high yields. The zeolites converted from fly ash were shown to have good ion-exchange property with heavy metals such as Cs and Co. Our results show that the converted fly ash has a great potential in immobilizing nuclear wastes and toxic ions in waste streams.

As an extension of our work on zeolites, the formation of mesoporous molecular sieves that were recently discovered by researchers at Mobil was investigated. The mesoporous molecular sieves are composites of organic (surfactant) and inorganic (for example, silicate) species. After calcination (heat treatment), the organic part is burned out and the remaining porous materials contain periodic pores of sizes in the order of 20-100 angstroms. The mesoporous materials have a wide range of possible applications such as catalysts, molecular sieves, and adsorbents. We have succeeded in converting fly ashes into mesoporous aluminosilicates. Furthermore, we synthesized mesoporous nickel silicates using the same approach. The mesoporous nickel silicates show great promise as energy storage electrodes in electrochemical cells. Currently our expertise in this area has been applied to the separation of CO_2/N_2 gases. In the DOE funded program, we worked on synthesizing a microporous membrane material that can effectively separate CO_2 from N_2 due to

preferential adsorption of CO_2.

10. Environmentally Friendly Materials

To improve the environment, we have initiated research in synthesizing materials that are nontoxic to the environment or human. In piezoelectric ceramics, we have studied the synthesis of sodium potassium niobates-lithium niobate solid solution as a candidate for lead-free piezoelectrics. In particular, the effect of antimony concentration on the piezoelectric properties of $(Na_{0.5}K_{0.5})_{0.945}Li_{0.055}Nb_{1-x}Sb_xO_3$ was examined for $0 \leq x \leq 0.1$. The piezoelectric coefficients exhibited a maximum, d_{33}=240 pC/N and d_{31}=-82 pC/N at x=0.04, coinciding with the maximum of the grain size and the apparent density at x=0.04. The grain size, the apparent density, and the piezoelectric coefficients decreased with an increasing x at higher x likely due to the onset of a Sb-rich second phase.

On the synthesis of nanoparticles, we have produced ZnS QDs that are shown to be nontoxic to typical human cells. In particular, cytotoxicity tests of zinc sulfide (ZnS) and cadmium sulfide (CdS) quantum dots (QDs) synthesized via all-aqueous process with various surface conditions were carried out with human endothelial cells (EA hy926) using two independent viability assays, i.e. by cell counting following Trypan blue staining and by measuring Alamar Blue (AB) fluorescence. The ZnS QDs with all four distinct types of surface conditions were nontoxic at both 1 μM and 10 μM concentrations for at least 6 days. On the other hand, the CdS QDs were nontoxic only at 1 μM, and showed significant cytotoxicity at 10 μM after day 4. The CdS QDs with (3-mercaptopropyl)trimethoxysilane (MPS)-replacement plus silica capping were less cytotoxic than those with 3-mercaptopropionic acid (MPA) capping and with MPS-replacement capping. Comparing the results of ZnS and CdS QDs with the same particle size, surface condition and concentration, it is indicated that the cytotoxicity of CdS QDs and the lack of it in ZnS QDs were mainly due to presence and absence of the toxic Cd element, respectively. The nontoxicity of the aqueous ZnS QDs makes them favorable for *in vivo* imaging applications.

11. Piezoelectric energy harvesters

Networks of low power wireless devices such as sensors, controllers, transmitters and receivers are increasingly used in applications ranging from environmental to factory automation monitoring. Most of these devices must be operative 24 hours a day and may be in locations where manual battery replacement is difficult or costly. It would be desirable if there exists a miniaturized device that can convert ambient mechanical energies such as vibrations or air flows -- which unlike sunlight are readily available 24 hours a day -- to power such wireless device networks. Over the past decade, piezoelectric cantilever energy harvesters have been increasingly investigated for this application. The challenge for piezoelectric cantilever energy harvesters are two folds: (1) To improve the voltage and power output within the constraints of size and weight and (2) To be able to effectively convert air flow especially low-speed air flow (< 5 m/s) into electricity as low-speed air flow is one of the most prevalent forms of ambient mechanical energies.

We examined (1) how a thin extension of a piezoelectric cantilever (PEC) affects its energy harvesting performance and (2) how a hollow bluff-body extension at the cantilever tip helps convert air flow energy into electricity. Traditional PECs use piezoelectric and nonpiezoelectric layers of the same length. In this work, we investigated the energy harvesting performance of PCs with unequal piezoelectric and nonpiezoelectric lengths, which we dub two-section PECs, both

theoretically and experimentally. For step-wise tip forces the results showed that a longer nonpiezoelectric layer is preferred for generating a higher induced voltage while a longer piezoelectric layer reduces the induced voltage due to charge cancellation. With harmonic base vibrations, the results showed that there exists an optimal nonpiezoelectric-to-piezoelectric length ratio at which output voltage, current, and power can be maximized. Theoretically, a two-section PEC was considered within the framework of a beam theory for step-wise tip forces and within the framework of Euler-Bernoulli beam theory with electromechanical coupling for harmonic base vibrations. The results of the theoretical analysis were in good agreement with the experiments, providing the fundamental understanding and basis for further design considerations.

Air flow, especially low-speed air flow is ubiquitous. To help a PEC convert flow energy into electricity, we attach a hollow bluff extension at the tip of a PEC as a piezoelectric flow energy harvester (PFEH). Because the hollow bluff extension is light-weight, it vibrates when the air flows past it, which in turn drives the PEC into vibration that can be converted into electricity. Turbulence and vortex shedding forces were identified as the two driving mechanisms of the PFEH. The voltage and power output of the PFEH increased with the increasing size of the bluff extension.

The flow induced vibration of the cylindrical extension causes the piezoelectric cantilever to vibrate at the natural frequency of the PFEH. The PFEH provides a low-cost, compact and scalable power source for small electronics by harvesting energy from ambient flows such as wind and water streams. Prototypes were tested in both laminar and turbulent air flows demonstrating the feasibility of the design. Turbulence excitation was found to be the dominant driving mechanism of the PFEH with additional vortex shedding excitation contribution in the *lock-in* region. The PFEH provides a low-cost, compact and scalable power source for small electronics by harvesting energy from ambient flows such as wind and water streams. Prototypes were tested in both laminar and turbulent air flows demonstrating the feasibility of the design. Turbulence excitation was found to be the dominant driving mechanism of the PFEH with additional vortex shedding excitation contribution in the *lock-in* region.

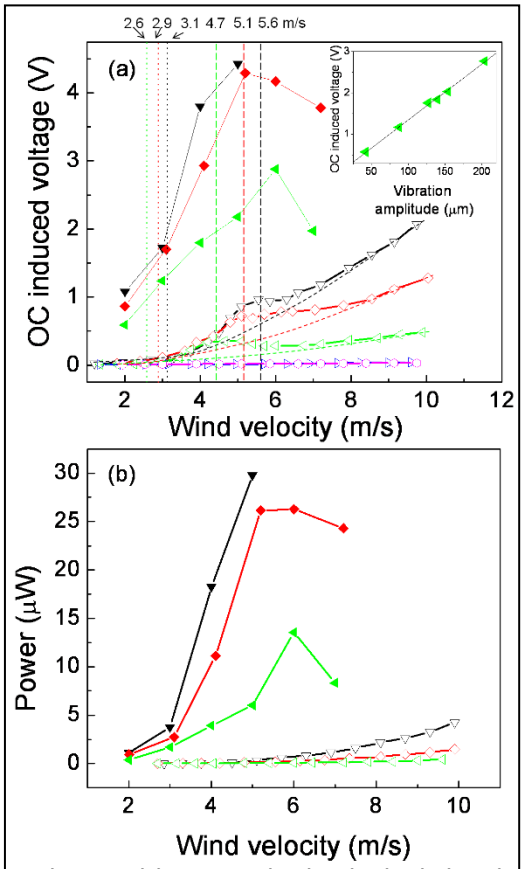


Figure. (a) Open-circuit (OC) induced voltage and (b) power output of PFEH-A (◁/◀), PFEH-B (◇/◆), PFEH-C (▽/▼), a 31×10mm PEC without a cylinder (▷) and a 67×10mm PEC without a cylinder (○). The open and solid symbols represent data in the wind tunnel test (laminar flow) and the fan test (turbulent), respectively. The insert in (a) shows the OC induced voltage versus the displacement measured at the mid-point of the cylinder in PFEH-A.

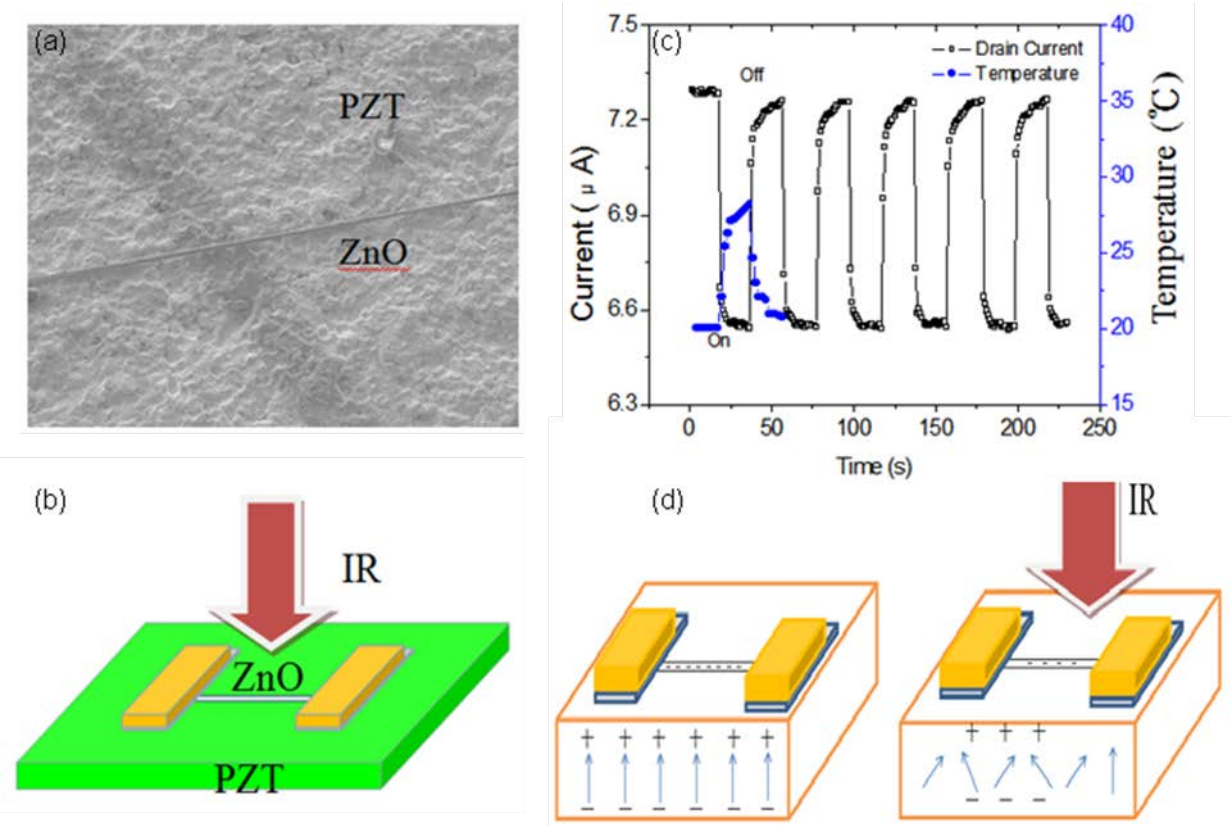
12. Graphene-PZT optothermal field effect transistors

We have developed a pyroelectric field effect transistor (FET) based on a graphene-lead zirconate titanate (PZT) system. Under the incidence of a laser beam, the drain current can be increased or decreased depending on the direction of the polarization of the PZT substrate. The drain current sensitivity of the

optothermal FET can reach up to 360 nA/mW at a drain field of 6.7 kV/m more than 5 orders of magnitude higher than that of the photogating transistors based on carbon nanotube on SiO_2/Si substrate. Graphene is an excellent component for pyroelectric FET due to its high optical transparency and conductance.

13. ZnO Nanowire-PZT optothermal field effect transistors

Ferroelectric materials such as $Pb(Zr_{0.3}Ti_{0.7})O_3$ (PZT) with up and down remnant polarizations have been employed in non-volatile ferroelectric field effect memories as gate dielectrics. On the other hand, PZT is also pyroelectric with changing polarization when temperature is varied. Inspired by this characteristic, a single ZnO nanowire (NW) field effect

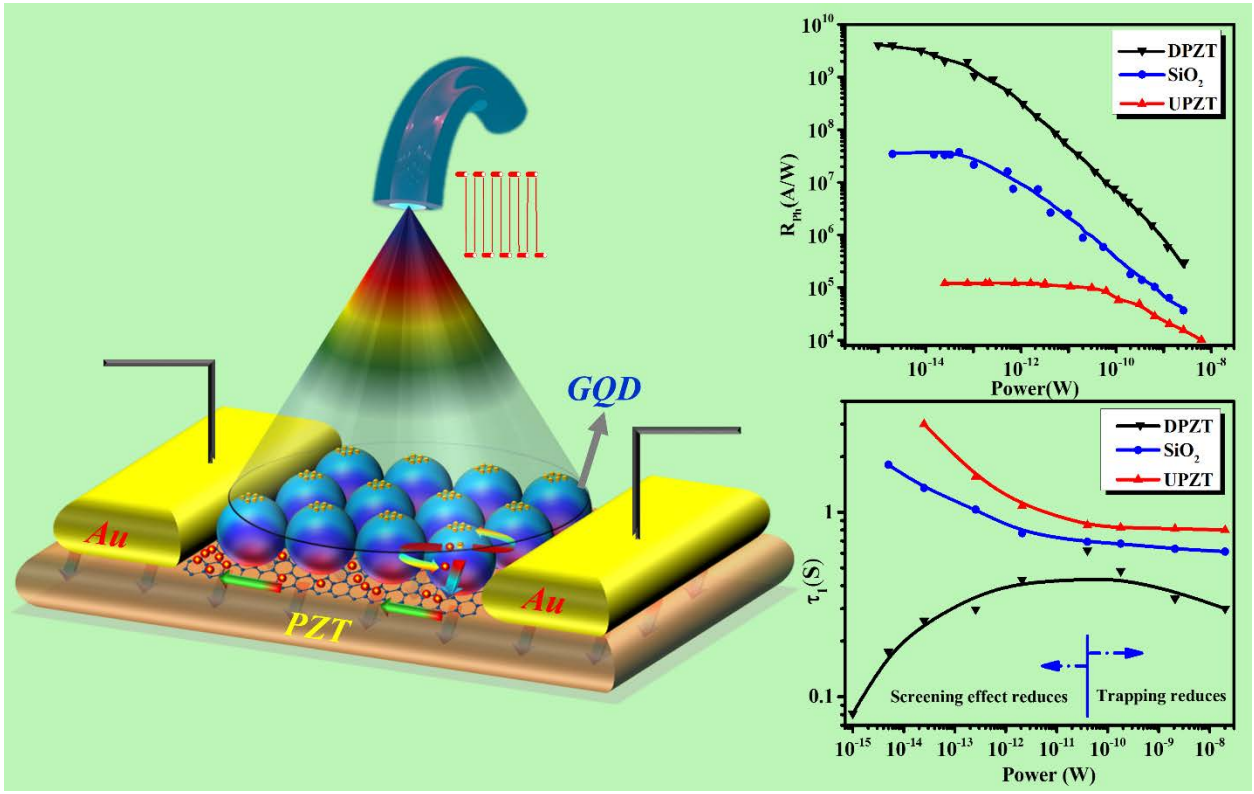


ZnO-PZT field effect transistor. (a) SEM image showing a single ZnO NW bridging two patches of PZT. (b) A schematic illustration of device configuration under IR illumination. (c) The drain current as a function of time modulated by IR laser of 250 mW with a light on or off PZT with upward polarization. The temperature rise correlates with the current drop. (d) IR illumination on the PZT with upward polarization decreases the positive bound charge density at the top surface of the PZT, which decreases the electron carrier concentration in the ZnO NW and decreases the drain current.

transistor (FET) is fabricated on a PZT substrate. It was discovered that the drain current in single ZnO NW could be modulated by an optothermal gating mechanism using PZT as the gate dielectric. Furthermore, the maximum current sensitivity by light was 25 nA/mW for down polarization at a drain field of 83 kV/m, which is about three orders of magnitude higher than the typical 20 nA/W at drain field of 50 kV/m of the photogating transistors based on carbon nanotube on SiO_2/Si substrate.

An infrared (IR) laser of 1064 nm wavelength was used as an optothermal source. The drain current in the ZnO NW can be increased or decreased by the IR illumination depending on the polarization orientation of the PZT substrate. For example, as shown in the figure, when the n-type ZnO NW was placed on top of the PZT substrate with a up polarization, the bound positive charges on the PZT surface would attract the electron carriers in the ZnO NW. When illuminated by the IR laser, the increased temperature reduced the polarization and thus decreased the density of the positive bound charges at the top inside surface of the PZT. As a result, the electron carrier concentration in the ZnO NW would decrease resulting in a decreased drain current. On the other hand, IR illumination on a PZT with down polarization would decrease the polarization and negative bound charge density at the top inside surface of the PZT. As a result, the electron carrier concentration in the ZnO NW would increase thereby increasing the drain current.

It is well known that when the laser is in the UV range, photocurrent can be generated in ZnO. Consequently, by combining the photocurrent behavior in the UV range and the optothermal



Permanent electric field of piezoelectric substrate (PZT) toward built-in electric field in DPZT device assists efficient transfer of photogenerated holes to the graphene channel which enhances the responsivity more than 100 times with 10 times faster response compared to the device on SiO_2 substrate. Opposite PZT electric field in UPZT device abate the responsivity more than 100 times with slower response time.

gating effect in IR range, the wide spectrum of response of current by light offers a variety of opportunities for nanoscale optoelectronic devices. The optothermal feature of the device is especially suitable for remote or wireless applications.

14. Electrical-Polarization-Induced Ultrahigh Responsivity Photodetectors Based on Graphene and Graphene Quantum Dots

Hybrid quantum dot–graphene photodetectors have recently attracted substantial interest because of their remarkable performance and low power consumption. However, the performance of the device greatly depends on the interfacial states and photogenerated screening field. As a consequence, the sensitivity is limited and the response time is relatively slow. In order to circumvent these challenges, herein, a composite graphene and graphene quantum dot (GQD) photodetector on lead zirconate titanate ($Pb(Zr_{0.2}Ti_{0.8})O_3$) (PZT) substrates has been designed to form an ultrasensitive photodetector over a wide range of illumination power. Under 325 nm UV light illumination, the device shows sensitivity as high as 4.06×10^9 A/W , which is 120 times higher than reported sensitivity of the same class of devices. Plant derived GQD has a broad range of absorptivity and is an excellent candidate for harvesting photons generating electron–hole pairs. Intrinsic electric fi eld from PZT substrate separates photogenerated electron–hole pairs as well as provides the built-in electric field that causes the holes to transfer to the underlying graphene channel. The composite structure of graphene and GQD on PZT substrate therefore produces a simple, stable, and highly sensitive photodetector over a wide range of power with short response time, which shows a way to obtain high-performance optoelectronic devices.

TRANSLATION RESEARCH:

Technology Licenses

1. **TBT, Inc**
   - TBT, Inc. **(**http://tbtgroup.net/materials-manufacturing.html) is a startup company that licensed the piezoelectric energy harvesting technology and the piezoelectric microcantilever sensor (PEMS) technologies for non-human clinical applications in 2007.
   - TBT Inc. has raised more than $5 M since then and hired 4 of our students as employees
   - TBT Inc. has developed a number of high-performance piezoelectric ceramic powders and thin piezoelectric sheets as products

2. United Electronic Life Sciences (UELS)

   - UELS has licensed the piezoelectric finger breast cancer detector technology in November 2010 under the trade name iBreastExam^{TM} (iBE)
   - I have prepared more than 11 detailed document, given training sessions and loaned them custom-made devices and circuit board to help UELS to get started
   - UELS and Drexel have received a grant from State of Pennsylvania to develop a piezoelectric breast cancer detector
   - UE Life Sciences has successfully obtained FDA-approval of iBE and entered a global partnership with GE Healthcare to commercialize iBE in more than 25 countries across Asia and Africa to benefit more than 500 million women.

3. MarginSurgical, Inc.

   - MarginSurgical is a startup company that licensed the aqueous quantum dots margin assessment technology to develop a commercial tool to help surgeon determine whether to remove additional tissue during breast conservation surgery in the operating room in July 2013.

4. Lenima Field Diagnostics, LLC.

   -- Lenima Field Diagnostics is a start-up company currently negotiating an option agreement for the piezoelectric plate sensor technologies for low-cost, rapid, and quantitative genetic detection in 30 min directly from patient samples without the

need of DNA isolation and amplification.

Companies founded

1. **Lenima Field Diagnostics LLC**
2. **AQD Life Sciences LLC**

PUBLICATIONS

Patents

1. J. Vartuli, D. L. Milius, Xiaoping Li, W.-H. Shih, W. Y. Shih, R. K. Prud'homme, and I. A. Aksay, "Multilayer Ceramic Piezoelectric Laminates with Zinc Oxide Conductors," United States Patent 6,329,741 issued Dec. 11, 2001.
2. Wei-Heng Shih, Hui Li, Melissa Schillo, and Wan Y. Shih, "Synthesis of Water Soluble Nanocrystalline Quantum Dots and Uses Thereof," US Patent No. 7,335,345, February 26, 2008, Drexel 04-0544D.
3. Wan Y. Shih, Wei-Heng Shih, and Zuyan Shen, "Piezoelectric Cantilever Sensors," US Patent No. 7,458,265, issued 12/2/08, PCT/US2004/036705, October 27, 2004, US20070089515, Drexel 03-0518D.
4. Wan Y. Shih, Wei-Heng Shih, Anna Markidou, Stephen T. Szewczyk, and Hakki Yegingil, "All-electrical Piezoelectric Finger Sensor (PEFS) for Soft Material Stiffness Measurement," US patent 7,497,133B2, March 3, 2009, US 2005/136,173, May 23, 2005, US2005/0277852A1, Amendment and Response to the Office Action filed 11/3/08, notice of allowance 11/19/08, Drexel 04-0457D
5. Wei-Heng Shih, Hui Li, Melissa Schillo, and Wan Y. Shih, "Water Soluble Quantum Dots," US continuation Patent 7,597,870B2, Oct. 6, 2009, US Utility Patent No. 11/968,228, Amendment and Response to the Office Action and the terminal disclaimer filed 11/14/08, US Utility Patent Application No. 11/968,228, filed March 12, 2009. Drexel 04-0544D.
6. Wei-Heng Shih, Hongyu Luo, Christian Martorano, and Wan Y. Shih, "Freestanding Films with Giant Electric-Field-Enhanced Piezoelectric Coefficients," US patent 7,744,773B2, June 29, 2010, US patent application No. 11/392,116, March 30, 2010, filed March 29, 2006, US2006/0223691, Office Action issued and a response due 10/22/08, Drexel 05-0591D.
7. W. Y. Shih, W.H. Shih, A. Markidou, S. Szewczyk, H. Yegingil, "All Electrical Piezoelectric Finger Sensor (PEFS) for Soft Material Stiffness Measurement," US 7,779,707B2, August 24, 2010, US Utility patent application No. 10/493,094 (or No. 12/328,639), December 4, 2008, US Utility patent application No. 12/837,590 published on November 11, 2010
8. Wei-Heng Shih, Wan Y. Shih, and Huiming Gu, "Method of Making Mixed Metal Oxide Ceramics," US patent 7,785,527B1, 8/31/10, US Patent Application No. 10/981,985, Nov. 5, 2004, Drexel 03-0496D.
9. W.-H. Shih, H. Li, and W. Y. Shih, "Water Soluble Nanocrystalline Quantum Dots," US continuation patent No. 7976819, July 12, 2011, US continuation patent No. 7824653, 11/2/2010.
9. Wan Y. Shih, Wei-Heng Shih, Qing Zhu, and Zuyan Shen, "Piezoelectric Microcantilevers and Uses in Atomic Force Microscopy," US patent No. 7,992,431, August 9, 2011, filed on November 28, 2007, US patent application No. 11/946,534, supplemental information Disclosure Statement filed 11/3/08, Drexel 06-0732D.

10. W. Y. Shih, W.H. Shih, A. Markidou, S. Szewczyk, H. Yegingil, "All Electrical Piezoelectric Finger Sensor (PEFS) for Soft Material Stiffness Measurement," US divisional patent, 8033185, October 11, 2011
11. W.-H. Shih, H. Li, and W. Y. Shih, "Water Soluble Nanocrystalline Quantum Dots," US utility patent No. 8080229, December 20, 2011
12. Wei-Heng Shih, Wan Y. Shih, and Hakki Yegingil, "Energy Harvesting Device," US patent 8110964B2, February 7, 2012, filed in January 29, 2008. US Provision patent application No. 60/887,051, First Notice Informing the Applicant of the Communication of International Application, PCT/US2008/052292, 10/30/08, Drexel 06-0714D,
13. Wan Y. Shih, Wei-Heng Shih, and Joseph A. Capobianco, "Electrical Insulation of Devices with Thin Layers," US patent 8,197,757, June 12, 2012. US patent application 12/306968, filed in July 7, 2007. International patent application No. PCT/US07/72940, Drexel 06-0711D.
14. Wei-Heng Shih, Huidong Li, Wan Y. Shih, "Lead-free Piezoelectric Ceramic Films and a Method for Making Thereof" US Patent 8,241,569, August 14, 2012, Drexel Docket No. 07-0863D
15. Wei-Heng Shih, Wan Y. Shih, and Hakki Yegingil, "Energy Harvesting Device," US patent 8421313B2, April 16, 2013
16. Wan Y. Shih and Wei-Heng Shih, "A Hand-Held Phase-Shift Detector for Sensor Applications," US8456150B2, June 4, 2013. Filed on February 1, 2008. US provisional patent application No. 60/887,686, PCT/US08/52388, Notification of Receipt of Search Copy, 10/27/08, Drexel 05-0604D
17. Wei-Heng Shih, Wan Y. Shih, and Huiming Gu, "Method of Making Mixed Metal Oxide Ceramics," US patent 8475706, July 2, 2013.
18. W.-H. Shih and W. Y. Shih, "Specificity and Sensitivity enhancement in cantilever sensing," US patent 8481335, July 9, 2013. 12/677613, 3/11/2010, 60/977,776, Oct. 4, 2007. PCT/US2008/078675, Oct. 3. 2008. PCT Application No. PCT/US2008/078675, March 13, 2009. Drexel 07-0784D.
19. Wei-Heng Shih, Wan Y. Shih, and Hui Li, "Synthesis of Water Soluble Nontoxic Nanocrystalline Quantum Dots and Uses Thereof," US patent 8491818, July, 23, 2013. Filed on November 28, 2007, US patent application No. 11/943790, 06-0753D (folded into 04-0544D)
20. W.-H. Shih, H. Li, and W. Y. Shih, "Lead-free piezoelectric ceramic films and a method for making thereof," US patent No. 8,496,870, July 30, 2013.
21. W. Y. Shih, W.-H. Shih, A. Markidou, S. Szewczyk, H. Yegingil, "All Electrical Piezoelectric Finger Sensor (PEFS)," US8549933B2, October 8, 2013. US Utility Patent Application No. 12/837,590, filed July 16, 2010.
22. W. Y. Shih, W.-H. Shih, H. Yegingil, and A. Brooks, "System and method for evaluating tissue," US8845555B2, 9/30/2014, US8562546B2, October 22, 2013, PCT/US2009/044250 filed on May 15, 2009, "Breast Tumor Malignancy and Invasiveness Determination Using Shear Modulus to Elastic Modulus Ratio Using Piezoelectric Fingers," US provisional patent application No. 61/054,100, May 16, 2008, Drexel 08-0925D/P
23. Wei-Heng Shih, Huidong Li, Wan Y. Shih, "Lead-free Piezoelectric Ceramic Films and a Method for Making Thereof" U.S. Patent No. 8,715,575, May 6, 2014. Filed on 11/23/07, US provisional patent application No. 60/954,479, (provisional 60/989,902), International Patent Application No. PCT/US2008/084190, filed on 11/20/08, Drexel 07-0863D

24. Wan Y. Shih, Joseph Capobianco, and Wei-Heng Shih, "Determination of Dissociation Constants Using Piezoelectric Microcantilevers," US patent US8722427B2, May 13, 2014. Expiration Date: May 20, 2032.US patent application No. 61/249,924, filed October 8, 2009
25. Wan Y. Shih, Qing Zhu, and Wei-Heng Shih, "Enhanced Detection Sensitivity with Piezoelectric Sensors," US 8741663 B2, June 3, 2014, International Patent Application No. PCT/US09/036048, filed March 4, 2009, US provisional patent application No. 61/035,669, March 11, 2008, Drexel 08-0901D
26. W. Y. Shih, W.-H. Shih, A. Markidou, S. Szewczyk, H. Yegingil, "All Electric Piezoelectric Finger Sensor (PEFS) for Soft Material Stiffness Measurement," US patent No. 8,826,749. September 9, 2014.
27. W. Y. Shih, W.-H. Shih, H. Yegingil, and A. Brooks, "System and method for evaluating tissue," US Patent No. US8845555 B2, September 30, 2014.
28. Wan Y. Shih, Wei-Heng Shih, Qing Zhu, and Zuyan Shen, "Piezoelectric Microcantilevers and Uses in Atomic Force Microscopy," US8857248 B2, October 14, 2014.
29. W.-H. Shih, W. Y. Shih, H. Li, A. Kopek, I. MacDonald, Yu-Chieh Lu, and Ryan O'Malley, "Water-soluble Nanocrystalline Quantum Dots Capable of Near Infrared Emissions," US8865477B2, October 21, 2014, US provisional patent application No. 61/046,889, April 22, 2008, patent application April 22, 2009, Drexel Docket #08-0940D.
30. Wan Y. Shih, Wei-Heng Shih, Zuyan Shen, Qing Zhu, Joseph Capobianco, and John-Paul McGovern, "Piezoelectric Microcantilever Sensors for Biosensing," US8927259 B2, January 6, 2015, US patent application 12/514941, filed on November 28, 2007, International patent application No. PCT/US07/85771, Drexel 06-0758D
31. Wei-Heng Shih, Hongyu Luo, Christian Martorano, and Wan Y. Shih, "Freestanding Films with Giant Electric-Field-Enhanced Piezoelectric Coefficients," US9039921 B2, May 26, 2015.
32. Wei-Heng Shih, Giang Au, Wan Y. Shih, "Methods for making water soluble quantum dots," US 9082918 B2, July 14, 2015, US provisional patent application No. 61/405,928, October 11, 2011
33. Wan Y. Shih, Wei-Heng Shih, Zuyan Shen, Qing Zhu, Joseph Capobianco, and John-Paul McGovern, "Piezoelectric Microcantilever Sensors for Biosensing," US9274087 B2, March 1, 2016
34. Wei-Heng Shih, Wan Y. Shih, Giang Au, Ari D. Brooks, Vanlilla K. Swami, "Capped and conjugated quantum dots," US 9417240 B2, August 16, 2016
35. Wei-Heng Shih, Wan Y. Shih, Zuyan Shen, Huidong Li, and Xiaotong Gao, "Sol-Gel precursors and methods for making Lead-Based Perovskite Films," US 9431598 B2, August 30, 2016
36. W. Y. Shih, W.-H. Shih, and Q. Zhu, "Enhanced Detection Sensitivity with Piezoelectric Microcantilever Sensors," US patent No. 9,488,622 B2, November 8, 2016.
37. W. Y. Shih, J-P McGovern, and W.-H. Shih, "Flow-Based Enhancement of Specificity for Label-Free Biochemical Assays," US patent No. 9,599,612 B2, March 21, 2017.

US Patent Applications

1. Wei-Heng Shih, Wan Y. Shih, Zuyan Shen, Huidong Li, and Xiaotong Gao, "Sol-Gel Synthesis of Lead-Based Perovskite Thin Films Through Multiple Depositions," filed in November 6, 2007. International patent application No. PCT/US07/83767, Notification

Concerning Availability of Publication of the International Application, 9/25/08, Drexel 06-0713D

2. W.-H. Shih, H. Li, M. Schillo, and W. Y. Shih, "Water Soluble Quantum Dots" US patent application No. 11/968,228, January 2, 2008.
3. W.H. Shih, W. Y. Shih, and H. Yegingil, "Energy Harvesting Device," EP National PCT No. 08780385.4, filed January 29, 2008.
4. W. Y. Shih and W.-H. Shih, "A Hand-Held Phase-Shift Detector for Sensor Application," Canada National PCT application No. 2/677,196, filed January 30, 2008.
5. W.Y. Shih, X. Gao, H. Li, Z. Shen, and W.-H. Shih, "Sol-gel Precursor for High-Temperature Lead-Based Perovskite Thin Films" US Utility Patent Application No. 12/513,308, May 1, 2009.
6. W. Y. Shih, W.-H. Shih, H. Yegingil, and A. Brooks, "System and method for evaluating tissue," Divisional Application No. 09747741.8, May 15, 2009.
7. W. Y. Shih, and W.-H. Shih, "A Hand-Held Phase-Shift Detector for Sensor Application," Japan National PCT application No. 2009-548403, filed August 1, 2009.
8. W.-H. Shih, H. Li, and W. Y. Shih, "Water Soluble Quantum Dots," US Patent Application No. 12/552,970, September 2, 2009.
9. Wan Y. Shih, Joseph Capobianco, and Hossein Borghaei, "Methods for Immune Response Detection," US patent application No. 61/249,950, filed October 8, 2009
10. Wan Y. Shih, John-Paul McGovern, and Wei-Heng Shih, "Flow-Based Enhancement of Specificity for Label-Free Biochemical Assays," US provisional patent application, filed February 24, 2010
11. Wei-Heng Shih, H. Luo, C. Martorano, and W. Y. Shih, "Freestanding Films with Field-Enhanced Piezoelectric Coefficients," US Divisional Patent Application No. 12/784,173, May 20, 2010.
12. W. Y. Shih, W.-H. Shih, H. Yegingil, and A. Brooks, "System and method for evaluating tissue," CN National PCT Application No. 200980122516, December 15, 2010.
13. W. Y. Shih, W.-H. Shih, H. Yegingil, and A. Brooks, "System and method for evaluating tissue," KR National PCT Application No. 2010-7028347, December 16, 2010.
14. W. Y. Shih, W.-H. Shih, H. Yegingil, and A. Brooks, "System and method for evaluating tissue," IN National PCT Application No. 2713/MUMNP/2010, December 16, 2010.
15. W.-H. Shih, W. Y. Shih, G. Au, A. B. Brooks, and V. K. Swami, "Clear Margin Determination during Cancer Surgery," International patent application PCT/US12/039532, May 25, 2012
16. Wei-Heng Shih, Giang Au, Wan Y. Shih, "Methods for making water soluble quantum dots," US patent application No. 13/880880, April 22, 2013.
17. W.-H. Shih, H. Li, and W. Y. Shih, "Synthesis of Water Soluble Non-Toxic Nanocrystalline Quantum Dots and Uses Thereof," US Divisional Patent Application No. 13/920,922, filed June 18, 2013.
18. W. Y. Shih, W.-H. Shih, A. Markidou, S. Szewczyk, H. Yegingil, "All Electrical Piezoelectric Finger Sensor (PEFS)," US Utility Patent Application No. 14/017508, filed September 4, 2013.
19. W. Y. Shih, W.-H. Shih, H. Yegingil, and A. Brooks, "System and method for evaluating tissue," EP National PCT Application No. 14/031,307, September, 24, 2013.

20. W. Y. Shih, G. Au, W.-H. Shih, A. Brooks, and V. Swami, "Clear Margin Determination During Surgery," EP National PCT Application No. 12846223.1, filed December 11, 2013, U.S. provisional application no. 61/491,006, filed May 27, 2011
21. W. Y. Shih, G. Au, W.-H. Shih, A. Brooks, and V. Swami, "Clear Margin Determination During Surgery," US National PCT Application No. 14/119,996, filed November 25, 2013.
22. W. Y. Shih, W.-H. Shih, and Q. Zhu, "Enhanced Detection Sensitivity with Piezoelectric Sensors," Divisional Patent Application No. 14/259,439, April 23, 2014.
23. W. Y. Shih, W.-H. Shih, W. Wu, M. Soylu, C. Kirimli, H. Guo, S. Joshi, Y.-H. Su, "Piezoelectric Plate Sensor and Uses Thereof," PCT/US2014/71555 filed December 19, 2014.
24. W. Y. Shih, W.-H. Shih, X. Xu, "Depth Measurement in Tissue using Piezoelectric Sensors Having Different Probe Sizes," PCT Patent Application No. PCT/US2015/010412, January 8, 2015.
25. W.-H. Shih, S. Han, W. Y. Shih, S. Fang, X. Niu,"Tin sulfide quantum dots for in vivo near infrared imaging," filed April 7, 2016
26. Wan Y. Shih, W.-H. Shih, X. Xu, W. Wu, C. Emery, and S. Joshi, "Rapid Antimicrobial Susceptibility Test," Foreign filing November 20, 2015.

Provisional Patent applications

Archival Journal Papers, H-index=30

1. W.-H. Shih and D. Stroud, "Theoretical Study of Freezing of Polystyrene Sphere Suspensions," *J. Chem. Phys.,* **79**, 6254 (1983)
2. W.-H. Shih and D. Stroud, "Theoretical Study of Miscibility and Glass-Forming Trends in Mixtures of Polystyrene Spheres," *J. Chem. Phys.*, **80**, 4429 (1984)
3. W.-H. Shih and D. Stroud, "Thermodynamic Properties of Liquid Si and Ge," *Phys. Rev. B,* **31**, 3715 (1985)
4. W.-H. Shih and D. Stroud, "Theory of Surface Tension of Liquid Metal Alloys," *Phys. Rev. B,* **32**, 804 (1985)
5. W.-H. Shih and D. Stroud, "Two-Component Lattice-Gas Model for Surface Segregation in Liquid Alloys," *Phys. Rev. B,* **33**, 8048 (1986)
6. M. Schick and W.-H. Shih, "Spin 1 Model of a Microemulsion," *Phys. Rev. B,* **34**, 1797 (1986)
7. W.-H. Shih, C. Ebner, and D. Stroud, "Potts Lattice-Gas Model for the Solid-Liquid Interfacial Tensions of Simple Fluids," *Phys. Rev. B*, **34**, 1811 (1986)
8. Y. Gefen, W.-H. Shih, R. B. Laibowitz, and J. M. Viggiano, "Nonlinear Behavior Near the Percolation Metal-Insulator Transition," *Phys. Rev. Lett.*, **57**, 3097 (1986)
9. M. Schick and W.-H. Shih, "Z(N) Model of Grain-Boundary Wetting," *Phys. Rev. B,* **35**, 5030 (1987)
10. J. Adler, Y. Gefen, M. Schick, and W.-H. Shih, "Order Propagation on Dilute Antiferromagnetic Potts Models," *J. Phys. A: Math. Gen.,* **20**, L227 (1987)
11. W.-H. Shih, Z. Q. Wang, X. C. Zeng, and D. Stroud, "Ginzburg-Landau Theory for the

Solid-Liquid Interface of BCC Elements," *Phys. Rev. A*, **35**, 2611 (1987)
12. M. Schick and W.-H. Shih, "Simple Microscopic Model of a Microemulsion," *Phys. Rev. Lett.,* **59**, 1205 (1987)
13. H. F. Cheung, Y. Gefen, E. Riedel, and W.-H. Shih, "Persistent Currents in Small One-Dimensional Metal Rings," *Phys. Rev. B,* **37**, 6050 (1988)
14. W. Y. Shih, W.-H. Shih, and I. A. Aksay, "Stability of Binary Charged Colloidal Crystals," *J. Chem. Phys.*, **90**, 4506 (1989)
15. W.-H. Shih, W. Y. Shih, S. I. Kim, J. Liu, and I. A. Aksay, "Scaling Behavior of Elastic Properties of Colloidal Gels," *Phys. Rev. A,* **42**, 4772 (1990)
16. W. Y. Shih, W.-H. Shih, and I. A. Aksay, "Semi-Dilute Athermal Polymer Solutions Near a Hard Wall: Monte Carlo Simulations," *Macromolecules,* **23**, 3291 (1990)
17. W. Y. Shih, J. Liu, W.-H. Shih, and I. A. Aksay, "Aggregation of Colloidal Particles with a Finite Interparticle Attraction Energy," *J. Stat Phys.*, **62**, 961 (1991)
18. A. A. Tseng, W.-H. Shih, C. Thomas, S. Chen, "Intelligent Processing of Polymer Sheets for Calendering," *Adv. in Poly. Tech.*, **12**, 241 (1993)
19. W.-H. Shih, W. Y. Shih, and I. A. Aksay, "Equilibrium-State Density Profiles of Centrifuged Cakes," *J. Am. Ceram. Soc.*, **77**, 540 (1994)
20. W.-H. Shih and Q. Lu, "Ultrafine Titanate Powders Processed via a Precursor-Modified Sol-Gel Method, *"Ferroelectrics,* **154**, 241-46 (1994)
21. W. Y. Shih, W.-H. Shih, and I. A. Aksay, "Size Effect in the Ferroelectric Properties of Small $BaTiO_3$ Particles: Effect of Depolarization," *Phys. Rev. B,* **50**, 15575 (1994)
22. W. Y. Shih, W.-H. Shih, and I. A. Aksay, "Elimination of an Isolated Pore: Effect of Grain Size," *J. Mat. Res.*, **10**[4], 1000-1015 (1995)
23. W.-H. Shih, D. Kisailus, and Y. Wei, "Silica Coating of Barium Titanate Particles," *Materials Lett.*, **24**, 13-15 (1995)
24. W.-H. Shih, L.-L. Pwu, A. A. Tseng, "Boehmite Coating as Consolidation and Sintering Aids in Aqueous Silicon Nitride Processing," *J. Am. Ceram. Soc.*, **78**[5], 1252-1260 (1995)
25. W.-H. Shih and L.-L. Pwu, "Rheology of Aqueous Boehmite-Coated Silicon Nitride Suspensions and Gels," *J. Mat. Res.*, **10**[11], 2808-16, (1995)
26. W.-H. Shih, D. Kisailus, W. Y. Shih, Y.-H. Hu, J. Hughes, "Rheology and Consolidation of Colloidal Alumina-Coated Silicon Nitride Suspensions," *J. Am. Ceram. Soc.*, **79**[5], 1155 (1996)
27. W. Y. Shih, W.-H. Shih, and I. A. Aksay, "Heteroflocculation in Binary Colloidal Suspensions: Monte Carlo Simulations," *J. Am. Ceram. Soc.*, **79**[10], 2587-91 (1996)
28. M. Buchta and W.-H. Shih, "Improved Aqueous Dispersion of Silicon Nitride with Aminosilanes," *J. Am. Ceram. Soc*., **79**[11], 2940-46 (1996)
29. W.-H. Shih and H.-L. Chang, "Conversion of Fly Ash into Zeolites for Ion-Exchange Applications," *Mat. Lett*., **28**, 263-68 (1996)
30. W. Y. Shih, W.-H. Shih, and I. A. Aksay, "Scaling Analysis for the Axial Displacement and Pressure of Flextensional Transducers," *J. Am. Ceram. Soc*., **80**[5], 1073-78 (1997)
31. X. Liu, W. Y. Shih, and W.-H. Shih, "Effect of Copper Coating on the Crystalline Structure of Small $BaTiO_3$ Particles," *J. Am. Ceram. Soc*., **80**[11], 2781-88 (1997)
32. X. Li and W.-H. Shih, "Size Effects in $BaTiO_3$ Particles and Clusters," *J. Am. Ceram. Soc*., **80**[11], 2844-52 (1997)
33. H.-L. Chang and W.-H. Shih, "A General Method for the Conversion of Fly Ash into Zeolites as Ion Exchangers for Cesium," *Ind. Eng. Chem. Res.,* **37**, 71-78 (1998)

34. Y. Wei, D. Jin, T. Ding, W.-H. Shih, X. Liu, S. Z. D. Cheng, and Q. Fu, "A Non-Surfactant Templating Route to Mesoporous Silica Materials," *Adv. Mater.*, **3**[4], 313-316 (1998)
35. P. C. Y. Lee, J.-D. Yu, X. Li, and W.-H. Shih, "Piezoelectric Ceramic Disks with Thickness-Graded Material Properties," *IEEE Trans. Ultrasonics, Ferro. Freq. Control*, **46**[1] 205-215 (1999)
36. C.-Y. Yang and W.-H. Shih, "Effect of pH on the Boehmite Coating on SiC," *J. Am. Ceram. Soc*. **82**[2] 436-440 (1999)
37. W. Y. Shih, W.-H. Shih, and I. A. Aksay, "Elastic and Yield Behavior of Strongly Flocculated Colloids," *J. Am. Ceram. Soc*. **82**[3] 616-624 (1999)
38. H.-L. Chang, C.-M. Chun, I. A. Aksay, and W.-H. Shih, "Conversion of Fly Ash into Mesoporous Aluminosilicates," *Ind. Eng. Chem. Res*., **38**, 973-977 (1999)
39. X. Li, W. Y. Shih, I. A. Aksay, and W.-H. Shih, "Electromechanical Behavior of PZT-Brass Unimorphs," *J. Am. Ceram. Soc*., **82**[7] 1733-40 (1999)
40. X. Liu, Y. Wei, D. Jin, and W.-H. Shih, "Synthesis of Mesoporous Aluminum Oxide with Aluminum Alkoxide and Tartaric Acid," *Mat. Lett*., **42**, 143-149 (2000)
41. X. Liu, C.-M. Chun, I. A. Aksay, and W.-H. Shih, "Synthesis of Mesostructured Nickel Oxide with Silica," *Ind. Eng. Chem. Res*., **39**, 684-692 (2000)
42. H.-L. Chang and W.-H. Shih, "Synthesis of Zeolites A and X from Fly Ashes and Their Ion-Exchange Behavior with Cobalt Ions," *Ind. Eng. Chem. Res*., **39**, 4185-4191 (2000)
43. P. C. Y. Lee, R. Huang, X. Li, and W.-H. Shih, "Vibrations and Static Responses of Asymmetric Bimorph Disks of Piezoelectric Ceramics," *IEEE Trans. Ultrasonics, Ferro. Freq. Control*, **47**[3] 706-715 (2000)
44. H.-L. Chang, P. Shady, and W.-H. Shih, "Effect of Sodium on Crystallite Size and Surface Area of Zirconia Powders at Elevated Temperatures," *J. Am. Ceram. Soc*., **83**[8], 2055-61 (2000)
45. C.-Y. Yang, W. Y. Shih, and W.-H. Shih, "Gelation, Consolidation, and Rheological Properties of Boehmite-Coated Silicon Carbide Suspensions," *J. Am. Ceram. Soc*., **83**[8], 1879-84 (2000)
46. X. Li, J. Vartuli, D. L. Milius, I. A. Aksay, W. Y. Shih, and W.-H. Shih, "Electromechanical Properties of a Ceramic d_{31}-Gradient Flextensional Actuator," *J. Am. Ceram. Soc*., **84**[5], 996 (2001)
47. W. Y. Shih, X. Li, H. Gu, W.-H. Shih, and I. A. Aksay, "Simultaneous Liquid Viscosity and Density Determination Using Piezoelectric Unimorph Cantilevers," *J. App. Phys*., **89**, 1497 (2001)
48. C. Y. Yang, W. Y. Shih, and W.-H. Shih, "Monte Carlo Simulations of the Nucleation and Growth Process of Colloidal Particles," *Phys. Rev. E*., **64**, 021403, (2001)
49. C. Y. Yang, W. Y. Shih, and W.-H. Shih, "Effects of Boehmite Coating Thickness on the Consolidation and Rheological Properties of Boehmite-Coated SiC Suspensions," *J. Am. Ceram. Soc*. **84**[12] 2834-40 (2001)
50. J. W. Yi, W. Y. Shih, and W.-H. Shih, "Effects of Length, Width, and Mode on the Mass Detection Sensitivity of Piezoelectric Unimorph Cantilevers," *J. App. Phys*. **91**[3], 1680-1686 (2002)
51. Q. Zhao and W.-H. Shih, "Effects of Processing Parameters on the Surface Area of Manganese Oxides at Elevated Temperatures," *Microporous and Mesoporous Materials* **53**, 81-86 (2002)
52. X. Li, W. Y. Shih, J. S. Vartuli, D. L. Milius, I. A. Aksay, and W.-H. Shih, "Effects of a

Transverse Tensile Stress on the Electric-Field-Induced Domain Reorientation in Soft PZT: In-situ XRD Study," *J. Am. Ceram. Soc.* **85**[4] 844-50 (2002)
53. X. Li, W. Y. Shih, J. Vartuli, D. L. Milius, R. Prud'homme, I. A. Aksay, and W.-H. Shih, "Detection of Water-Ice Transition Using a Lead Zirconate Titanate/Brass Transducer," *J. App. Phys*., **92**[1], 106-111 (2002)
54. H. Gu, W. Y. Shih, and W.-H. Shih, "A Single-Calcination Synthesis of Pyrochlore-Free 0.9PMN-0.1PT and PMN Ceramics by a Coating Method," *J. Am. Ceram. Soc*., **86**[2], 217-21 (2003)
55. W.-H. Shih, W. Y. Shih, C.-Y. Yang, H. Gu, and J. W. Yi, "Nanocoating of Particulate Surface in Colloidal Processing for Piezoelectric Sensors Applications," *NATO Science Series*, **Nanostructured Materials and Coatings for Biomedical and Sensor Applications**, Edited by Y. G. Gogotsi and I. V. Uvarova, Kluwer Academic Publishers, Netherlands, 377-394 (2003)
56. H.-L. Chang, P. Shady, and W.-H. Shih, "The Effects of Containers of Precursors on the Properties of Zirconia Powders," *Microporous and Mesoporous Materials*, 59, 29-34 (2003)
57. J. W. Yi, W. Y. Shih, R. Mutharasan, and W.-H. Shih, "*In Situ* Cell Detection Using Piezoelectric PZT-Stainless Steel Cantilevers", *J. Appl. Phys*., **93**[1], 619-625 (2003)
58. H. Luo, W. Y. Shih, and W.-H. Shih, "Comparison in the Coating of $Mg(OH)_2$ on Micron-sized and Nanosize Nb_2O_5 Particles," *Int. J. Appl. Ceram. Tech.*, **1**[2], 146-154 (2004)
59. Q. Zhao, W.-H. Shih, H.-L. Chang, and P. Andersen, "The Effect of Curing on the Thermal Stability of Si-doped ZrO_2 Powders," *Applied Catalysis, A*, **262**(2), 215-221 (2004)
60. H. Gu, W. Y. Shih, and W.-H. Shih, "Low-Temperature, Single Step, Reactive Sintering of Lead Magnesium Niobate Using $Mg(OH)_2$-Coated Nb_2O_5 Powders," *J. Am. Ceram. Soc*., **88**[6] 1435-1443 (2005)
61. A. Markidou, W. Y. Shih, and W.-H. Shih, "Soft-Materials Elastic and Shear Moduli Measurement Using Piezoelectric Cantilevers," *Rev. Sci. Instrum*., **76**, 064302 (2005)
62. Invited book chapter, W. Y. Shih and W.-H. Shih, "Nanosensors for Environmental Applications," invited book chapter in Series on Nanotechnology for Life Sciences - Vol 5: Impact of Nanomaterials on Environment, ed. C. Kumar (Wiley-VCH), 2006.
63. Z. Shen, W. Y. Shih and W.-H. Shih, "Mass Detection Sensitivity of Piezoelectric Cantilevers with a Nonpiezoelectric Extension," *Rev. Sci. Ins.* **77**[6], 065101 (2006)
64. S. T. Szewczyk, W.Y. Shih, and W.-H. Shih, "Palpation-Like Soft Materials Elastic Modulus Measurement Using Piezoelectric Cantilevers," *Rev. Sci. Ins.*, **77**, 044302 (2006)
65. Q. Zhao, Q. Zhu, W. Y. Shih, and W.-H. Shih, "Array Adsorbent-Coated Lead Zirconate Titanate (PZT)/Stainless Steel Cantilevers for Dimethyl Methylphosphonate (DMMP) Detection," *Sensors & Actuators, B.* **117**, 74-79 (2006)
66. Z. Shen, W. Y. Shih, and W.-H. Shih, "Self-Exciting, Self-Sensing PZT/SiO_2 Piezoelectric Microcantilever Sensors with Femtogram/Hz Sensitivity," *Appl. Phys. Lett.* **89**, 023506 (2006)
67. J. Capobianco, W. Y. Shih, and W.-H. Shih, "Methyltrimethoxysilane-Insulated Piezoelectric Microcantilevers for Direct, All-electrical Biodetection in Buffered Aqueous Solutions," *Rev. Sci. Instru.* **77**, 125105 (2006)
68. W. Y. Shih, H. Luo, C. Martorano, H. Li, and W.-H. Shih, "Freestanding Films with Giant Piezoelectric Coefficients," *Appl. Phys. Lett.*, **89**, 242913 (2006)
69. H. Yegingil, W. Y. Shih, and W.-H. Shih, "All-Electrical Palpation Shear Modulus and Elastic Modulus Measurement Using a Piezoelectric Cantilever with a Rectangular Tip," *J.*

Appl. Phys., **101**, 054510 (2007)
70. H. Li, W. Y. Shih, and W.-H. Shih, "Synthesis and Characterization of Aqueous Carboxyl-Capped CdS Quantum Dots for Bioapplications," *Ind. & Eng. Chem. Res.*, **46**, 2013-2019 (2007)
71. J. Capobianco, W. Y. Shih, and W.-H. Shih, "3-Mercaptopropyltrimethoxysilane as Insulating Coating and Surface for Protein Immobilization for Piezoelectric Microcantilever Sensors," *Rev. Sci. Instru*., **78**, 046106 (2007)
72. H. Li, W. Y. Shih, and W.-H. Shih, "Non-Heavy Metal ZnS Quantum Dots with Bright Blue Photoluminescence by a One-Step Aqueous Synthesis," *Nanotechnology*, **18**, 205604 (2007)
73. Q. Zhu, W. Y. Shih, and W.-H. Shih, "In-Situ, In-Water Detection of Salmonella typhimurium Using Lead Titanate Zirconate/Gold-Coated Glass Cantilevers at any Dipping Depth," *Biosensors and Bioelectronics*, **22**, 3132-3138 (2007)
74. J.-P. McGovern, W. Y. Shih, and W.-H. Shih, "In-Situ Detection of Bacillus Anthracis Spores Using Fully Submersible, Self-Exciting, Self-Sensing PMN-PT/Sn Piezoelectric Microcantilevers," *The Analyst*, **132**, 777-783 (2007)
75. Q. Zhu, W. Y. Shih, and W.-H. Shih, "Real-time, Label-Free, All-Electrical Detection of Salmonella typhimurium Using Lead Titanate Zirconate/Gold-coated Glass Cantilevers at any Relative Humidity," *Sensors & Actuators B.*, **125**, 379–388 (2007)
76. W.-S. Su, Y.-F. Chen, W. Y. Shih, H. Luo, and W.-H. Shih, "Domain switching in lead magnesium niobate-lead titanate polycrystalline sheets at single grain level," *Appl. Phys. Lett*., **91**, 112903 (2007)
77. H. Li, W. Y. Shih, and W.-H. Shih, "Effect of Antimony Concentration on the Crystalline Structure, Dielectric, and Piezoelectric Properties of $(Na_{0.5}K_{0.5})_{0.945}Li_{0.055}Nb_{1-x}Sb_xO_3$ Solids," *J. Am. Ceram. Soc. Comm.*, **90** [10] 3070–3072 (2007)
78. H. Li, W. Y. Shih, and W.-H. Shih, "Stable aqueous ZnS quantum dots using (3-mercaptopropyl) trimethoxysilane as capping molecule," *Nanotechnology*, **18**, 495605 (2007)
79. H. Yegingil, W, Y, Shih, and W.-H. Shih, "Probing Elastic Modulus and Depth of Inclusions in Model Tissues Using Piezoelectric Cantilevers," *Rev. Sci. Instru*., **78**, 115101 (2007)
80. Z. Shen, W. Y. Shih and W.-H. Shih, "Mass Detection Sensitivity of Piezoelectric Cantilevers with a Nonpiezoelectric Extension," *IEEE Trans. on Ultra. Ferro. Freq. Cont.*, **54**, 2001 (2007)
81. H. Luo, W. Y. Shih, and W.-H. Shih, "Double Precursor Solution Coating approach for Low-Temperature Sintering of $[Pb(Mg_{1/3}Nb_{2/3})O_3]_{0.63}[PbTiO_3]_{0.37}$ Solids," *J. Am. Ceram. Soc.*, **90**, 3825 (2007)
82. Q. Zhu, W. Y. Shih, and W.-H. Shih, "Mechanism of the Flexural Resonance Frequency Shift of a Piezoelectric Microcantilever Sensor in a DC Bias Electric Field," *Appl. Phys. Lett.*, **92**, 033503 (2008)
83. J.-P. McGovern, W. Y. Shih, R. Rest, M. Purohit, Y. Pandya, and W.-H. Shih, "Label-Free Flow-Enhanced Specific Detection of *Bacillus anthracis* Using a Piezoelectric Microcantilever Sensor," *The Analyst*, **133**, 649-654 (2008), PubMed#18427687
84. Q. Zhu, W. Y. Shih, and W.-H. Shih, "Mechanism of Flexural Resonance Frequency Shift of a Piezoelectric Microcantilever Sensor During Humidity Detection," *Appl. Phys. Lett*., **92**, 183505 (2008), PMC2682738, NIHMSID#112993
85. J. Capobianco, W. Y. Shih, Q.-A. Yuan, G. P. Adams, and W.-H. Shih, "Label-free, All-electrical, In-Situ Human Epidermal Growth Receptor-2 Detection," *Rev. Sci. Instrum.*, **79**, 076101 (2008), PubMed#18681738, PMC2678786

86. H. Li, W.-H. Shih, W. Y. Shih, L. Chen, S-J. Tseng, and S.-C. Tang, "Transfection of Aqueous CdS Quantum Dots using Polyethylenimine," *Nanotechnology*, **19**, 475101 (2008)
87. Q. Zhu, W. Y. Shih, and W.-H. Shih, "Length and Thickness Dependence of Longitudinal Flexural Resonance Frequency Shifts of a Piezoelectric Microcantilever Sensor due to Young's Modulus Change," *J. Appl. Phys*., **104**, 074503 (2008)
88. W. Y. Shih and W.-H. Shih, "Response to "Comment on 'Mechanism of flexural resonance frequency shift of a piezoelectric microcantilever sensor during humidity detection' Appl. Phys. Lett., 93, 096101 (2008)," *Appl. Phys. Lett*., **93**, 096102 (2008)
89. C.-Y. Hsieh, Y.-F. Chen, W. Y. Shih, Q. Zhu, and W.-H. Shih, "Direct Observation of Two-Step Polarization Reversal by an Opposite Field in a Substrate-free Piezoelectric Sheet," *Appl. Phys. Lett*., **94**, 131101 (2009)
90. Q. Zhu, W. Y. Shih, and W.-H. Shih, "Enhanced detection resonance frequency shift of a piezoelectric microcantilever sensor by a DC bias electric field in humidity Detection," *Sensors and Actuators B*, **138**, 1–4 (2009), NIHMSID#112322
91. H. Li, W. Y. Shih, and W.-H. Shih, "Synthesis of $Na_{0.5}K_{0.5}NbO_3$ Piezoelectrics by a Solution Coating Approach," *Inter. J. Appl. Ceram. Tech*., **6** [2] 205–215 (2009)
92. Q. Zhao, W. Y. Shih, and W.-H. Shih, "Effects of Processing Parameters on the Morphology of Precipitated Manganese Oxide Powders," *Ind. & Eng. Chem. Res.*, **48**, 1490-94, (2009)
93. X. Gao, W. Y. Shih, and W.-H. Shih, "Induced Voltage of Piezoelectric Unimorph Cantilevers of Different Nonpiezoelectric/Piezoelectric Length Ratios," *Smart Mater. Struct.*, **18**, 125018 (2009)
94. Adam B. Nover, Shami Jagtap, Waqas Anjum, Hakki Yegingil, Wan Y. Shih, Wei-Heng Shih and Ari D Brooks, "Modern Breast Cancer Detection: A Technological Review," *International Journal of Biomedical Imaging*, Volume 2009, Article ID 902326, 14 pages, doi:10.1155/2009/902326
95. J.-P. McGovern, W.-H. Shih, M. Mattiucci, R. Rest, M. Purohit, K. Pourrezaei, B. Onaral, and W. Y. Shih, "Array PZT/Glass Piezoelectric Microcantilevers for real-time detection of BA with 10 spores/ml sensitivity and 1/1000 selectivity in bacterial mixtures," *Rev. Sci. Instru.*, **80**, 125104 (2009)
96. H. Li, W. Y. Shih, and W.-H. Shih, "Highly Photoluminescent and Stable Aqueous ZnS Quantum Dots," *Ind. Eng. Chem. Res.* **49**, 578–582 (2010)
97. Q. Zhao, W. Y. Shih, H.-L. Chang, and W.-H. Shih, "Redox Activity and NO Storage Capacity of MnO_x-ZrO_2 with Enhanced Thermal Stability at Elevated Temperatures, *Ind. Eng. Chem. Res.* **49**, 1725–1731 (2010)
98. H. Li, W. Y. Shih, and W.-H. Shih, "Lead-Free Piezoelectric Freestanding Films with Sheet Geometry-Enhanced High-Field Piezoelectric Coefficients," *J. Am. Ceram. Soc.*, **93**[7], 1852-1855 (2010)
99. H. Yegingil, W. Y. Shih, and W.-H. Shih, "Probing Model Tumor Interfacial Property Using Piezoelectric Cantilevers," *Rev. Sci. Instrum.* **81**, 095104 (2010)
100. J. Capobianco, W.-H. Shih, J.-H. Leu, G. Lo, and W. Y. Shih, "Label Free Detection of White Spot Syndrome Virus Using Lead Magnesium Niobate-Lead Titanate Piezoelectric Microcantilever Sensors," *Biosensors and Bioelectronics*, **26**, 964–969 (2010)
101. X. Gao, W.-H. Shih, and W. Y. Shih, "Vibration Energy Harvesting Using Piezoelectric Unimorph Cantilevers with Unequal Piezoelectric and Nonpiezoelectric Lengths" *Appl. Phys. Lett.* **97**, 233503 (2010)
102. H. Li, M. Li, P. I. Lelkes, W. Y. Shih, and W.-H. Shih, "Cytotoxicity Tests of Water

Soluble ZnS and CdS Quantum Dots," *Journal Nanoscience and Nanotechnology*, **11**, 1–9 (2011)
103. L. Loo, J. A. Capobianco, W. Wu, X. Gao, W. Y. Shih, W.-H. Shih, K. Pourrezaei, M. K. Robinson, and G. P. Adams, "Highly Sensitive Detection of HER2 Extracellular Domain in the Serum of Breast Cancer Patients by Piezoelectric Microcantilevers," *Anal. Chem*., **83**, 3392–3397 (2011)
104. L. Loo, W. Wu, W. Y. Shih, W.-H. Shih, H. Borghaei, K. Pourrezaei, and G. P. Adams, "A Rapid Method to Regenerate Piezoelectric Microcantilever Sensors (PEMS)," *Sensors*, **11**, 5520-5528 (2011)
105. J. Capobianco, W. Y. Shih, G. P. Adams, and W.-H. Shih, "Label-free, In-Situ Human Epidermal Growth Receptor-2 Detection in Diluted Human Serum and K_d Assessment Using a PZT/glass Piezoelectric Microcantilever Sensor," *Sensors and Actuators B*, **160**, 349-356 (2011)
106. X. Li, W. Wu, Y. Chung, W. Y. Shih, W.-H. Shih, Q. Zhou, and K. K. Shung, "80 MHz Intravascular Ultrasound (IVUS) Transducer using PMN-PT Free-Standing Film," *IEEE Trans. Ultra. Ferroelec. Freq. Control*, **58** (11), 2281-2288 (2011)
107. C.-Y. Hsieh, Y.-T. Chen, W.-J. Tan, Y.-F. Chen, W. Y. Shih, and W.-H. Shih, "Graphene-PZT Optothermal Field Effect Transistors," *Appl. Phys. Lett*., **100**, 113507 (2012)
108. Giang H. T. Au, S-Ja Tseng, Wan. Y. Shih, and W.-H. Shih, "Aqueous $Cd_{1-x}Pb_xS$ Quantum Dots for Near-Infrared Imaging," *Nanotechnology*, **23**, 275601 (2012)
109. C.-Y. Hsieh, M.-L. Lu, J.-Y. Chen, Y.-T. Chen, Y.-F. Chen, W. Shih, and W.-H. Shih, "Single ZnO nanowire-PZT Optothermal Field Effect Transistors," *Nanotechnology*, **23**, 355201 (2012)
110. C.-Y. Hsieh, W.-H. Liu, Y.-F. Chen, W. Y. Shih, X. Gao, and W.-H. Shih, "Voltage Generation of Piezoelectric Cantilevers by Laser Heating" *J. Appl. Phys.*, **112**, 104506 (2012)
111. X. Gao, W.-H. Shih and W. Y. Shih, "Flow Energy Harvesting Using Piezoelectric Cantilevers with Cylindrical Extension," *IEEE Transactions on Industrial Electronics*, 60, 1116-1118 (2013)
112. G. H. T. Au, W. Y. Shih, W.-H. Shih, L. Mejias, V. K. Swami, K. Wasko, and A. D. Brooks, "Assessing Breast Cancer Margins Ex Vivo Using Aqueous Quantum-Dot-Molecular Probes," *International Journal of Surgical Oncology*, Vol. 2012, 861257
113. W. Wu, C. Kirimli, W.-H. Shih, and W. Y. Shih, "Real-time, *In Situ* DNA Hybridization Detection with Attomolar Sensitivity without Amplification Using $(Pb(Mg_{1/3}Nb_{2/3})O_3)_{0.65}$-$(PbTiO_3)_{0.35}$ Piezoelectric Plate Sensors," *Biosensors and Bioelectronics*, **43**, 391-399 (2013)
114. M. Cagri Soylu, W.-H. Shih, and W. Y. Shih, "Insulation by Solution 3-Mercaptopropyltrimethoxysilane (MPS) Coating: Effect of pH, Water, and MPS Content," *Ind. Eng. Chem. Res.*, **52**(7), 2590–2597 (2013)
115. Q. Zhu, W.-H. Shih, and W. Y. Shih, "Enhanced Dimethyl Methylphosphonate (DMMP) Detection Sensitivity by Lead-Magnesium Niobate-Lead-Titanate/Copper Piezoelectric Microcantilever Sensors via Young's Modulus Change," *Sensors and Actuators B*, **182**, 147-155 (2013)
116. W. Wu, W. Y. Shih, and W.-H. Shih, "Enhancing detection sensitivity of piezoelectric plate sensor by increasing transverse electromechanical coupling constant," *J. Appl. Phys*., **114**, 064505 (2013)

117. C. Kirimli, W. Y. Shih, and W.-H. Shih, "Flow-Enhanced Detection Specificity of Mutated DNA against Wild Type with Reporter Microspheres," *Analyst*, **138**, 6117–6126 (2013)
118. G. H. T. Au, W. Y Shih, and W.-H. Shih, "High-Conjugation-Efficiency Aqueous CdSe Quantum Dots," *Analyst*, **138**, 7316-7325 (2013)
119. Xin Xu, C. Gifford-Hollingsworth, R. Sensenig, W.-H. Shih, W. Y. Shih and A. D. Brooks, "Breast Tumor Detection Using Piezoelectric Fingers: First Clinical Report," *Journal of the American College of Surgeons* **216**, 1168 (2013).
120. G. H. T. Au, L. Mejias, V. K. Swami, A. D. Brooks, W. Y Shih, and W.-H. Shih, "Quantitative Assessment of Tn antigen in Breast Tissue Micro-arrays using CdSe Aqueous Quantum Dots," *Biomaterials*, **35**, 2971-2980 (2014)
121. Ceyhun E. Kirimli, Wei-Heng Shih, and Wan Y. Shih, "DNA Hybridization Detection with 100 zM Sensitivity Using Piezoelectric Plate Sensors with Improved Noise-Reduction Algorithm," *Analyst* **139**, 2754-2763 (2014)
122. Wei-Chun Tan, Wei-Heng Shih and Yang-Fang Chen, 'Highly Sensitive Graphene-Organic Hybrid Photodetector with Piezoelectric Substrate,' *Advanced Functional Materials*, 24, 6818-6825 (2014)
123. Cheng Chen, Zhigang Zhu, Xiangrong Zhu, Wei Yu, Mingju Liu, Qiaoqiao Ge, and Wei-Heng Shih, "A composite hydrogels-based photonic crystal multi-sensor," *Materials Research Express* **2**, 046201 (2015)
124. C. E. Kirimli, W.-H. Shih, and W.Y. Shih, Specific in situ hepatitis B viral double mutation (HBVDM) detection in urine with 60 copies ml^{-1} analytical sensitivity in a background of 250-fold wild type without DNA isolation and amplification. *Analyst*, **140**(5), 1590-1598 (2015)
125. Cheng Chen, Zhi-Gang Zhu, Wei-Heng Shih, Qiao-Qiao Ge, Ming-Ju Liu, and Xiang-Rong Zhu, "Facile Preparation and Self-Assembly of Monodisperse Polystyrene Nanospheres for Photonic Crystals," *Journal of Nanoscience and Nanotechnology*, **15**(4), 3239-3243 (2015)
126. Laura T Beringer, Xin Xu, Wan Shih, Wei-Hang Shih, Raymond Habas, Caroline Schauer, "An electrospun PVDF-TrFe fiber sensor platform for biological applications," *Sensors and Actuators a-Physical*, **222**, 293-300, (2015)
127. Giang Au, Wan Y. Shih, and Wei-Heng Shih, "Efficient Intranuclear Gene Delivery by CdSe Aqueous Quantum Dots Electrostatically-Coated with Polyethyleneimine," *Materials Research Express*, **2**, 015401 (2015)
128. Cheng-Hsin Lu, Wan Y. Shih, and Wei-Heng Shih, "Effects of Pb Treatment on Optical Properties of Aqueous CdSe Quantum Dots," *Ind. Eng. Chem. Res.*, **55**, 99−106 (2016)
129. Ceyhun E. Kirimli, Wei-Heng Shih, and W. Y. Shih, "Amplification-free *In Situ K-Ras* Point Mutation Detection at 60 copies/ml in Urine in a Background of 1000-fold Wild Type," *Analyst*, **141**, 1421 (2016)
130. Golam Haider, Prathik Roy, Chia-Wei Chiang, Wei-Chun Tan, Yi-Rou Liou, Huan-Tsung Chang, Chi-Te Liang, Wei-Heng Shih and Yang-Fang Chen, "Electrical Polarization Induced Ultra-high Responsivity Photodetectors Based on Graphene and Graphene Quantum Dots," *Adv. Funct. Mater.* **26,** 620–628 (2016**)**
131. Wei Wu, Wei-Heng Shih, and Wan Y. Shih, "Direct observation of binding Stress-Induced crystalline orientation in Piezoelectric Plate Sensors (PEPS)," *Journal of Applied Physics* **119**, 124512 (2016)

132. Cheng-Hsin Lu, Jiaang Hu, Wan Y. Shih, Wei-Heng Shih, "Control of morphology, photoluminescence, and stability of colloidal methylammonium lead bromide nanocrystals by oleylamine capping molecules," *J. Colloid & Interface Science,* **484**, 17–23 (2016)
133. Xin Xu, Youngsoo Chung, Ari D. Brooks, Wei-Heng Shih, and Wan Y. Shih, "Development of Array Piezoelectric Fingers towards *In Vivo* Breast Tumor Detection," *Review of Scientific Instrument*, **87**, 124301 (2016)
134. Kannaporn Pooput, Cheng-Hsin Lu, Wan Y. Shih, and Wei-Heng Shih, "Stable Aqueous Wurtzite Kesterite Suspensions by Direct Precipitation with Capping Molecules," *J. Nanosci. Nanotechnol.*, **17**(3), 2185-2190 (2017)
135. Song Han, Wan Y. Shih, and Wei-Heng Shih, "Charge-Neutral, Stable, Non-Cytotoxic, Near-Infrared SnS Aqueous Quantum Dots for High Signal-to-Noise-Ratio Biomedical Imaging," *Chemistry Select*, **2**, 7332-39 (2017)
136. Qi Tang, Haixiang Zhu, Cheng Chen, Yanxiang Wang, Zhigang Zhu, Jianqing Wu, Weiheng Shih, "Preparation and Characterization of Nanoscale Cobalt Blue Pigment for Ceramic Inkjet Printing by Sol-Gel Self-Propagating Combustion," *Materials Research*, **20**(5), 1340-1344 (2017)
137. Han-Wen Hu, Golam Haider, Yu-Ming Liao, Pradip Kumar Roy, Rini Ravindranath, Huan-Tsung Chang, Cheng-Hsin Lu, Wei-Heng Shih, and Yang-Fang Chen, "Wrinkled Two-dimensional Materials: A Versatile Platform for Low-threshold Stretchable Random Lasers," *Advanced Materials*, **29**, 1703549 (2017)
138. Volkan Kalem, Wan Y. Shih, and Wei-Heng Shih, "Dielectric and piezoelectric properties of PMN-PT ceramics doped with strontium," submitted to *Ceramic International* **44**(3), 2835-2842 (2018)
139. Jing Huang, Yi-Hua Wu, Zhi-Gang Zhu, Wan Y. Shih, and Wei-Heng Shih, "Control of oleylamine to perovskite ratio in synthesis of $MAPbBr_3$ nanoparticles," Chemical Physics Lett., 702, 21-25 (2018)