■ VISION 43 ■

Curiosity Drives Research Activity – A Strong Desire to Know and Learn

— What makes a researcher successful in creating skin-like wearable devices?

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Dr. **Takao Someya**

At one time, it was generally thought that semiconductor devices had to be made on a hard silicon substrate. Then, in the 2000s, researchers started exploring flexible electronic devices, although most of the research focused on display devices. In this environment, in 2004, Prof. Takao Someya (who specializes in electrical engineering at the University of Tokyo's Graduate School of Engineering) developed artificial skin ("E-skin") for use on robots. More recently, he has earned acclaim by successfully developing an ultra-light nanomesh sensor that causes no inflammation even when it is left attached to human skin for a week. We interviewed Professor Someya for this article.

Profile of Professor Takao Someya

Takao Someya received his Ph.D. degree in Electrical Engineering from the University of Tokyo in 1997. Since 2009, he has been a professor of the Department of Electrical and Electronic Engineering at The University of Tokyo. From 2001 to 2003, he worked at the Nanocenter (NSEC) of Columbia University, and at Bell Labs and Lucent Technologies as a Visiting Scholar. He also conducts the NEDO/JAPERA Project as Project Leader (since 2011) and the JST/ACCEL Super-bioimager Project as Research Director (2017–2022).

An exceptional math teacher in junior high helped me decide to pursue a career in math and science

What was your childhood like?

Someya: Two things stood out. The first was having a truly excellent math teacher in junior high school. Thanks to him, I fell in love with math. The second was the fact that my father was an engineering researcher. I was strongly influenced by him from an early age.

So I chose to study math and science. After entering the university, I was again fortunate to have many wonderful teachers, who guided me in finding a path as a researcher.

What are your hobbies?

Someya: In junior high school, I joined the astronomy club. We observed and photographed the stars and planets at night and developed the photos the next day. Photography is still my hobby. For nearly 10 years after my research lab got started, I took most of the photos destined for external publication. Some of these were featured on the covers or in the opening articles of well-known magazines, including TIME.

In senior high school, I was a member of a chorus club. I sang bass, and I continued to sing in university. Although I like classical music best, I also developed an interest in jazz after coming into contact with it while studying in the U.S.

Studying in the U.S. inspired an interest in organic electronics

What led you to become involved in your current research?

Someya: In university, I chose engineering because it is a field that can be directly useful to people. I became interested in semiconductors, which were said to be Japan's key industry, and I decided to major in electronic engineering.

I studied at a research lab where nanostructures of inorganic compound semiconductors – one type of semiconductors that are microfabricated - were created. The physical properties of the electrons sealed inside them were also examined. My supervisor at the time was Prof. Hiroyuki Sakaki, who has been active in many fields and has made distinguished contributions. It was also in that lab that I encountered ULVAC equipment.

After graduation, I began to do research on the optical and engineering properties of nanotechnology in the lab of Prof. Yasuhiko Arakawa. Although it did not lead directly to my current area of interest, it was so-called mainstream research, focusing on semiconductor miniaturization.

The trend toward miniaturization was approaching its physical limits, and yet I had just begun research and had more than thirty years to go before I would reach retirement age at 65! So I began to think about taking on a subject in a new, slightly different field that had never before been tackled.

In 2001, I received a scholarship to study for about two years at Bell Laboratories in the U.S. That is where I learned about a research project in which organic semiconductors were being applied to transistors. This was my encounter with organic electronics.

Development of "E-skin" for robots as the second step

How did you proceed after that?

Someya: At Bell Laboratories, I was researching how to produce electronic circuits of organic transistors on plastic film using a stamping method. While I was studying there, a Bell Laboratories researcher successfully developed a prototype of the world's first electronic paper. This was really big news, but back then all research on flexible electronics was on display devices. Nevertheless, this gave me a great opportunity to transition to a new field and its challenges.

After coming back to Japan, I began researching organic transistors jointly with Prof. Takayasu Sakurai at the University of Tokyo's Institute of Industrial Science. Prof. Sakurai is one of the best-known Japanese researchers of silicon integrated circuit designs.

He also had experience working in private industry and was an authority on reducing both the power consumption of silicon devices and the cost of circuit designs. Back then, it was said that circuits could be made inexpensively if printing was used. Prof. Sakurai already knew the truth, which was that printing would not necessarily make circuits less expensive. However, he has continued to identify other good reasons to use printing.

Since the use of silicon allows a large number of transistors to be microfabricated on a small area, the cost per transistor is low. However, silicon is not good for making transistors sparsely on a large area. If you want to make circuits on a large area, printing has an advantage. It seemed possible that if we used printing on a film, it might be possible to produce flexible sensors over a large area. Silicon would be unsuitable for this. I decided to begin research on developing such sensors.

In the period from 2003 to 2004, I developed a prototype of E-skin, which feels similar to human skin and can be applied to robots. In 2005, TIME magazine featured this as a cover story.

This was the second leap for me. E-skin has kept evolving, and we are now developing sensors that can be applied not only to robots, but also to human skin. For the results of our latest research, please see Latest Research Trends [1] and [2] (p. 16-17).

The next research step was hidden within failure

What is your philosophy as a researcher?

Someya: I always try to make tasks enjoyable for myself and others. Research means doing something nobody has done before. Since there are naturally more failures than successes, it is extremely important for a researcher never to give up, even after failing, but to keep going and be very persistent.

When things are not going well in research, it's easy to get discouraged. However, the hint for the next step often lies precisely amidst the things that have not been going well. So even if you have failed, you need to learn from the failure and keep challenging the problem. This process is apt to be difficult, but we can devote ourselves to it if the subject is something we find interesting and we enjoy the process. If we genuinely enjoy something, we can keep doing it.

If you can convince yourself of how interesting it is, you will discover the spirit of research and the joy of trying to create something new. You will feel that the process is your life's purpose. Then, you might become completely absorbed in the project. Research is something you cannot do unless you have this kind of fresh engagement and passion. Curiosity–the strong desire to know and learn– is the main driving force behind research activities at universities. In corporations, profitability as a business is required, but at universities, the researcher's interest and curiosity are the starting point. Therefore, university research can sometimes lead to a discovery that would not be possible if one were only concerned about the market or business feasibility. From a corporate viewpoint, reaping the fruits of such research activities could lead to more academic-industrial collaboration.

Research on organic electronics leads to a better understanding of humans

What is the roadmap to commercialization, and what is your dream?

Someya: Among the ideas we have been researching, some are finally entering the commercialization stage and are approaching the verification phase. Therefore, I want to expand collaboration with outside organizations to move towards verification.

For example, we have received an offer from a hospital to immediately start a trial of a device that involves applying a stretchable sensor directly to the skin. However, we can make only a small number of prototypes at the university.

To validate the usefulness of a product, we need a technology that will allow us to produce 100, or in some cases 1,000, product prototypes with a reasonable level of quality. Universities are limited in this sense. I think that bridging the gap between universities and corporations, and fostering more academic-industrial collaboration, will help technology advance.

What is your dream?

Someya: My research is extremely focused on producer-driven solutions. The starting point of my research is how to produce soft devices with the idea that they could become one of the major means of narrowing the gap between artificial things and living organisms. The research on narrowing that gap must first identify exactly where the gap exists.

Obtaining information from a human body involves measuring what kinds of signals the body is emitting, and what kind of activity the person is engaged in while living in a natural state. This information can yield a better understanding of human beings. So improving the performance of semiconductor devices can deepen our understanding of human beings. This relationship is quite intriguing, isn't it?

Since measuring and understanding the activities of human bodies in their natural state requires carrying out a long-term plan, what I can hope to accomplish in the remaining years of my career is limited. I hope the members of our lab will continue this research based on their own interests, so that the project keeps evolving even after I stop being an active researcher.

I think the term "flexible electronics," which is being used right now, will disappear in the future. That is, nearly all electronic devices will begin to use flexible technology, making the term redundant. Even though flexible circuit boards are currently used in devices such as smartphones, most consumers do not realize that their devices use flexible electronics. As these technologies advance, flexible sensors and semiconductors will continue to be incorporated into people's daily lives without their realizing it. When that happens, as a future development of wearable devices, devices will be capable of collecting data from various symptoms users are experiencing - such as how well the wearer is coping with stress, and any resulting rise or fall in blood pressure. Data collected via such a device will be able to add a scientific basis to measurements of human behavior and essential characteristics.

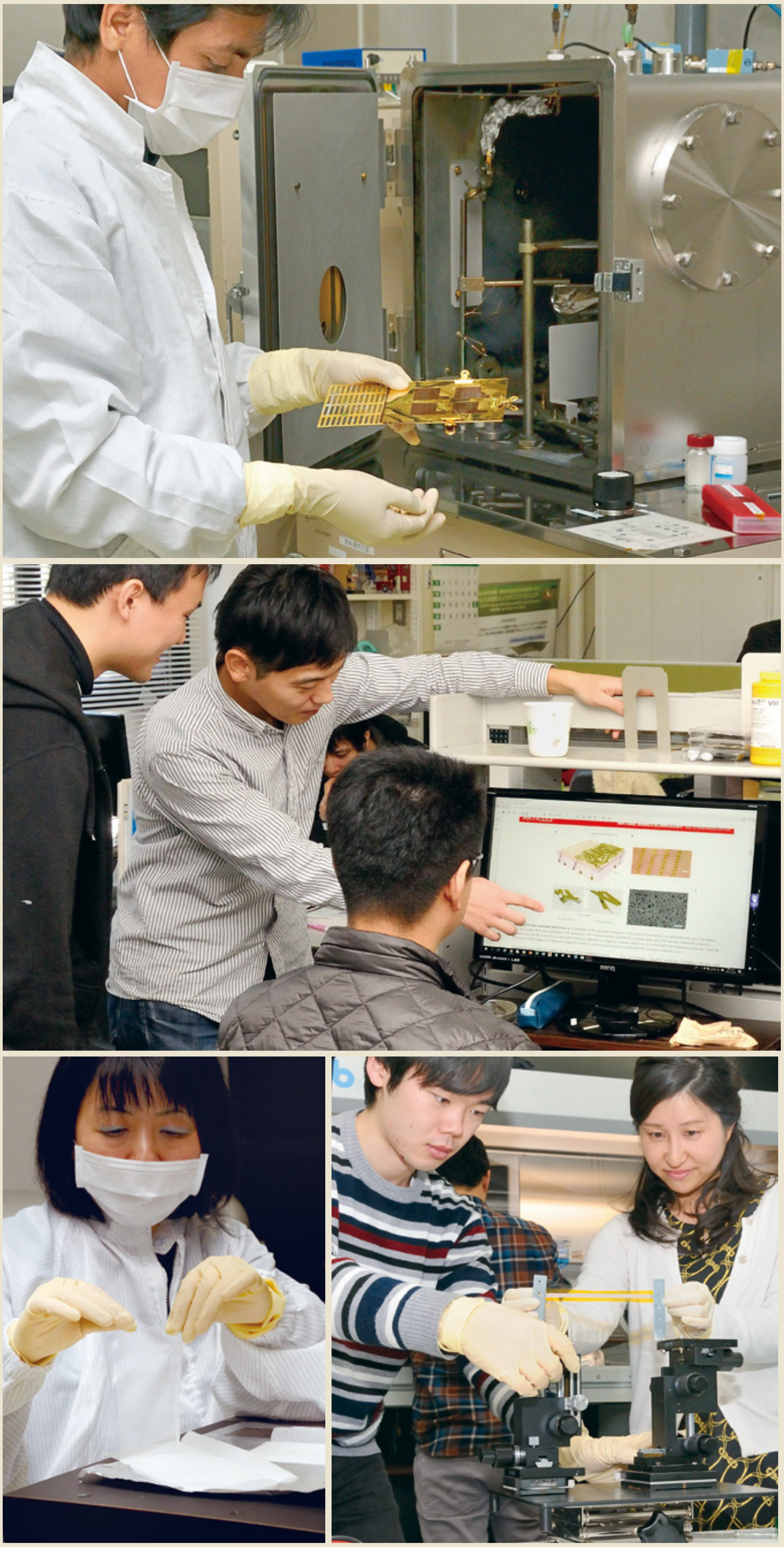
I hope for further advances in research on wearable devices, such as a new scientific measurement method that will lead to a more essential understanding of what it means to be human. That is my dream.

We need technologies and devices that support individual customization

What would you like ULVAC to do?

Someya: Wearable devices for humans need to be custom-made for each individual. One thing I would like ULVAC to do is develop manufacturing technologies capable of inexpensively customizing electronic parts to fit the wearer's body. This is not limited to ULVAC equipment. I think we will see increasing demand for such equipment throughout the industry.

During the course of my research on skin-like flexible sensors, they have been made manually one by one, like artisanal pieces. We cannot produce a large volume of industrial products this way. I would like to ask ULVAC to develop equipment that could inexpensively maintain high throughput while keeping a high yield, and that would keep costs low even when making different devices to suit different individuals.



More than two-thirds of the members of the Someya Lab are students from other countries. Citizenship is varied, and therefore research discussions are carried out in English, as a rule. The power of the world's young people is working to open the door to a bright future through research on "intriguing" devices.

Latest Research Trends [1] **Published in May 2017**

Strategic Basic Research Programs of the Japan Science and Technology Agency (JST)

Elastic Conductor with Highest Performance in the World

Promising application to new materials based on discovery of natural formation of silver nanoparticles in rubber

Takao Someya (Professor, Graduate School of Engineering, University of Tokyo)
Naoji Matsuhisa (PhD Candidate in Electrical Engineering, Graduate School of Engineering, University of Tokyo)

We have succeeded in developing an elastic conductor that demonstrates the world's highest conductivity of 935 S/cm, even when stretched to five times its original length. This elastic conductor can be used to make free-form wiring patterns, using a printing technique to apply a paste material onto an elastic material such as rubber or a textile. When we observed the structure of the new material using a high-resolution electron microscope, we discovered a phenomenon in which simply mixing micrometer-sized silver flakes into rubber caused nanometer-sized silver particles to naturally and uniformly occur inside the rubber.

Printable elastic conductors represent a technology that will be essential for achieving sportswear-type wearable devices requiring a high degree of stretchability, as well as artificial skin for robots, which requires a higher degree of stretchability than human skin. Conventional elastic conductors had a problem in that their conductivity dropped significantly when stretched, but this problem can be solved by the new phenomenon discovered in our research. Our research findings make it possible to easily form highly stretchable sensors on sportswear and the joints of robots. These are expected to be utilized in a variety of applications in the future, such as healthcare and artificial tactile sensing.

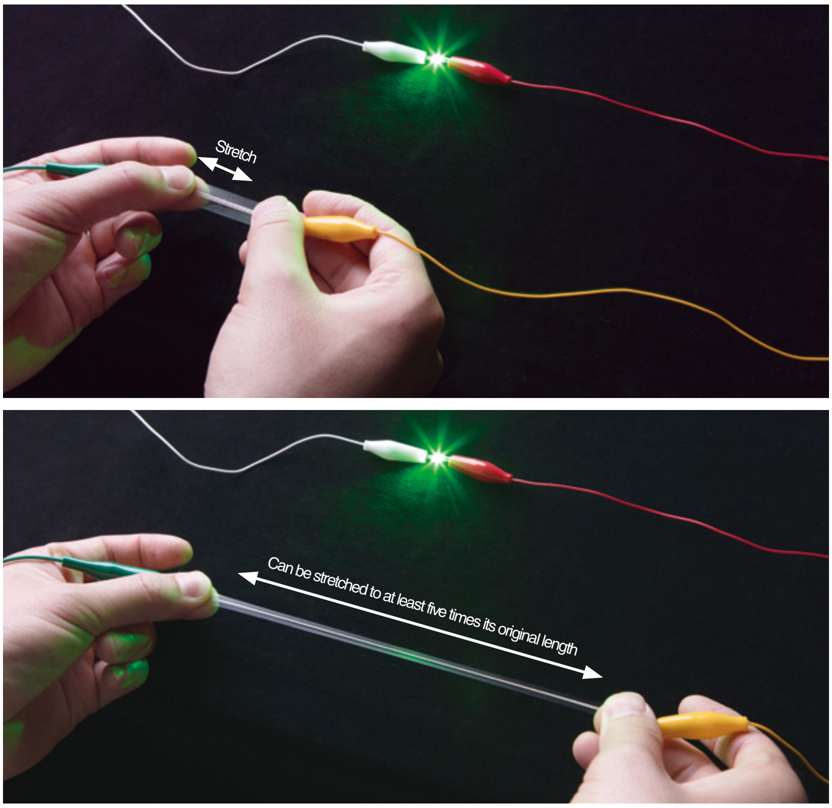


Figure 1: Since the elastic conductor printed on a rubber sheet maintains a high degree of conductivity even when stretched to five times its original length, it is still capable of brightly illuminating a light-emitting diode (LED). The top photo shows the conductor's original state; the bottom photo shows the results of its being stretched to at least five times its original length.

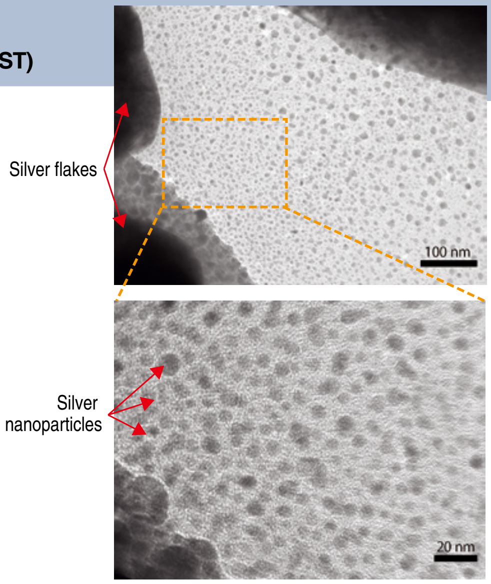


Figure 2: Transmission electron microscope (TEM) image of the newly-developed elastic conductor. High-density silver nanoparticles naturally formed among silver flakes are uniformly dispersed.

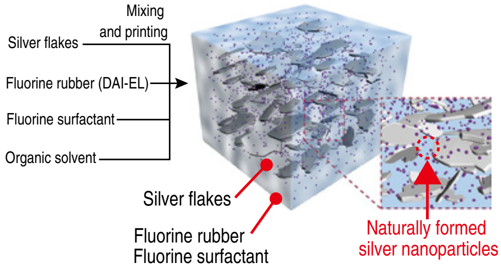


Figure 3: This figure shows a schematic diagram of the production process for the newly developed elastic conductor and its material structure. Silver nanoparticles, which were not originally contained in the material, form naturally inside the fluorine rubber. DAI-EL is the name of a product made by Daikin Industries, Ltd.

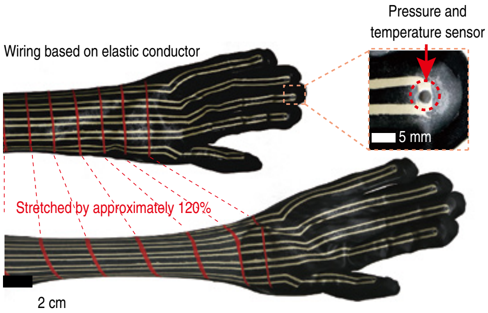


Figure 4: Elastic pressure and temperature sensor made by printing. It can be easily affixed to a textile substrate using hot melt adhesive.

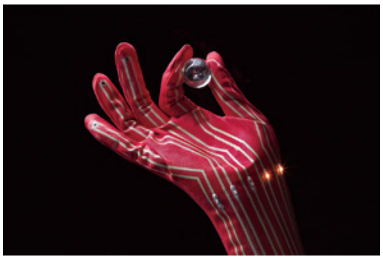


Figure 5: Sensors mounted on the fingertips of a glove are used to measure the intensity of the pressure at the fingertips, and the LED illumination intensity varies accordingly. This makes it possible to know how strongly force is being applied, which image data cannot indicate.

Latest Research Trends [2] **Published in July 2017**

Strategic Basic Research Programs of the Japan Science and Technology Agency (JST)

Wearable nanomesh sensor that allows the skin to breathe naturally

Promising for long-term health monitoring because the sensor does not cause inflammation, even after being worn on the skin for a week

Takao Someya (Professor, Graduate School of Engineering, University of Tokyo)
Masayuki Amagai (Professor, School of Medicine, Keio University)

We have successfully developed a nanomesh electrode that does not cause any apparent inflammation, even after being continuously worn on the skin for a week. It is so light and thin that users forget they even have it on. This electrode (hereafter referred to as "nanomesh electrode") was constructed from nano-scale meshes containing gold and a polymer, polyvinyl alcohol (PVA)—materials considered safe and biologically compatible with the body. This nanomesh electrode can be easily applied to the skin using a tiny amount of water. We conducted a week-long patch test—for irritation and skin allergies—on 20 subjects and detected no apparent inflammation on the participants' skin. We were able to achieve this high level of biological compatibility because the nanomesh structure is highly gas permeable, allowing the skin to breathe naturally, which could not be achieved using conventional substrates made of film or rubber sheet.

Furthermore, we measured changes in resistance when the nanomesh electrode came into contact with or was removed from a conductive material such as metal, and we verified the operation of the temperature and pressure sensor. We also measured the electrical activity of arm muscles to prove the nanomesh electrode's applicability to health monitoring. The electrode does not cause inflammation, even after being continuously worn on the skin for a week, and is so light and thin that users forget they even have it on. Thus, the nanomesh electrode represents an essential technology for making long-term measurements in medical applications, and for achieving detailed analyses of bodily motions in sports. It can be expected to be utilized in a variety of applications in the future.

Figure 1: Wearable nanomesh electrode affixed to an index finger, with power supplied from a flexible battery that turns on an LED

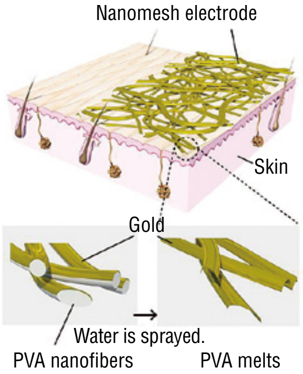


Figure 2: Nanomesh electrode structure and how it is worn. Nanomesh structure in a sheet form constructed from gold and polyvinyl alcohol (PVA)—materials considered safe and biologically compatible with the body—can be affixed to the skin by placing it on the skin and then spraying a tiny amount of water.

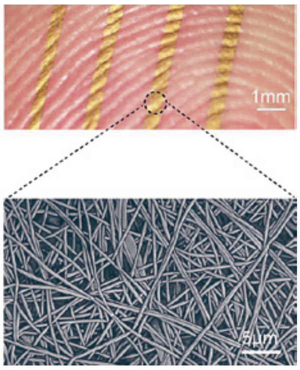


Figure 3: Nanomesh electrode applied to the fingerprint side of a finger (top); a scanning electron microscope (SEM) image of an electrode formed on a skin replica (bottom). This shows a state in which 300- to 500-nm mesh conductors are intertwined.

Figure 4: Wearable nanomesh electrode applied to the back of a hand The electrode closely follows the skin contours. It lets the skin breathe naturally and is so thin and light that wearers forget they have it on.