Special Section Editorial: Russell Messier's Lifetime of Nanomorphology

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This Special Section of the *Journal of Nanophotonics* on nanomorphology comprises papers written by friends, colleagues, and former students of Russell Messier, Professor Emeritus of Engineering Science and Mechanics at the Pennsylvania State University, to commemorate his 65th birthday.

Fig. 1. Russ Messier: 64 years young and golfing as often as he can these days.

1 RUSS MESSIER

Let me introduce you to my friend, colleague, and mentor, Russell Francis Messier, who prefers to omit his middle name for some reason. He prefers to be called *Russ*. One look at him, and you will agree that he is definitely a *Russ*. Not only a *Russ*, but he is a *New-England Russ*, as you will quickly guess from his pronunciation: when he calls out to his lovely wife Linda, *Linder* comes out of his mouth.

Russ was born on July 30, 1944, into a working-class family with no history of formal education beyond high school. His father made shoes at a local factory and his mother did piecework for Sprague Electric. While growing up in southern New Hampshire, his childhood was typical of middle-class America at that time. He spent lots of time outdoors, playing games and sports and socializing, with ample time to simply lie down on the grass and look into the sky and fantasize about where he came from and where he wanted to go.

Mathematics and science came easily and enjoyably, but baseball, basketball, soccer, and golf were his focus. Soccer, especially, taught him many life lessons, those of dedication, hard work, and teamwork leading to success in many different ways. During three years on his high-school's premier soccer team, the last as a co-captain, his school came in third, first, and second, successively, in the New Hampshire state championships. But golf was, and remains,

his major passion, with winning the British Open his teenage dream. (After retirement, he has resumed golfing and hopes to become a "phenom" on the veteran's circuit.) Work was always part of the mix: picking up trash at a local fried-clam stand at 5:30 am, delivering newspapers in the afternoon, and caddying most every day throughout his teenage years.

Fig. 2. Linda and Russ Messier in Linda's garden.

The era of Sputnik emerged while Russ was in high school. Its influence was to direct him towards engineering and education as an immediate life goal. Being a statistical realist, he realized that professional golf was not his future route to the American dream of that time—to do better than your parents by going to college and fulfilling both their dreams and yours.

Northeastern University was a blue-collar university in Boston, with a good reputation in engineering and, most importantly, was, and still is, the largest co-operative education school in the nation. With money in Russ' family always in short supply, the co-op work experience was of more immediate value than providing the route to his career in materials research. Between scholarships, his savings from his teenage work, and his co-op wages, his parents' total cost for his college education was \$500 plus room and board while on his work assignments.

A co-op assignment took him to Sanders Associates, an early microelectronics company in Nashua, New Hampshire. He had the good fortune of working in the applied physics research laboratory at Sanders off and on for three years. This laboratory was then developing high-frequency delay lines and transducers for military electronic-countermeasure systems. He started out polishing crystals of cadmium sulfide to thinner and thinner dimensions in order to achieve higher and higher operating frequencies. The relentless demand for even higher frequencies drove him from a top-down approach (polishing) to a bottom-up approach (thin-film deposition). This was the beginning of his work in the nano-world of thin-film science and technology. By this time shoe-manufacturing jobs had disappeared from the American workplace, an early victim to cheaper foreign labor, and his father was now working at Sanders as a technician. Russ has a bittersweet memory during his junior year when he returned to his co-op job and found out he was earning more than his father—a consequence of education and opportunity. It was a proud moment for his parents.

By the time Russ graduated from Northeastern in 1967 with a BS degree in electrical engineering, he realized that materials science was his career passion and, although his training in electrical engineering provided a wonderful base, education at a graduate school was essential. After considering Rensselaer Polytechnic Institute, the University of Rochester, Johns Hopkins University, and Penn State, Russ made the life-defining decision to go to Penn State and to carry out his research in one of the new Materials Research Laboratories (MRL) funded by the National Science Foundation. Prof. Rustum Roy, then the director of MRL,

became his thesis advisor. He also gave Russ the opportunity to go in a direction that was new for MRL: deposition of thin films of new materials using new plasma-based technologies. Radiofrequency sputtering became a commercial reality in 1967, and Russ ended up with the first rf-sputter deposition system made by the Materials Research Corporation. That system was used as a demonstration model in 1968. It allowed Russ to explore the nano-world of thin films with the use of concurrent ion bombardment during film growth, an aspect covered in his paper in this special section.

During his years as a graduate student, Russ was neither a bookworm nor a lab freak. His life headed in several directions besides research: "preparation for later life," as he would say afterwards. By the spring of 1968, he was elected president of the Graduate Student Association at Penn State. Those were tumultuous times for student activism on American college campuses. For the next year his days weren't long enough, being torn between classes and research in one direction and campus politics, protests, and social events in the other direction. Yet he found time to nurture his relation with the chair of his social committee, a Spanish major and friend. Linda O'Brien became his wife by the time his presidency, though not his involvement, came to an end. That was 39 years, two children, and four grandchildren ago. And their love for one another is still going strong.

After receiving his PhD degree in 1973 in solid-state science, an interdisciplinary program in materials, and continuing his research as a postdoctoral scholar for an additional year, Russ left Penn State to pursue a different area of research: development of phosphor powders for medical x-ray technology. However, his interest in thin-film science was not quenched, and he returned to Penn State to pursue this career direction. Starting with a year-to-year contract position in 1976, his career in materials research flourished with funding initially in the solar-energy materials area and then on thin-film morphology.

Funding from the U.S. Air Force Office of Scientific Research from 1982 to 1985 focused and consolidated his work on thin-film morphology. During that period, I met Russ. He was then a senior research associate at MRL and also an associate professor of solid-state science. I was a research associate in the Department of Engineering Science and Mechanics. We met in the office of a senior colleague, perhaps in August 1984. Russ began telling us about fractals and the fractal morphology of thin films. He showed us top-surface and cross-sectional scanning electron micrographs of various types of thin films. He showed us a thick sample of pyrolytic graphite. I knew nothing about fractals then. I had heard about scanning electron microscopes, but had not seen micrographs earlier. Russ was very patient. Thereafter, we met several times.

A year passed. One day, a 1000-W lamp turned on in my brain, when I reacquainted myself with Dr. Seuss' *The Cat in the Hat Comes Back*. "Ah! So that's what a fractal is," I said to myself. Russ agreed, when I called him. Thereafter, we co-authored several papers on the Sierpinski gasket and other fractal structures. Along with Joe Yehoda, then a PhD student of Russ, we also grew wild-type cauliflowers in order to find their fractal dimension.

Richard McNitt, then the head of my department, offered a tenure-track appointment to Russ in 1985. Russ was tenured in 1986. Four years later, Russ was promoted to professor of engineering science and mechanics. Retiring in 2005, he was given the emeritus rank.

In 1988, Juan-Manuel García-Ruiz came to visit MRL for a year from Spain, to work with Heinz Henisch at MRL. Juan-Manuel, Russ, and I formed a discussion group. We met a couple of times a month, to chat about thin films and their morphology. Our big question was as follows: If thin films have a fractal morphology, why does matter at the length scales of everyday experiences form objects with Euclidean morphology? At one of these meetings, we suddenly realized competition between growth elements, both processes and material particles, is responsible for that transition. A paper was published by us some years later, and led directly to the conceptualization of sculptured thin films shortly thereafter.

By this time, Russ had become very famous for low-temperature diamond coatings. He made the first page of the September 14, 1986, issue of the *New York Times*. His grinning

visage showed up in the cover story of the *Money* section of *USA Today* on March 18, 1987; perhaps, that was the reason for the Dow Jones Index soaring that day. Numerous other newspapers and magazines featured reports on this work. Russ went on to make distinguished contributions to the deposition and the characterization of ultrahard coatings and founded the first, and perhaps still the only, journal dedicated to that topic.

The morphology of thin films remained Russ' true passion throughout his academic career at Penn State. His dedication and contributions were recognized by the Leroy Randall Grumman Medal of the Grumman Corporation in 1987 and by the Fellowship of the American Vacuum Society in 1996. The Penn State Engineering Society gave him an Outstanding Research Award in 1990. His name figures in the ISI List of Highly Cited Researchers.

Lest it be construed that Russ is only a brilliant researcher, let me note that he oversaw undergraduate education in the Department of Engineering Science and Mechanics at Penn State for three years ending in 2005. During this period, he was so popular with undergraduate students that the Penn State Engineering Society gave him an Outstanding Advising Award in 2004.

Throughout his career Russ was a natural mentor. More than a dozen visiting researchers from Taiwan, Spain, Germany, Mexico, Japan, and India have profited from his readiness to impart both information and knowledge to anybody at any time of the day (or, even the night, as Linda would add). A dozen junior faculty members have been mentored by him as well. There is no counting the number of graduate students whom he mentored: some were his own, others adopted him an unofficial research advisor. Thanksgiving and Christmas meals at the house of Russ and Linda and their two children, Stephen and Tamara ("Tammy"), would resemble a mini-meeting of the United Nations. Several graduate students in financial distress simply stayed with Russ and Linda until better times came. No wonder, Penn State conferred on him the Howard B. Palmer Mentoring Award in 2003.

Now that Russ and Linda have crossed the Mason-Dixon Line to live in Virginia, Russ is occupied with golfing and occasionally helping Linda in her garden. Both are doting grandparents to two dashing little boys and two breathtakingly beautiful little girls. The Messiers' absence at Penn State is acutely felt by his colleagues. Fortunately, telephones and the Internet lessen the distance between the two locations. Also, Russ and Linda often visit Penn State.

Fig. 3. Linda and Russ Messier with their two children, their children's spouses, and their four grandchildren.

2 NANOMORPHOLOGY

Russ is widely known and admired for elucidation of the nanoscale morphology of thin films prepared by vapor deposition under low-adatom-mobility conditions, especially clustering at the sub-5-nm level. Over a career spanning four decades, Russ has examined all aspects of vapor-deposited nanomaterials and the evolution of their morphology from the nanoscale to the microscale. He has examined and developed various thin-film deposition processes ranging from physical vapor deposition to chemical vapor deposition techniques, and the morphologies produced by alterations of deposition conditions. He has focused on the translation of fundamental knowledge of morphology toward the manufacturing of useful thin-film materials. The culmination of the first three decades of his research can be appreciated by his wide-ranging contributions to (i) the science and technology of diamond, cubic boron nitride, and related ultrahard materials, and (ii) the emergence of sculptured thin films.

Research on thin-film materials became his focus, when as an undergraduate student he interned at Sanders Associates in the area of ultrasonic dielectric materials prepared by evaporation techniques. His graduate research at MRL expanded his thin-film preparatory methods to radiofrequency sputtering, an emerging field at the end of the 1960s, which allowed for the study of a wide range of insulating and semiconducting materials at much lower temperatures than their melting points. This led naturally to his PhD thesis on a new approach to understanding the formation of noncrystalline solids during which he developed an approach to preparing and understanding the continuum of free-energy states ranging from amorphous to nanocrystalline to microcrystalline to single crystal.

After two and a half years in industry in research on bulk luminescent materials, he returned to Penn State to continue research on thin-film materials. The ability to engineer their properties, and to make new materials, defined much of his subsequent research. By the early 1980s, his work was revealing the commonality of film morphology independent of the material and dependent primarily upon the substrate temperature and ion bombardment during deposition. His 1984 paper on the evolutionary structure zone model of thin films prepared under low-adatom-mobility conditions is a seminal contribution to our understanding of columnar thin-film morphology. With a fractal-like conceptual and theoretical model in his mind, Russ used various microscopy techniques to connect the columnar morphology of thin films, prepared under low-adatom-mobility conditions, from the nanometer scale to the micrometer scale. His morphological studies of thin films prepared at temperatures about 0.3–0.5 of the bulk melting point (in Kelvin), demonstrated that 1-to-3-nm clusters are the building blocks of an evolving surface morphology and the related internal void network. The effects, and quantification, of concurrent ion bombardment on the nanoscale and microscale morphology were also demonstrated for the first time. Extensive preparation and characterization studies of films provided the experimental database needed to develop and test the evolutionary zone model. Not surprisingly, he became the leading proponent of the importance of the quantification of thin-film morphology as a critical step in quantitative preparation-property relations.

Russ' expertise on morphology led me to call him in 1992, after I came across a sample of ulexite. Within a few weeks, we had developed a conceptual understanding of dynamically modifying the shapes of the growing columns (or nanowires) in a columnar thin film. When that understanding was reduced to practice in collaboration with colleagues at the University of Alberta, we enunciated the concept of sculptured thin films for optical, chemical, biological, and other applications. Many optical and some other applications have been realized since then, and more than 25 research groups worldwide are actively working on sculptured thin films today.

While his research on nanoscale morphology was in full swing, Russ also became the leader of a major group effort at Penn State on diamond films prepared by vapor deposition

processes. This was the first group in the U.S. to recognize the importance of work begun in the USSR and Japan in the early 1980s. In 1985 his group repeated that work and published their first results. Since then, they have generated a large amount of scientific and even public interest through both government- and industry-funded research. Russ became the founding Editor-in-Chief of the international journal *Diamond and Related Materials*, serving in that position for about 15 years. From artificial diamonds to cubic boron nitride, a superhard material similar to diamond, was but a short step for Russ who went on to establish the bombardment stabilization of this metastable phase.

I would be remiss if I did not tell you that Russ is the discoverer of the explosive crystallization phenomenon in amorphous germanium and related thin films, which were used extensively in the late 1970s and early 1980s to study laser recrystallization of semiconductor films. Russ was also the first to demonstrate a high T_c (13.7 K) in thin-film ceramic superconductors with the perovskite structure. These were the precursor to the current wave of 90-K perovskite high-temperature superconductors. He elucidated negative-ion resputtering in oxide-sputtering processes and the anisotropically etched morphology that results from that resputtering.

3 PRINCIPAL PUBLICATIONS OF RUSS MESSIER

The concluding section of this editorial is a list of the principal publications of Russ Messier. He is also named as an inventor or co-inventor on seven U.S. patents.

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