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Researcher of the Year 2018 - Professor T. Venkatesan: An unified journey of high-throughput Nanoscale technology

Dear Readers,

International Association of Advanced Materials (IAAM, www.iaamonline.org) names the researcher of the year who had the greatest contribution in the field of Advanced Materials. The advanced materials community would like to take this opportunity to pay rich tributes to Professor T. Venkatesan for his pioneering research and notable contributions to nanoscience and nanotechnology. Advanced Materials Letters have been selected his photo for the cover of this special year-end issue.

Prof. Venkatesan has been a Physicist and manager for 17 years with Bell Labs and Bellcore and in the last 17 years has been with the Center for Superconductivity Research at University of Maryland, College Park.

He founded the Surface Center at Rutgers University where he was a Professor for about five years (85-90). Most recently he was leading an effort in Oxide Electronics at UMD. Since 2008 he is directing the NanoCore Research Center at the National University of Singapore. He pioneered the Pulsed Laser deposition process and was the first to elucidate the intricacies of the process to make this a reproducible laboratory technique for the growth of high quality multi-component oxide thin films. He is an ISI highly cited Physicist (>20,000 citations ranked 66) has over 450 papers and 27 patents in the area of oxides involving superconductors, magnetic and optical materials. He is a Fellow of the American Physical society, World Innovation Forum, winner of the Bellcore award of excellence and the UMD graduate Board award. He was a member of the Physics Policy Committee and is the founding member of the International Oxide Electronics Workshop.

In 1989 he founded Neocera, a company specializing in pulsed laser and electron deposition equipments and also commercialized the HTS SQUID based magnetic microscope MAGMA for semiconductor failure analysis used by virtually all leading semiconductor manufacturers in the world today. A technology based on the scanning microwave near field microscope for silicon low K metrology was commercialized and sold to Solid State Measurements (SSM). He has helped many of his students and post docs in starting companies and 8 of them have started small companies or are holding executive positions in entrepreneurial ventures. He has raised venture capital money over several rounds and has been on the advisory board of the New Market Venture fund of UMD Dingman Center, the UMD incubator and has been involved in promoting entrepreneurship among young researchers. He holds a PhD from the University of New York and Bell Laboratories, USA and an MSc and a BSc (Honors) from the Indian Institute of Technology in Kanpur, India. Research contributions of Professor T. Venkatesan is as follow:

1973 – Today: Optical biostability- optical transistor

With the team of Hyatt Gibbs and Sam McCall, Venkatesan investigated the fabrication of the world's first optical transistor. The first device was demonstrated in sodium vapor when this team discovered the role of a nonlinear refractive index in addition to absorption which resulted in three US patents and a PRL [**1**]. Subsequently, Venkatesan demonstrated optical bistability in ruby and later with the team an ultra-small micron scale device in GaAs [**2**]. Subsequently, he performed an all-optical fiber optic based link in which the optical pulsed were completely manipulated using another optical beam at km demonstrating that all-optical signal processing is possible in a fiber optic link. Most recently, graphene nanobubbles were shown by him to exhibit optical bistability inside an interferometer [**3**].

1977-1983: Laser annealing of semiconductors

Venkatesan was one of the first to make an impact in this area by demonstrating the annealing of p-type GaAs using lasers [**4**]. Subsequently, in collaboration with David Auston, they were able to demonstrate the dynamics of the surface melting process using time-resolved reflectivity studies on the nanosecond time scale [**5**].

1979-1984: Ion beam interactions with organic thin films, graphite and carbon thin films.

As part of the Bell Labs team on focused ion beams and their applications, he helped build first Ga focused ion beam system at Bell, investigated the liquid metal ion sources (demonstrating one of the largest Stark splitting ever seen in gallium atomic emission lines), and developed numerous strategies for inorganic and organic ion beam resists. One of the important conclusion was that the enhanced resist sensitivity of ion beams will not be of much help due to Schott noise limitation [**6**]. Venkatesan's further important contribution was the original study of the effect of ion beams on organic materials in inducing conductivity, phase changes and the production of novel phases [**7**]. In collaboration with Millie Dresselhaus (MIT), they were able to fully understand solid phase epitaxy processes in graphite using ion channeling techniques. They were also able to show that graphite can be melted by pulsed laser beams answering a long-standing question as to whether a melt phase exists for carbon or not [**8**].

1984 - 1987: Enhanced diffusion mechanisms in GaAs/ GaAlAs heterostructures due to divancy formation by silicon substitution

When an amphoteric dopant like silicon is incorporated in GaAs this enables the formation of divacancies which then enhance the diffusion of Al in the GaAs system. The role of divacancies was conclusively demonstrated by the dependence of the diffusion coefficient of Al as the second power of silicon concentration [**9**]. This was also a period in which he demonstrated a number of semiconductor lasers based on non-flat mirrors which would lead to much higher power lasers on account of lower intensity on the mirrors during a sabbatical visit at Caltech in Prof. Yariv's group.

1984 - 1986

This was when Venkatesan moved from Bell Labs to Bellcore as manager of a surface group. Due to space problems, he negotiated with Rutgers University to locate his Surface division in the University in exchange for his help in creating a Surface Modification Center at Rutgers that would integrate the entire University effort. He was then made a Joint Director/ Professor at Rutgers and Manager at Bellcore and was successful in building up the Surface Modification Center (which exists even today), not only equipping the Center with experimental facilities but also helping in the hiring of top researchers- Madey, Gustaffson and Bartynski.

1987 - 1990: Invention of the pulsed laser deposition process

One of the most significant periods in Venkatesan's research life. Due to the difficulty in reproducing the film The composition of the multi-component oxides in the process of pulsed laser deposition which he developed at Rutgers-Bellcore came as a boon to the research on multi-component inorganic films [**10**]. Simple as the process seemed in reproducing the composition of complex materials, a clear recipe needed for the development and a systematic study of the process enabled him to lay out the conditions for preserving the stoichiometry of the film and the entire invention was laid out in publications and patents [**11**]. His team was able to leapfrog most of other techniques in producing high quality YBCO films, which put them at the front of the race on applying high Tc superconductors for numerous applications. They developed the heterojunction processes for making vertical Josephson junctions, high Q microwave resonators (put on a Navy Satellite), high efficiency bolometers (launched as IR detectors on the Cassini mission of NASA) and with John Clarke at UC Berkeley showed their films to have the lowest flux noise among the state of the art films, which validated the superiority of the PLD process [**12**]. His team received funding from DARPA, EPRI, Navy and other government organization to help move high Tc technology forward. He had a large global collaboration during this time and a very large publication output as well. He filed at least 6 different patents relating to High Tc technology out of a total of 13 patents with the Bell system.

1989 - Now

Venkatesan formed Neocera to commercialize oxide-based technologies in May 1989. The first product that became pulsed laser deposition systems. In addition, as Neocera was a global expert on high Tc films they received numerous government contracts from NSF, DARPA, DOD, NASA, DOE, DOC (as many 65 over two decades totaling over $22M). Neocera became a vehicle for commercializing technologies that spun off from academia. High precision temperature controller, SQUID based magnetic imaging system for fault isolation in integrated circuits, scanning microwave resonator to map low K dielectric constant films on silicon surfaces, pulsed electron deposition systems were some of the products introduced to the market place through Neocera (**Fig. 1**). Today the company is a world leader in selling pulsed laser deposition systems in over 36 countries and is selling Magma, the magnetic imaging system, to many semiconductor companies. The importance of Magma for the emerging 3D silicon integrated circuits is immense as this is becoming the only technique that can image defects through multi-layer stacks of silicon.

Fig. 1. Prof. T. Venkatesan discussing the process of pulsed laser deposition with his then graduate student, now Asst. Prof. at Nanyang Technological University, Dr. Renshaw Wang.

1990 - 2007

He left Bellcore for University of Maryland (UMD), Center for Superconductivity research in 1990 as he had formed Neocera (as there was too much conflict between his Bellcore job and the demands of his company) as a full Professor in Electrical and computer Science engineering and the Physics Department. He launched an effort to build a globally competitive program in Oxide electronics, hiring Ramesh from Bellcore to join his team at UMD. This team was successful in bringing in NSF MRSEC grants over three cycles covering a period of 15 years and a total funding of over 25M. In addition, his group procured a major ten-year contract with the Army, DARPA, and Navy. His research at Maryland covering a period of 17 years generated over 300 publications and 4 patents (licensed by Sumitomo Corporation). He graduated over 30 PhD candidates and over 15 Post-Doctoral candidates during this period.

During this period his group excelled in research on High Tc superconductors, n-type super conducting films in particular, electric field effects in superconductors [**13**], spin-polarized quasiparticle pair breaking in HTS, YBCO/PBCO superlattices [**14**] and the observation of large lattice distortions in YBCO correlating with various electronic transitions.

When research in colossal magneto resistive manganites initiated, his group was one of the pioneering ones to demonstrate, using spin polarized photoemission, the half metallicity of the manganites [**15**] and also showing the strong temperature dependent decay of the surface magnetization [**16**], explaining the difficulty of preparing large tunnel junctions with large room temperature magneto-resistance. Large electro-resistive effects in manganites [**17**] and large ferroelectric tunneling switching [**18**] were demonstrated for the first time which subsequently have led to a great deal of research activities in these areas growing unabated even today.

When the diluted magnetic semiconducting oxides research began his group was the first to demonstrate oscillatory exchange coupling in an all-oxide superlattice system and clustering of Co in Co-doped TiO_2 and also show conclusively that the magnetism originated from defects rather than from the magnetism of the dopants. The first demonstration of cationic defect mediated magnetism was demonstrated for the first time in Nb-doped TiO_2 by the measurement of Kondo scattering in this system and subsequently identifying the defect responsible to be Ti vacancies using x-ray absorption studies [**19**].

2007 - Now

Venkatesan was invited to Singapore to form a Nano Institute around this time and after exploring the research landscape at NUS he accepted the position of Director of a new Institute named NanoCore (**Fig. 2**). The University made a significant investment in this Institute (>S$40M) and after a few years when the unit started to gather momentum the University administration decided to consolidate several laboratories- NUS Nano science and nanotechnology initiative (NUSNNI), Singapore synchrotron light source (SSLS) and NanoCore under a single management under Venkatesan with co-management support from Prof. Mark Breese. The overall Institute is now called NUSNNI.

Fig. 2. Prof. T Venkatesan with the President of National University of Singapore, Dr. Tan Chorh Chuan.

Several new facilities were set up for users including a major PLD facility, Fs lasers, spintronic and spectroscopy laboratories, clean room and litho facility, cryogenic facility, and a bio-laboratory. In addition, he initiated a program with Zeiss Corporation whereby the company created a state of the art microscopy facility in NUSNNI called, Zeiss Microscopy Lab at NUS. Venkatesan was instrumental in hiring outstanding researchers to come to NUS, Barbaros Oezyilmaz (graphene), Hyunsoo Yang (spintronics), Ariando (Oxide interfaces), Andrivo Rusydi (spectroscopy of Correlated systems), Slaven Garaj (Nanopores), Qing Wang (photovoltaics/ batteries), and Steven Pennycook (TEM). All these researchers including Venkatesan have generated a combined research funding exceeding S$100M from the National Research Foundation. His research at NUS has been very broad with oxides for electronics, memory, magnetics, photonics, energy and bio applications. Some of the exciting results at NUSNNI- NanoCore are as follows:

At the interface of a polar and a non-polar oxide insulator, a 2D electron gas is observed. Venkatesan and his team have shown for the first time that besides conductivity these interfaces also support a variety of magnetic phases (electronic phase separation) [**20**]. They have shown such electronic phases to exist even when the interface is not atomically flat, but is corrugated as in a (110) orientation. His team further explained in detail the role of electronic reconstruction and oxygen vacancies in contributing to the interface conductivity. The most spectacular demonstration of charge reconstruction was the phase transition from an antiferromagnetic phase to a ferromagnetic phase when six layers of $LaMnO_3$ are grown on $SrTiO_3$ with the fifth later remaining antiferromagnetic [**21**], a collaborative work involving three institutions under Venkatesan's leadership. In VO_2 physics the long-standing question of whether a crystallographic phase transition is needed along with the vanadium dimerization transition was answered by the synthesis of an A/B phase composite which shows the electrical phase transition (with dimerization transition confirmed by Raman measurements) while the crystallographic phase remains unchanged across the transition. Based on the high quality of the films and heterostructures made by his group he has forged extremely strong collaborations with faculty at MIT, UC Berkeley, Cornell, Yale, Northwestern, U Twente and Purdue.

Besides the work on electronic properties, conclusive evidence for cationic vacancy mediated ferromagnetism was demonstrated in TiO_2 [**22**] with the observation of co-existence of ferromagnetism and Kondo scattering in the same TiO_2 system.

In oxide based ferroelectric tunnel junctions a bilayer of barium titanate (BTO) is adequate to show large tunneling switching on/off ratio disproving the theoretical prediction that BTO will cease to be a ferroelectric below three unit cells.

In the oxide bio interface, he has shown that bacterial, cell growth and cell differentiation is strongly influenced by the chemistry of surfaces. The science behind this seems to be primarily due to macromolecular physics- adhesion of lipids and extracellular matrix protein adhesion to the surfaces seems very important. His bio team has deployed surface plasmon resonance as a way to quantitatively design nano- drug delivery schemes [**23**]. His bio-team is now deploying a proton exchange mass spectrometer to look at the correlation between cancer patients and volatile organic compounds in their breath (metabolomics) [**24**]. The very same mass spectrometer is being utilized in experiments involving material libraries of catalysts for CO_2 reduction where volatile methanol and other organic products produced by solar irradiation of the catalysts library will enable one to identify novel catalysts for CO_2 upconversion [**25**].

Currently, his research team at NUS is tackling cutting-edge problems in the areas of electronics, memory, magnetics, energy, bio-inorganic interfaces and health (**Fig. 3**). His main focus now is in using organic and oxide systems to develop an artificial synapse, the holy grail of artificial intelligence [**26**].

Fig. 3. Prof. T. Venkatesan with the architect of his organic electronics program, graduate student Sreetosh Goswami.

Professor T. Venkatesan is a pioneer and a continuous source of inspiration to the nanoscience and nanotechnology research in the world. The scientific community of advanced materials offers salutations to Professor T. Venkatesan for his continuous services is rendered in the promotion of modern education as well as research in Asia and USA. On this special occasion, we tribute to Professor Venkatesan, a distinguished professor, technologist, scientist, educationist, academician and researcher whose achievements will continue to inspire and guide the advanced materials community for a long time to come.

We congratulate to Professor T. Venkatesan for Researcher of the Year 2018.

With kindest regards,
Dr. Ashutosh Tiwari
Editor-in-Chief, Advanced Materials Letters

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