Energy efficiency with organic electronics: Ching W. Tang revisits his days at Kodak

Interviewed by **Stephen Forrest**
and **Nicole Casal Moore**

Ching W. Tang, widely considered the father of organic electronics, built the first organic solar cell and the first organic light-emitting diode (OLED) in the 1980s. The enabling innovation for both devices was made possible by an organic heterojunction—a bilayer structure of an electron donor and an electron acceptor. This structure can be used to fabricate exceptionally efficient OLEDs and organic solar cells. Tang's insights unleashed a torrent of activity in the field and eventually sparked an industry. His seminal articles on organic photovoltaics and OLEDs were published in *Applied Physics Letters* **48** (1986) p. 183 and **51** (1987) p. 913, respectively. Now a professor at the University of Rochester, Tang discussed with *MRS Bulletin* his days at Kodak.

***MRS BULLETIN*: How did you get interested in organic electronic devices?**
CHING W. TANG: I took an organic chemistry lab as a junior at the University of British Columbia. I liked the class, but I was really bad in organic synthesis. I clearly remember these words the professor said: "Hold this beaker like this and use the stirrer like this, and make sure you don't punch a hole through your beaker." Before he finished the sentence, I got a hole in the beaker and tried desperately to collect my material with my bare hands. It dawned on me then that organic chemistry was not for me, so I concentrated on physical chemistry.

I went to Cornell University to do my PhD, where I studied the photoconductive properties of chlorophyll. That was the beginning of my work in organic electronics. There was a lot of interest in photovoltaics then, and I started working in that area. I constructed photovoltaic cells with chlorophyll and learned that they were really inefficient, like 0.01%. Although I didn't make any breakthroughs, I learned a great deal about organic/metal contacts and how to manipulate them, which I found very useful in my future work on OLEDs.

Kodak hired me as a postdoc to work on organic solar cells. After exploring a few classes using dyes without much success, I learned about a technology using aggregate photoconductors, which was being developed at Kodak for electrophotography applications. Basically, the aggregate photoconductor is a mixture of a polymer, an absorbing dye, and a hole-transport molecule that can be induced to segregate to form two separate and interpenetrating phases—one capable of transporting holes and the other electrons. I used the aggregate photoconductor as an absorber in a solar cell. It worked much better, but fundamentally the carrier mobility was too low for the aggregate photoconductor to be useful in solar cells. Nevertheless, the idea of using a heterogeneous mixture of two phases to enhance the charge generation and transport properties in an organic photovoltaic cell was formed. This idea was encapsulated in one of my first patents.

I was the only person working on organic solar cells, while the other researchers in the group were working on cadmium telluride solar cells. I would get 0.1% with a lot of struggles, and they would get 10% on a routine basis. It was very humbling, even when I achieved a major breakthrough—getting 1% from a novel heterojunction structure. During the first few years, I spent most of my time on solar, but then serendipitously I discovered that using the same heterojunction device structure, I could get light emission. So my direction began to shift almost 180 degrees.

Your patents came out in 1981, but your seminal papers were 1986 for solar cells and 1987 for organic light-emitting diodes in *Applied Physics Letters*. Why the delay?
I wrote the solar cell paper in 1980 or 1981, after I was finished with the organic solar cell project and moved on to OLEDs. I submitted it for corporate clearance but was not approved

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usually evaporate chromium first, and then you evaporate gold, with the chromium acting like a sticking layer. So I tried silver with magnesium. Once I started doing that, boom! The electrode worked! It solved the day-to-day variability issues.

Once we were confident that we could produce these cells on a routine basis, in around 1986, we went on to construct simple passive-matrix display panels for demonstration. However, due to patterning issues, we had a great deal of trouble making a display good enough to convince ourselves or our managers that we could develop OLED into a display technology. Although we succeeded in fabricating several functional panels after about a year, we were unsure of the path forward, and I decided it was time to write a paper on OLED for publication. I wrote a short paper with Steve Van Slyke for *Applied Physics Letters* and submitted it for corporate clearance. The 1986 solar cell paper took years to get clear, and this OLED paper took almost no time. The moment it was published, I got calls from researchers from companies in Japan wanting to learn more about OLEDs. Pioneer, Hitachi, Toshiba, and Sony began their development of OLEDs. Kodak also decided to expand their OLED research effort.

because of the proprietary nature of one of the materials described in the paper. It was held up for a few years, then somehow in 1986, it was approved for external publication. By then I was fully involved in OLED research.

The OLED paper is another story. It was published in 1987 with my colleague Steven Van Slyke. Our two-layer heterojunction structure work began around 1980. The first structure was based on a layer of copper phthalocyanine and a layer of spin-on blue fluorescent dyes. The efficiency was not very good, and stability was our biggest problem. The light produced by these first devices would just fade away right in front of you. It was very frustrating. Not until much later, in 1981 or 1982, did we come upon a class of metallized 8-hydroxyquinolinato dyes. Almost immediately we realized that the stability of this class of dyes was much better, and the best known OLED molecule—Alq or tris (8-hydroxyquinolinato) aluminum—was discovered. But I also had to develop the electrodes, which was a big problem. I knew we needed to have a low work function metal as the cathode for electron injection, so I tried magnesium, but magnesium wouldn't always stick to an organic layer. It was very frustrating; one day you get a good cell and another day you wouldn't. To solve this problem, I used something called "metal nucleation layers." When you try to make gold stick in a vacuum deposition process, you

We talked about OLEDs for display. What about lighting? Today in the laboratory, LEDs have an efficacy of about 250 lumens per Watt, and OLED panels are at about 100 lumens per Watt, but moving upward. Do you see a real opportunity in the synergistic use of these two lighting sources to substantially change our domestic energy use?

I have no doubt that LEDs or OLEDs will contribute to the future of lighting. The adoption of LEDs is just starting. LED is expensive. You pay $10 for LED light bulbs versus $1 for a compact fluorescent. People have to get over that kind of sticker shock and realize that over the long run, the cost of LEDs or OLEDs will come down.

In terms of energy impact, it's potentially a huge savings. Electricity consumption for lighting in this country, if I remember correctly, is about 20 percent of total electricity use. You're talking about more than 100 lumens per Watt for future LEDs and OLEDs. An incandescent bulb is about 16 or 20 lumens per Watt. It's a five-fold or more difference.

What do you see as the prospects and the market potential for organic photovoltaics?

I am pleasantly surprised that the current organic photovoltaic efficiency is getting as high as 10 percent. That is an order of magnitude higher than what I achieved. All you need is another factor of two now. Can we get that? I think over time we will.

But in order to sustain an industry, you need applications in both short and long terms. Organic solar cells may be less efficient than inorganic solar cells, but they are lighter in weight. Imagine if you could just pack it and roll it out in your camping site! Or maybe you could attach it to the back of your cell phone and then, by pointing it to light, you could make that one last call. Those could be value-added applications.

From a science point of view, organic material is very messy. In crystalline silicon, you know how to control its properties and tailor them for specific device applications. That's not how organic electronics works. There's a lot of guessing here and there. OLED is a good example. We can get a beautiful display technology out there while continuing to refine the set of organic materials needed to produce brilliant colors with the highest efficiency. I think it's an exciting time for organic electronics.

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