Micro-technology

Visions and Activities on Micro-technology

IMAMURA Makoto [*1] *ISOZAKI Katsumi* [*2] *TANAAMI Takeo* [*3]

Yokogawa's Corporate R&D Headquarters has been focusing on the development of three key micro-technologies: silicon semiconductor key devices to be applied to Yokogawa's new products, a microreactor for Green Production, and gene measuring systems for personalized medicine, the safety of foods and the preservation of nature and water. These themes are necessary to achieve the R&D vision, expand technologies to help create a low-carbon sustainable society, and create technologies for revolutionizing the social structure toward individual-oriented production and services.

INTRODUCTION

Development themes related to micro technology in Yokogawa's Corporate R&D Headquarters are categorized into the three groups shown below.

1) Developing silicon semiconductor key devices to be applied to Yokogawa's new products
2) Developing a microreactor for Green Production
3) Developing gene measuring systems for personalized medicine, the safety of foods and the preservation of nature and water

The themes of group 1 are for advanced development by the Corporate R&D Headquarters, while those of groups 2 and 3 are medium- or long-term development themes for research and incubation, aiming at exploring and expanding new markets. In this paper, we introduce our visions and activities on these themes.

*1 Advanced Device Development Div., Corporate R&D Headquarters
*2 Advanced Technology Research Center, Corporate R&D Headquarters
*3 Biomolecule Analysis Center, Corporate R&D Headquarters

CONTINUOUS SCALING DOWN OF SILICON SEMICONDUCTOR KEY DEVICES

Key devices which are crucial for the performance of measurement and control equipment often either are not commercially available or do not meet the required specifications, and so need to be developed by ourselves. As a leading company in the measurement and control field, it is our responsibility to develop and continuously supply such key devices. We have long focused on such devices. [(1)(2)]

Existing key devices or those under development for next-generation products include timing generators for LSI test systems, analog-to-digital converters for digital oscilloscopes [(2)], resonant-type differential pressure sensors capable of measuring ultra-high pressure (100 MPa) [(2)] and high-breakdown voltage solid state relays (SSR). High speed and high integration are essential for these devices, as well as low energy consumption and compactness. As semiconductors become ever faster yet consume less power due to downsizing, state-of-the-art processes are indispensable. We develop practical devices by using such processes and cutting-edge packaging technologies.

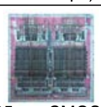
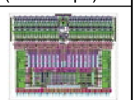
In the following sections, we introduce our activities on timing generators for LSI test systems, packaging technologies and build-up substrates. For details on SSRs for recorder scanners with twice the breakdown voltage, refer to "3000 V class MOSFET switch for semiconductor relays using MEMS process" in this Yokogawa Technical Report.

Evolution of timing generators for LSI test systems

LSI test systems are mainly used in clean rooms and so should occupy minimal space and produce minimal heat to reduce the energy burden. In addition, the maximum number of LSI pins to be tested is increasing, and even for LSIs with fewer pins, the number of LSIs to be inspected simultaneously is increasing in order to raise throughput. In the last decade, the number of pins has grown from 256 to 2048, and the timing generators used have had to match this number.

In order to reduce the space occupied and power consumed, the process technology node has become more than 10 times finer from 1 µm to 90 nm, and 16 times larger integration has been achieved as Figure 1 shows. The power consumption per timing generator (TG) has dropped to below 1/2 to 1/4. We adopt an analog type Timing Vernier (TV) that generates a minimum time step, thus reducing power consumption. On the other hand, advanced circuit design technology is required to deal with the lower voltages that accompany process scaling. Accordingly, we have been pursuing lower voltages and have achieved low jitter and high linearity characteristics even with a supply voltage of 1.8 V as shown in Figure 2.

As integration improves, the number of TG connections has risen six-fold from 208 to 1296 while the bandwidth of the test pattern that generates the waveform has expanded more than 100-fold from 540 Mbps to 70 Gbps. We have resolved the increase in connections through the packaging technology described below and the increase bandwidth through 2.5 Gbps Serializer Deserializer (SerDes) interface.

LSI test system		 TS600	 TS6000H+	 ST7000
Number of transistors		140 kTr.	1500 kTr.	46 MTr.
Power consumption		7.0 W / pin	1.5 W / pin	0.35 W / pin
Power supply voltage		0.5 V	3.3 V	3.3 V / 8.1 V / 2.1 V
Key perfor -mance	Data Rate	60 MHz	750 MHz	1 GHz
	Jitter	20 psrms	10 psrms	3 psrms
	Interface	20 Mbps x 27 bit (= 540 Mbps)	133.3 Mbps x 64 bit (= 8.53 Gbps)	2.5 Gbps x 28 bit (= 70 Gbps)
Chip micrograph technology		 1.0 µm CMOS	 0.35 µm CMOS	 90 nm CMOS
Package		208 Pin HQFP	576 Pin HBGA	129 Pin FCBGA AuSn soldering*1

psrms: pico second root mean square
HQFP: Heat spreader Quad Flat Package
HBGA: Heat spreader Ball Grid Array
FCBGA: FlipChip Ball Grid Array
*1: In-house fabrication

Figure 1 Evolution of key devices for LSI test system

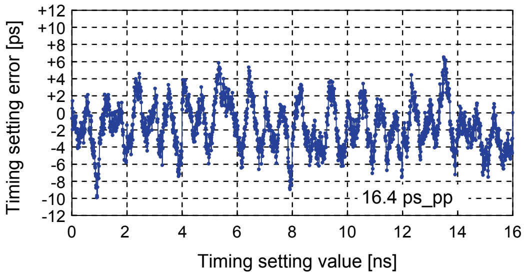


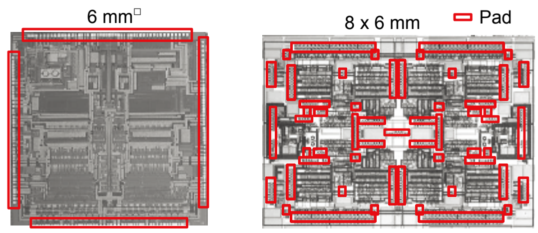
Figure 2 Linearity of timing generator

LSI packaging technology

Traditionally, the silicon chip package assembly is achieved by wirebonding. However, as larger signal bandwidth causes further signal degradation due to wire inductance, flip-chip bonding has become the norm. But flip-chip bonding is for mass-production, and so is not suitable for our business of producing small quantities of diverse products each having different capabilities achieved through process. Furthermore, as long-term procurement is not guaranteed, we are developing the flip-chip technology by ourselves.

We are working on Au-Sn bonding which covers area bumping that enables a bump to be formed at any position and lead-free electrodes to be made smaller.

Area bumping allows bonding at any position as shown in Figure 3 and has advantages in dealing with larger numbers of connecting pins. In addition, it offers wiring flexibility to reduce the power wiring, and effectively reduces the chip size. The resulting smaller chips and shorter signal wiring successfully reduce power consumption.



(a) Peripheral wire bonding (190 Pad) (b) Area flip-chip bonding (461 Pad)

Figure 3 Difference of pad area by bonding

Au-Sn flip-chip bonding is usually used for connecting chips and flexible printed circuit boards based on polyimide. However, it is difficult to connect chips and a solid build-up substrate with Au-Sn bonding, because the substrate becomes soft at the underfill (adhesives bonding the chip and substrate) curing temperature, which is higher than the glass transition temperature (Tg). Therefore, sufficient load can not be applied for alloying gold and tin. We have therefore separated the alloying process from the process of hardening the underfill and set the temperature and load appropriately for each process. As a result, sufficient adhesive strength and reliability are obtained for bonding even below 80 µm pitch as shown in Figure 4.

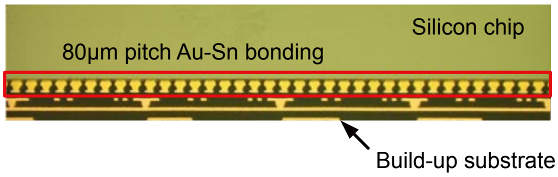


Figure 4 Cross-sectional view of the developed AuSn flip-chip bonding

Development of build-up substrate

To raise the wiring density and reduce the wiring capacity, even finer wiring in the substrate is needed. We are also developing the build-up substrate. Figure 5 depicts a cross-sectional view of a three-layered build-up board.

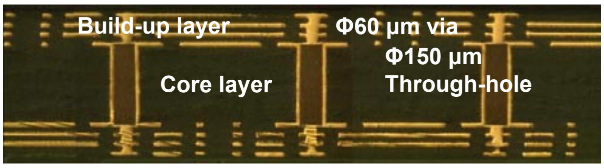


Figure 5 Cross-sectional view of developed build-up board

Future development of silicon semiconductor key devices

These are just a glimpse of our leading-edge processes and packaging technologies designed to reduce power consumption and save space. We continuously strive to develop environment-conscious devices.

DEVELOPMENT OF A MICROREACTOR

Achieving a sustainable society is a major challenge for human beings. Presently, the equipment used in the pharmaceutical and fine chemical industries are designed for inefficient multistage batch production. Major technical breakthroughs are needed in this area to convert to efficient green production systems. Microreactors are a revolutionary technology that makes it possible to shift from inefficient batch production of small quantities of many products to efficient on-site production or batch-less continuous production. This is an area where we can leverage Micro Electronics and Mechanical System (MEMS) technology, which we have accumulated as differentiating technologies, as well as measurement and control technology which we have been providing to support efficient production mainly in the petroleum refining and petrochemical industries. (2)

The microreactor is now at the stage of moving from the prototype model for research to a practical commercial model, and commercially-viable models are expected to reach widespread use by 2015. (3) General-purpose microreactors for R&D are already being marketed led by a German manufacturer, and some models are designed to be used in production systems. Universities and advanced chemical manufacturers are now testing whether particular reactions are improved by using them, but the situation is not promising so far. To improve the microreactor to an acceptable level in a real plant, knowledge of chemosynthesis as well as device development is required. However, joint efforts beyond each field of expertise have yet to materialize, leading to the present situation.

Although a general-purpose reactor needs to be developed, at this stage we are focusing on jointly developing a system incorporating distinct technology for some key applications requested by progressive users. Currently, we are promoting the following four areas in forming academia-industry partnerships: 1) Developing a catalyst test system to assist chemical-related research, 2) Developing an on-site/on-demand production system for chemical products, 3) Developing a production system for pharmaceutical intermediates, and 4) Developing measurement and control technology for the microreactor.

Development of microreactor catalyst test system

Catalysts play a crucial role in facilitating efficient chemical reactions, and from an industrial perspective, the performance of a catalyst has a great influence on economic efficiency. In traditional catalyst development, an experienced researcher seeks answers by repeatedly conducting experiments and making adjustments and evaluations, and so it is difficult to speed up the development process. In this field, the combinatorial method has just been introduced which can generate many groups of compounds at a time. However, one bottleneck is the lack of an automatic evaluation system that can evaluate many catalysts in a short period. (4) We have introduced microreactor technology in catalyst tests, and are developing an automatic catalyst screening system to realize multi-channel simultaneous evaluation with smaller amounts of catalysts (one tenth of the conventional quantity) and gas (one tenth of the conventional quantity). Figure 6 shows the 4-channel type microreactor for the catalyst evaluation test to handle heterogeneous reactions.

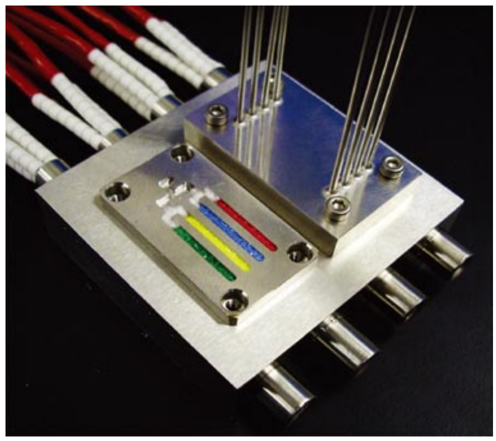


Figure 6 4-channel microreactor for catalyst evaluation test

Figure 7 shows the catalyst test system under development. Using catalyst test know-how of Aika Laboratory in Tokyo Institute of Technology, we have developed a system including a microreactor with automatic control functions, and improved it to a multi-channel system.

We have conducted experiments for three types of reforming reactions: CO_2 reforming reaction, partial oxidation reaction, and steam reforming reaction, using 5 wt%Co/ TiO_2 catalyst for methane reforming, and have proved the effectiveness of the system. We have also conducted a simultaneous screening operation test under the same condition by filling the multi-channel microreactor with three types of catalysts of differing composition, and proved the effectiveness of the system.

This system is anticipated to be used in areas such as catalysts for the Gas To Liquid Process (GTL) which is a new process, fuel cells, diesel vehicle emission process, and photocatalyst.

Figure 7 Catalyst test system

On-site/On-demand production of chemical products

Jointly with Mitsui Chemicals Material Science Laboratory, we are developing an on-site semiconductor gas generating system using a microreactor.

Semiconductor gas is typically manufactured by a chemical company in a large plant while a delivery company then handles transportation and services. This requires high-pressure gas piping for gas feeding as well as extensive safety measures ranging from the gas tank yard to various equipment. Gas types vary from explosive to those that decompose easily. If a ubiquitous production system that produces only as much gas as needed could be introduced, it would not only improve safety but also reduce total cost. Microreactors will solve this problem, and so we are developing an electrolysis reactor for generating semiconductor gas. The core is vapor-liquid separation technology that rapidly removes the gas generated during electrolysis from the electrode surface. We have completed basic experiments and are now in the development phase.

The production of chemical products is polarizing into mass production for general-purpose products and batch production for small quantities of many products. The ubiquitous production system is an ideal approach for the latter type of production.

Development of microreactor for functional chemical materials and pharmaceutical products

a) Development of microreactor for electrochemistry

One of our researchers is participating in a project under way in a research center in Kyoto University which is playing a central role, called “Development of Microspace and Nanospace Reaction Environment Technology for Functional Materials” by the New Energy and Industrial Technology Development Organization (NEDO). Microreactors for electrolysis synthesis are being developed toward practical use. This is a 5-year project and is scheduled to be completed at the end of March 2011.

Through joint development with universities and advanced chemical manufacturers conducting top-level research, micro plants are now being developed with a view to production. Currently we are working on key technologies toward the interim assessment in 2008. Electrolysis reaction has the following advantages: 1) High selectivity, 2) Less waste without oxidant and reductant, and 3) Easy to control reaction selectivity (voltage control). However, the reaction also has the following issues: 1) High operational cost (electricity) and 2) Insufficient data on electrolysis synthesis. The former is expected to be resolved by raising the efficiency of micro electrolysis systems, while the latter will be solved through developing a demonstration system in the NEDO project. A microreactor with high current efficiency is being developed, and the oxidation reactions of toluene derivative and amine derivative have been selected as model reactions.

b) Development of microreactor for vapor-liquid reaction

Jointly with Yanagi Laboratory of Osaka Prefecture University, a microreactor for medical intermediates is under development. By combining Yanagi Laboratory’s know-how on carbonyl reactions by carbon monoxide and microreactor technology, a reactor that converts the vapor-liquid batch reaction to continuous reaction was developed and basic actions were confirmed. This conversion will allow production by a small reactor. Microreactors are characterized by a large surface area per unit volume. By using this feature, which enlarges the contact area in vapor-liquid reactions, we are improving the reaction efficiency.

Measurement and control system for microreactors

To make microreactors practical, it is necessary to develop measurement and control technology for fluids in micro space, including measurement and analysis of temperature, pressure, and flowrate. Since flowrate measurement is the most difficult of these, we have been developing a micro flowmeter for microreactors from the early stage.

We use a unique measurement principle that covers a wide measurement range with a single hardware configuration by combining two methods: the thermotransfer method to measure the distortion of temperature distribution that occurs corresponding to the flowrate, and the thermal Time of Flight (TOF) method to measure the heat pulse generated by a heater using a downstream sensor. Figure 8 shows an external view of the thermal micro flow sensor chip. Refer to “Micro Flow Sensor for Microreactors” in this Yokogawa technical report for details.

Figure 8 External view of thermal micro flow sensor chip

Development of microreactor for the future

We have described the current situation concerning academia-industry joint development of the key devices for microreactors, with the aim of creating a new production system in the pharmaceutical and fine chemical field. We have conducted various development work and trials, which are now showing results. Our next goal is to apply this technology to an actual production system at an early date to meet the needs of main users.

DEVELOPMENT OF GENE MEASURING SYSTEM

Fifty years ago, the double helix structure of deoxyribo nucleic acid (DNA) was discovered, and the Human Genome Project was finally completed in 2003. The enormous quantities of genome information from the project have had a huge impact on various fields of science and industrial technology, and will revolutionize the medical and pharmaceutical areas in particular. This progress has led to the emergence of the new "personalized medicine" sector.

New medicine by gene analysis

"Personalized medicine" is an attempt to provide medical services in which drugs and treatments are tailored to an individual patient by examining the expression of DNA and ribo nucleic acid (RNA) of the individual. It is effective with few side effects, and aims to improve the patient's quality of life (QOL). It also offers good cost-benefit performance from the medical economic standpoint by providing appropriate diagnoses, treatments and drugs.

For example, there are dozens of anti-cancer drugs and medical bills for such drugs can exceed 1 million yen a month. Yet as Figure 9 shows, the effectiveness of anti-cancer drugs varies among patients by a factor of up to 100. If a patient only ends up with suffering from side effects as a result of the drug, it should not be given in view of the pain and medical costs for the patient. However, actually it is not known which drug will work for which patient, meaning that treatment is based on trial and error: when one drug does not help or causes side effects, the patient is given another drug. Gene analysis is expected to provide information on the relationship between individual constitution, symptoms and treatments in advance, and to contribute to administering an adequate dose of appropriate drugs.

Figure 9 Dependence of effectiveness of anti-cancer drug on the patient

Personalized medicine is applicable in many areas, not limited to anti-cancer drugs. As shown in Figure 10, the gene analysis market in Japan is forecasted to reach 150-180 billion yen between 2015 and 2020. [5]

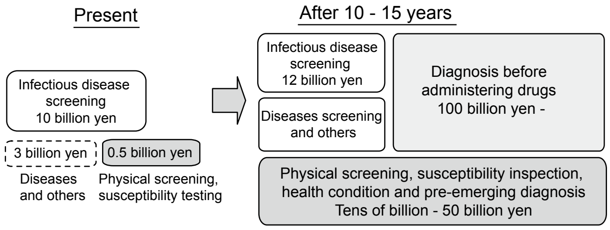


Figure 10 Forecast for domestic gene diagnosis market

Gene analysis by DNA chip

Figure 11 shows procedures for gene analysis by DNA chip (micro array). On the DNA chip substrate, many types of known DNA are attached. Separately, DNA is extracted from a specimen sample of the patient and a fluorescent label is attached to it. When this sample fluid is mixed with DNA on the DNA chip, genes from the specimen (DNA in sample fluid) bind with DNA of the corresponding nucleic acid array to form a double strand. This process is called hybridization. Specific spots are then illuminated by fluorescent light and scanned by laser beam to identify the genes in the sample.

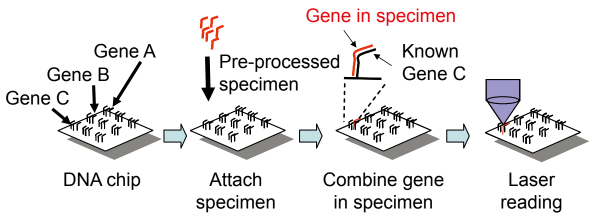


Figure 11 Gene analysis by DNA chip

Development of gene measuring system

As mentioned, gene analysis is solution for personalized medicine. However, DNA chip pre-processing involves complex, highly skilled work and the ability to use dedicated systems. To use them in clinical sites, it is necessary to secure safety against viruses and ensure that sequences can be performed reliably. Yokogawa has been developing a "gene measuring system" for practical gene analysis at actual clinical sites and inspection and research sites.

The gene measuring system is composed of an integrated cartridge and a biochip reader. A sample such as blood or specimen is processed by the dedicated integrated cartridge then read and analyzed by the biochip reader. Analytical results are fed back to physicians and used in diagnosis and treatment.

In the cartridge, a blood sample or specimen from a patient is processed. By using fluid process and reaction technology, a series of processes - from cell lysis, DNA extraction and purification, DNA amplification, refinement of amplified products up to detection by a DNA chip - is performed internally as shown Figure 12. Amplification uses the polymerase chain reaction (PCR) method, which is capable of amplifying the selected specific DNA in an extremely small amount of DNA fluid.

Our cartridge is structured such that reagent is sealed in advance and waste solution is never leaked, thus allowing the operations from pre-processing to detection to be done automatically. Thus, it is called the "integrated type". The gene measuring system is realized by combining micro processing technology such as MEMS and optical measurement technology.

Yokogawa has succeeded in automatically performing the series of continuous processes using living organisms - from DNA extraction, purification, amplification, refinement and detection by DNA chip - for the first time in the world.

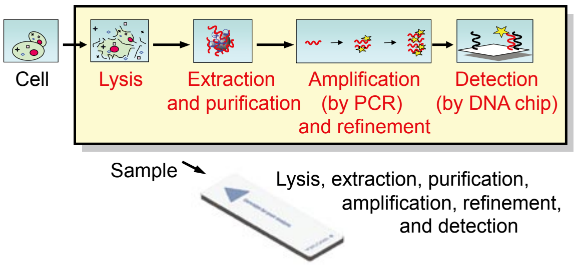


Figure 12 Gene analysis by integrated cartridge

Development of gene measuring system in the future

Next-generation medicine utilizing gene measuring technology is taking off. Faced with constantly-changing problems concerning our surroundings, the environment, and industry, the gene measuring system is expected to help lead to healthier lives and environmental hygiene through the safety of foods and the preservation of nature and water. In this paper, we have focused on its application in medicine, but the reader system and integrated cartridge are also applicable in the areas mentioned above.

Currently, many revolutionary technological developments in addition to gene analysis are being made in the biotechnology sector. In order to reach the goal of a sustainable society, we need to address issues including environmental awareness, globalization, aging population and low birthrate. Yokogawa will continue to make the utmost effort in R&D to help solve these issues.

For details and applications of the gene measuring system, refer to "Gene Measuring System capable of safe and reliable diagnoses" in this Yokogawa Technical Report.

CONCLUSION

We have outlined our visions and activities on micro-technology in this paper. We continue to conduct R&D to attain "technological expansion contributing to a low-carbon society that allows sustainable growth, " and "the creation of technology to support the social structural revolution for personalized production and services".

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