Z.L. Wang’s Summary of Achievements

Dr. Zhong Lin (ZL) Wang is a Regents' Professor, COE Distinguished Professor and Director, Center for Nanostructure Characterization, at Georgia Tech. He has authored and co-authored four scientific reference and textbooks and over **610** peer reviewed journal articles (13 in *Nature* and *Science*), 55 review papers and book chapters, edited and co-edited 14 volumes of books on nanotechnology, and held 20 patents and provisional patents. Dr. Wang is the world’s top 10 most cited authors in nanotechnology. His entire publications have been cited for over **31,000** times. The H-index of his publications is **86**.

Dr. Wang was elected to a fellow of American Physical Society in 2005, fellow of AAAS in 2006, fellow of Materials Research Society. He has received 1999 Burton Medal from Microscopy Society of America, 2001 S.T. Li prize for Outstanding Contribution in Nanoscience and Nanotechnology, the 2000 and 2005 Georgia Tech Outstanding Faculty Research Author Awards, Sigma Xi 2005 sustain research awards, Sigma Xi 1998 and 2002 best paper awards, and the 2009 Purdy Award from American Ceramic Society. His breakthrough researches in the last 15 years have been featured by over 50 media world wide including CNN, BBC, FOX News, New York Times, Washington Post, NPR radio, Time Magazine, National Geography Magazine, and Scientific America.

Dr. Wang has made significant profound contributions to the synthesis, discovery, characterization and understanding of fundamental physical properties of oxide nanobelts and nanowires. He pioneered the *in-situ* mechanical measurement in TEM. His breakthroughs in developing nanogenerators established the principle for self-powered nanodevices by harvesting mechanical energy from environment and biological systems.

Wang is widely credited for the discovery and synthesization of oxide nanobelts (*Science*, 209 (2001) 1947; > 2800 citation. This is the most cited paper in the history of Georgia Tech). The nanobelts are a new class of one-dimensional nanostructures denoting a wide range of semiconducting oxides with cations of different valence states and materials of distinct crystallographic structures. Wang's pioneering work opened a new chapter in functional nanomaterials for building nanodevices. This landmark paper is among the list of the top 30 most influential papers published in *Science* in the last 10 years, the top 10 most cited paper in materials science in last decade. The rational approach outlined in this work has subsequently served to nucleate a large body of studies by other researchers worldwide. As a result, ZnO is the most exciting type of one-dimensional nanostructures for oxides that holds equal importance to Si nanowires and carbon nanotubes.

Wang was the first who synthesized and understood the growth processes of novel oxide nanostructures. Owing to the positive and negative ionic charges on the zinc- and oxygen-terminated ZnO basal planes, respectively, a spontaneous polarization normal to the nanobelt surface is induced. As a result, helical nanosprings/nanocoils are formed by rolling up single crystalline nanobelts and nanorings (*Science*, 303 (2004) 1348; > 383 citation; *Science*, 309 (2005) 1700; >187 citation). These are the first papers that described the spontaneous polarization-induced novel nanostructures and they open a new direction of research for studying piezoelectric properties at nano-scale. This research has led to the fabrication and applications of electromechanical coupled sensors, transducers and resonators for MEMS and biomedical sciences.

Wang invented nanogenerators and first established their working mechanism for harvesting mechanical energy using nano-enabled technology (*Science*, 312, (2006) 242; >180 citation). Developing novel technologies for wireless nanodevices and nanosystems are of critical importance for in-situ, real-time and implantable biosensing. An implanted wireless biosensor requires a power source, which may be provided directly or indirectly by charging of a battery. It is highly desired for wireless devices and even required for implanted biomedical devices to be self-powered without using battery. Therefore, it is essential to explore innovative nanotechnologies for converting mechanical energy, vibration energy, and hydraulic energy into electric energy that will be used to power nanodevices without using battery. A groundbreaking research by Wang in 2006 is the invention of the piezo-electric generators for self-powered nanodevices. He demonstrated an innovative approach for converting nano-scale mechanical energy into electric energy by piezoelectric zinc oxide nanowire arrays. By deflecting the aligned nanowires using a conductive atomic force microscopy (AFM) tip in contact mode, the energy that was first created by the deflection force and later converted into electricity by piezoelectric effect has been measured for demonstrating nano-scale power generator. The operation mechanism of the electric generator relies on the unique coupling of piezoelectric and semiconducting dual properties of ZnO as well as the delicate rectifying function of the Schottky barrier formed between the metal tip and the nanowire. This research was chosen as the world top 10 most outstanding discovery in science by the Chinese Academy of Sciences. Wang was featured by *Science Watch* in Dec. 2008 issue for his pioneer work in nanogenerator. The fiber based nanogenerator was selected as the top 10 most important emerging technologies in 2008 by the british *Physics World, MIT Technology Review*, and *Beijing Daily* newspaper.

Wang has demonstrated his outstanding creativity through the development of DC nanogenerators driven by ultrasonic wave (*Science* 316 (2007) 102). The nanogenerator is composed of aligned ZnO nanowires and a zigzag top electrode, which is a novel, adaptable, mobile and cost-effective approach with a great potential in nanotechnology. The nanowires can be grown on solid substrates or polymer substrates as flexible power generators. In 2008, he has developed the first microfiber-nanowire hybrid nanogenerator (*Nature* 451 (2008) 809-813; *Nature Nanotechnology* 4 (2009) 34), establishing the basis of using textile fibers for harvesting mechanical energy. The principle and technology demonstrated have the potential of converting mechanical movement energy (such as body movement, muscle contractions, blood pressure), vibration energy (such as acoustic/ultrasonic wave), and hydraulic energy (such as flow of body fluid, blood flow, contraction of blood vessel) into electric energy that may be sufficient for self-powering nanodevices and nanosystems. The prototype technology established by the nanogenerator set a platform for developing self-powering nanosystems with important applications in implantable in-vivo biosensing, wireless and remote sensing, nanorobotics, MEMS and sonic wave detection (*Scientific American*, January issue (2008) 82). The fiber nanogenerator is selected by *New Scientist* as the top 10 most potential technologies in the coming 30 years, which will be as important as cell phone and iPod.

Wang pioneered the field of nano-piezotronics (*Advanced Materials*, 19 (2007) 889), which couples piezoelectric and semiconducting properties of nanowires and nanobelts for the designing and fabricating of electronic devices and components, such as piezoelectric field effect transistors and piezoelectric diodes. It is anticipated to have a wide range of applications in electromechanical coupled electronics and sensing.

Wang pioneered the field of in-situ nanomeasurements in transmission electron microscopy on the mechanical, electrical and field emission properties of individual nanotubes, nanobelts and nanowires. Characterizing the physical properties of carbon nanotubes is limited not only by the purity of the specimen but also by the size distribution of the nanotubes.

Traditional measurements rely on scanning probe microscopy. Based on transmission electron microscopy, Wang and his colleagues have developed a series of unique techniques for measuring the mechanical, electrical and field emission properties of individual nanotubes in 1999. His in-situ TEM technique is not only an imaging tool that allows a direct observation of the crystal and surface structures of the material at atomic-resolution, but also an in-situ apparatus that can be effectively used to carry out nano-scale property measurements (*Science*, 283 (1999) 1513; >883 citation). A nanobalance technique and a novel approach toward nanomechanics have been demonstrated (*Phys. Rev. Letts*. 85 (2000) 622), which was selected by APS as the breakthrough in nanotechnology in 1999.

Wang is an extremely influential scientist in materials science and fundamental electron microscopy. His textbook entitled of *Functional and Smart Materials - structural evolution and structure analysis* (Plenum Press, 1998) is "a unique, cutting-edge text on smart materials ... it is recommended as an adjunct to device design books used for engineers as well as scientists during the development of smart devices and structures" (*Physics Today* , Nov. 1998, p. 70). His textbook on *Elastic and Inelastic Scattering in Electron Diffraction and Imaging* (Plenum Press, 1995) is "a noteworthy achievement and a valuable contribution to the literature" (*American Scientist*, 1996). His textbook on *Reflected Electron Microscopy And Spectroscopy For Surface Analysis* (Cambridge University Press, 1996) is “a book that any materials science or physics library should be holding" (*MRS Bulletin*, Oct., 1998).