Semiconductor as the Engine of Modern Civilization

---- in commemoration of Global IT Award ----

Introduction

In November last year (2013), I received “Global IT Award” from the President of the Republic of Armenia. This award was established in 2010 in the Republic of Armenia aiming for building the IT based nation, and it is awarded to one individual each year who has made global contribution in the IT field. The winners in the past are all eminent figures such as Craig Barrett (Former Intel Chairman), Steve Wozniak (Apple co-founder), Federico Faggin (the world’s first microprocessor development leader). And with them, I was chosen as the fourth one.

It is an honor more than I deserve, but I think this is the award not given to me alone, but the one to be shared with everyone in the semiconductor field who I worked with. I deeply appreciate all the support given to me. The award commemorative lecture sponsored by SSIS (Society of Semiconductor Industry Specialists) was held on July 10th, 2014 and this paper is based on the presentation at the time.

What kind of country is Armenia?

I would like to start with a short introduction of Armenia. As you can see in the map below, Armenia is a small country located in Caucasian region which is between the Black Sea and the Caspian Sea.

Fig.1　Map of Armenia and its vicinity

The population is 3 million, but there are 7 million Armenians living abroad who are called Diaspora. This is a very unique feature of its population composition which has much to do with its IT development. Their religion is mostly Christian, and Armenia is known as the first nation that established Christianity as the state religion.

Ethnic history is old, and recently the winery facilities which were built 6,000 years ago have been discovered. The unified state was formed around the 10th century B.C., but because of its

important location for transportation, the nation had to go through difficult times of being invaded by the surrounding forces repeatedly, often putting the nation under their ruling. We can call them “the nation of phoenix”, indeed.
It became independent in 1991 with the collapse of the Soviet Union, and the Republic of Armenia is a young country of 23 years old (as of 2014). And “IT country” is the national strategy which they chose as their future direction.

Why “IT country”?

They had been included in the planned economy system prior to 1991 as one of the member countries of the Soviet Union. Along with its independence, the gear of the planned economy stopped to turn, and the country’s economy became extremely depressed. Amid such hardships, they sought about the future direction of the country and decided to proceed with the IT fields as a national strategy.

What is its background?

1） IT is the driving force of the 21st century civilization and is the most promising field for Armenia as well.
2） Armenia has poor natural resources such as energy, and only human resources are the country’s fortune.
It has always been regarded that their intellectual level is high from ancient times, with the following saying; “Jews are smart and good at business, and three non-Jewish people together cannot match one Jewish. But even three Jewish together cannot match one Armenian.” Such high intellectual level is the great asset in the IT field.
3） In the era of the Soviet Union, the center of the high-tech field was in Armenia, and it was called “Silicon Valley of Soviet Union”. They can make use of the technology assets of those days.
4） As mentioned above, there are 7 million Diaspora living abroad against 3 million domestic population. Diaspora living in the advanced countries of IT are close to the IT market, and the global environment is in place where they live. This is a great advantage in advancing “IT country”.
5） Major products in the IT field are software. It has no physical weight, and the transportation cost is minimal. The location far from the market is not disadvantageous to Armenia.
6） Many excellent young people are sent out to the society every year from domestic universities, and it is an urgent matter to secure high-level jobs for them. From this point as well, it can be said that aiming at “IT country” has great significance.

Establishment of Global IT Award

In Armenia, they are aiming at “IT country” as the whole country. The President and the Prime Minister are heading for the promotion of various policies in this strategy.
Started in 2010 as a part of such measures is the “Global IT Award” which states as follows: “This is to award one person in each year who made great contributions to humanity through the

advancement in IT. The winners' contributions in the IT field must be innovative, it must have a great impact on humanity, and also it has to be widely recognized worldwide".

In the evening of November 15, 2013, the award ceremony was held at the President's Palace. Approximately 100 guests were there at the ceremony including the President and the first lady, and the Prime Minister and his wife.
On time, the moderator announced the opening, and the speeches started sequentially.
In the beginning, the explanation about "Global IT Award" was given, and it was stated that the expectation for this award was extremely high, by quoting the following words of Steve Wozniak who was the second winner. "The Nobel Prize does not include the IT field. For me this award is the same as the Nobel Prize in the IT field."
Subsequently, my career and achievements were introduced as the winner of this time. There were also some extra compliments which made me feel a little embarrassing, but I appreciated and listened to it. The summary is as follows.
"Dr. Makimoto is one of the best visionaries in Japan and played a major role in the semiconductor technology conversion from the 1970's. He led the conversion from NMOS technology that was mainstream at the time to CMOS technology with low power consumption. The technological change dramatically improved the performance of IT equipment, and it changed our world drastically. All the IT equipment today is based on semiconductor technology called CMOS which he promoted."
After this, there was an awarding ceremony of Certificate, Medal, and Trophy which were handed from the President Serge Sargsyan.

Fig.2　Presentation of Certificates, Medals, and Trophy by President Serge Sargsyan

Following the award ceremony, the President gave a congratulatory speech as follows.
"Dr. Makimoto has been leading the world with a vision far ahead of the time. Looking back over the past fifteen years, new mobile devices such as smart cards, smart phones, e-books and others

were made and our social life has changed completely. All such changes were enlightened and realized by his foresight."

Next, it came to my turn to make a speech by the moderator's nomination.

After expressing my appreciation to the President and the attending people, I talked how the world has changed due to the progress of semiconductors, by introducing examples of easy-to-understand cases. And the words I chose as the core message were, "IT is the locomotive of modern civilization. And the semiconductor is the engine of that locomotive."

Semiconductor as the engine of modern civilization

As I talked in the speech of the award ceremony, it can be said that it is the semiconductor innovation that supports the foundation of the modern civilization.

Fig.3 below shows it symbolically. Cray's supercomputer introduced in 1976 had a performance of 160 MFLOPS, which is comparable to that of the iPod today. Moreover, the price was 6 million dollars, and the weight was 5.5 tons. How did such a huge machine come to be on the palm? The answer is semiconductor innovation. Cray's supercomputer was based on 5μ bipolar device technology (ECL), whereas the current iPod is based on 45nm CMOS technology. This has been made possible by the progress in miniaturization of geometry and device innovation.

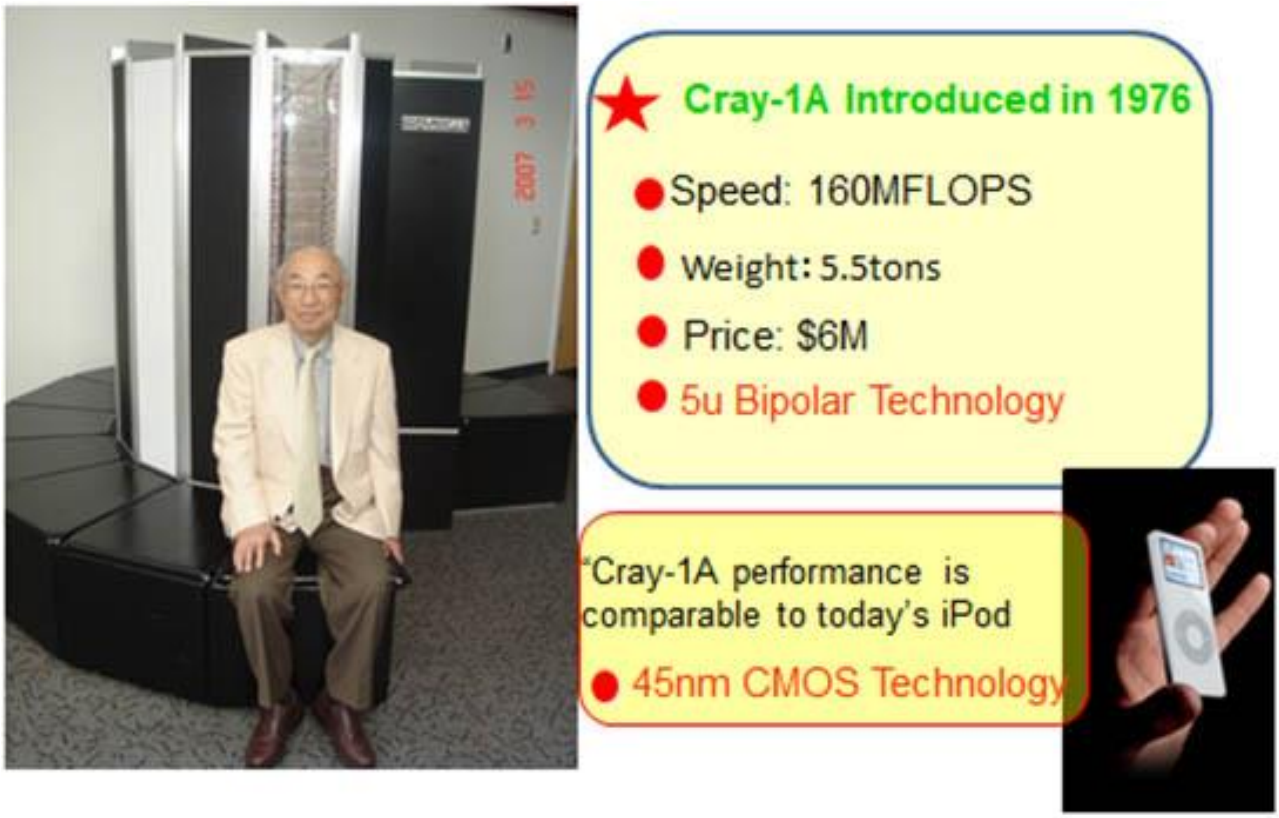

Fig.3　Supercomputer in 1970's is now on our palm

The degree of integration has been enhanced by miniaturization of processing technology, and the result is known as "Moore's Law". Fig. 4 below shows that this rule does not simply follow the path of single device evolution, rather, in a form like baton relay of various devices; starting from bipolar device to PMOS, to NMOS, and to CMOS.

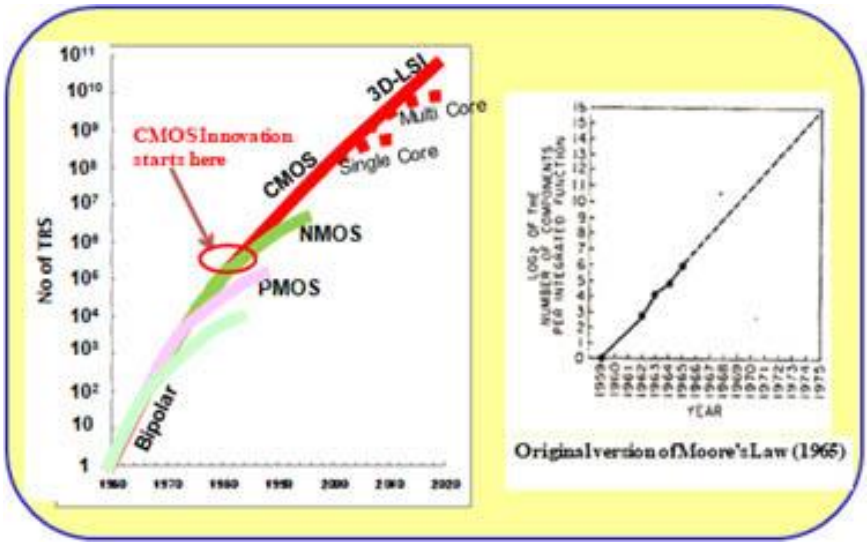

Fig.4　Moore's Law and CMOS Innovation

Since the 1980's, the core device has been CMOS, but there had been twists and turns before CMOS was recognized as the mainstream of the semiconductor industry. I will talk about that situation.

Until the 1970's, it was the common understanding in the industry that "CMOS is a niche device with low power but slow speed." It was a consensus that the mainstream was NMOS.

In order to break this common sense, it was necessary for CMOS to achieve high speed comparable to that of NMOS while maintaining the characteristics of low power.

It was made possible by the invention of "Twin well CMOS" technology invented by Yoshio Sakai and Toshiaki Masuhara of Hitachi Central Laboratories. And 4K bit SRAM using that technology was developed in 1978, and it demonstrated that CMOS could actually surpass the mainstream NMOS.

Subsequently, it was shown that CMOS was superior to NMOS in microprocessor application and also in DRAMs, and CMOS innovation gradually expanded to different kinds of devices.

As can be seen from the figure below, conversion to CMOS did not occur at once, but it gradually expanded to various devices and systems in the times of several decades.

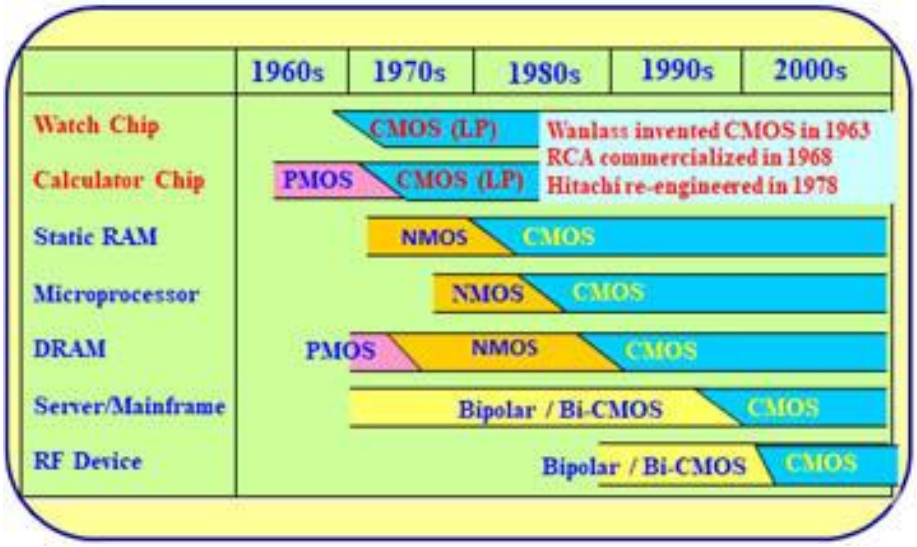

Fig.5　Evolution of CMOS innovation

Looking at today's IT-related equipment, CMOS is used for all equipment ranging from large systems like supercomputers and servers to small systems like smartphones and wearable devices.

Due to the expansion of CMOS innovation, the power consumption of electronic equipment has been drastically decreased. And as the result of such innovation our social life has changed dramatically. "Nomad Style" has become more normal and common, in which activities of people are not constrained from time and location; like looking into smartphones on commuting trains.

I anticipated from sometime in the middle of 1990's that such a time would come in the future, and I published a book "Digital Nomad"(1997, UK) with David Manners who is a friend of mine. The Chinese version was published next year in Taiwan, and the Japanese version also followed it.

Just 10 years after the publication of the book, in 2007, iPhone was put into the market from Apple, and the new life style has gradually expanded. It can be said that the mobile society has finally arrived thanks to CMOS innovation.

Fig.6　The mobile society created by the CMOS innovation

Future prospect

Technological innovation will continue to make progress, and its final goal is still out of our visible sight. In what kind of direction will the technology advance, and what kinds of changes will it bring to the civilization?

Let's see the "big trend" which can occur from now. So far, the technological innovation of semiconductors has greatly advanced the function that corresponds to human brains. Progress in this direction will go further, and in addition to this, progress will be further accelerated in the function corresponding to the "five senses" of human being.

A representative example is a robot. Information processing capability of robot today is already in a level far surpassing PCs, and the requirement for the increase of its capability will continue in the future without fail.

As a result, the intelligence of robot will unlimitedly approach to the level of human being.

Meanwhile, various functions covering the area of human “five senses” such as optical sensor, MEMS sensor, and chemical sensor will come out. In other words, semiconductor technology will become more sophisticated as it will diversify in the future

Robots are expected to become technology drivers for the future semiconductor field, and to become market drivers at the same time.

Such prediction was made in 2002 IEDM (International Electron Devices Meeting) as shown in Fig. 7. Although more than 10 years have passed since then, there is no need for change in this prediction.

With the evolution of semiconductor technology in the past, new “waves” appeared one after another in the electronics field.

The “Analog Wave” started to rise in the 1970’s and 1980’s centered around TVs and VCRs, and then the “First Digital Wave” followed it centered on PCs in the 1980’s and 1990’s. And now we see the rise of the “Second Digital Wave” from the 1990’s where digital consumer products are mutually connected in the networks.

I predicted in 2002 that the “Robotics Wave” would be the next big wave and that this would be a long continuing wave. It is because the evolution of robots will continue together with the progress of semiconductor, and it will be far ahead in the future when the synergistic relationship between them reaches the saturation point.

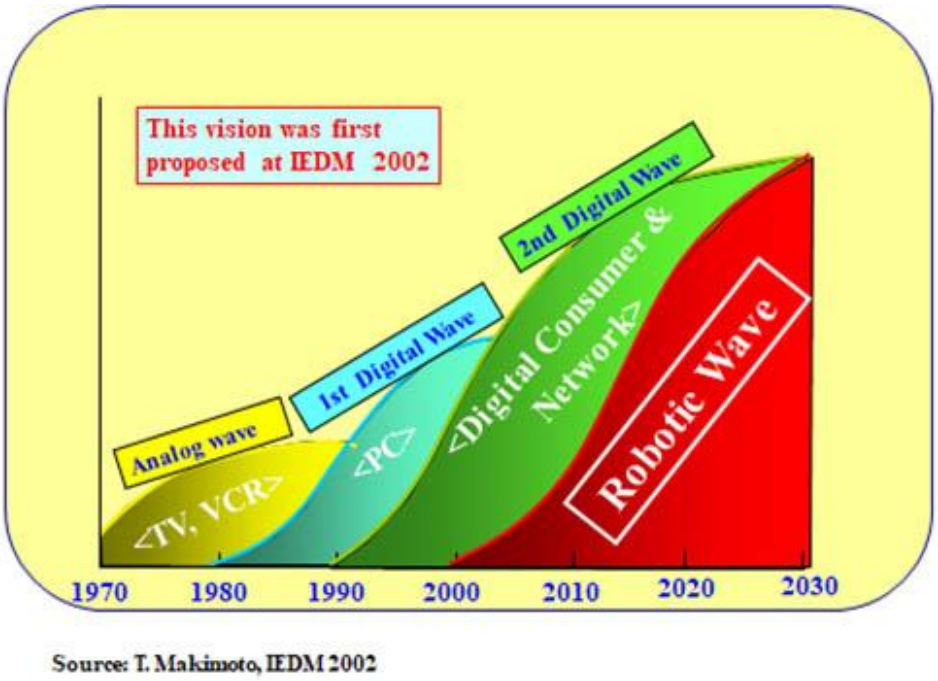

Fig.7　Rising wave of robotics

I would like to touch on another important technical prospect that supports such a new era. This is the future prediction seen from “Makimoto’s Wave” shown in Fig.8

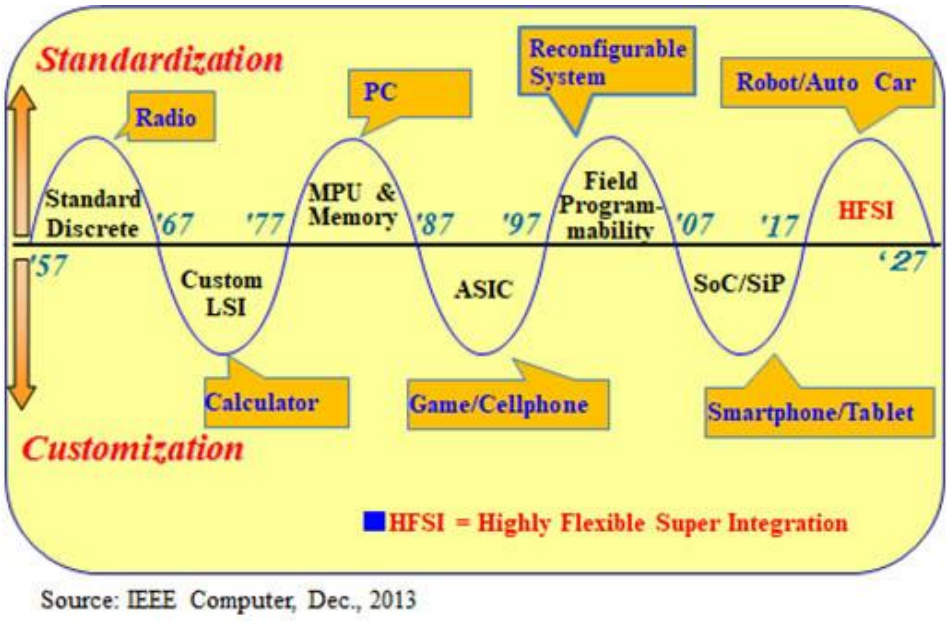

Fig.8　Future prediction seen from “Makimoto Wave”

“Makimoto’s wave” was open to the public in 1991, when it was published in the Electronics Weekly (UK). David Manners, a writer for the newspaper showed a great interest in this concept, and he named it “Makimoto’s Wave” at the time of publication.

This wave shows that trends towards standardization and customization in the semiconductor industry alternate direction every 10 years. The trend was shown up to 2007 in the original version, but it was revised as shown in Fig. 8, to cover up to 2027, when it was published in the December 2013 issue of IEEE Computer magazine

In this figure, together with the alternation of direction between standardization and customization, it is also shown that new application fields are opened up that meet each trend.

The current period (2007-17) is regarded as a customization-oriented era led by SoC/SiP, and, needless to say, the big market here is smartphone market.

Application fields requiring “high performance and low power” were developed in the customization-oriented cycles in the past, but we can see the characteristics of “high performance and high flexibility” are required in standardization-orientated cycles.

If we look into the future based on such historical trends as shown in the above figure, it is expected that the decade beginning in 2017 will become a standardization-oriented cycle. The device in that cycle must have high performance as well as extremely high flexibility.

I named this trend HFSI (Highly Flexible Super Integration). And the big market that this era creates will be robots and autonomous cars.

Currently in the automotive field, advancement using IT is being pursued, but the boundary between cars and robots will disappear when fully autonomous cars are realized.

Robots will continue to be diversified and sophisticated further and become familiar existence in daily life. An international project aiming to make a robot soccer team which can beat human champion teams in 2050 is underway under the name of “RoboCup”.

When such an era comes to be real, it is necessary to reconsider how human beings coexist with robots. From now on, new semiconductors will create new civilization.

Concluding remarks

I would like to conclude with the following words.

“Semiconductor is the engine of modern civilization. There is no future for a country, if it loses this engine. Therefore, the rise and fall of a country relies on the semiconductor! “

Among the members of SSIS, I think that there are many people who know how important an industry the semiconductors are for Japan. However, unfortunately, such a perception is not widespread and shared as we look widely around the country. I think that it is one big role for SSIS to expand recognition of the importance of semiconductors. This is what is expected of SSIS.

The original version of this article was published, in Japanese, on October, 2014 issue of Encore, a periodical magazine of SSIS.