MEMS and Nanotechnology Research for the Electronics Industry

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ABSTRACT

The 20th Century has witnessed breathtaking developments in the miniaturization and the large-scale integration of microelectronic devices that have had an enormous impact on human affairs. The same miniaturization paradigm can be applied to mechanical devices using MEMS technology leading to ultra small micromachines that cannot otherwise be fabricated using conventional machining and assembly techniques. The MEMS technology is expected to have a great impact in the 21st century by enabling many complex electromechanical systems to be fabricated and integrated. In this paper, applications of MEMS to many areas relating to information and biotechnology are discussed. These topics are presented in the context of ongoing research at the Samsung Advanced Institute of Technology (SAIT). SAIT is the central research laboratory for the Samsung Corporation whose charter is to develop breakthrough technologies to be the leader in the 21st century.

Keywords: MEMS, nanotechnology, biotechnology, micro gyroscope, nano storage, microfluidics.

1. INTRODUCTION

Technological innovations, such as microprocessors, compact mass storage and flat panel displays, have led to miniaturization and personalization of computers that became the main driver for the current information age. Along with the internet and the wireless telecommunications infrastructure, the personalization and portability of computing will continue at an ever increasing rate leading toward pervasive and wearable computing platforms and environments. With the wireless access to the internet, the future mobile communications and computing devices will require fast computing power and massive amount of storage. Following this explosive growth in the information revolution, a new era of biotechnology is beginning to take shape with an outlook on potentially great commercial markets brought on by people wanting to live

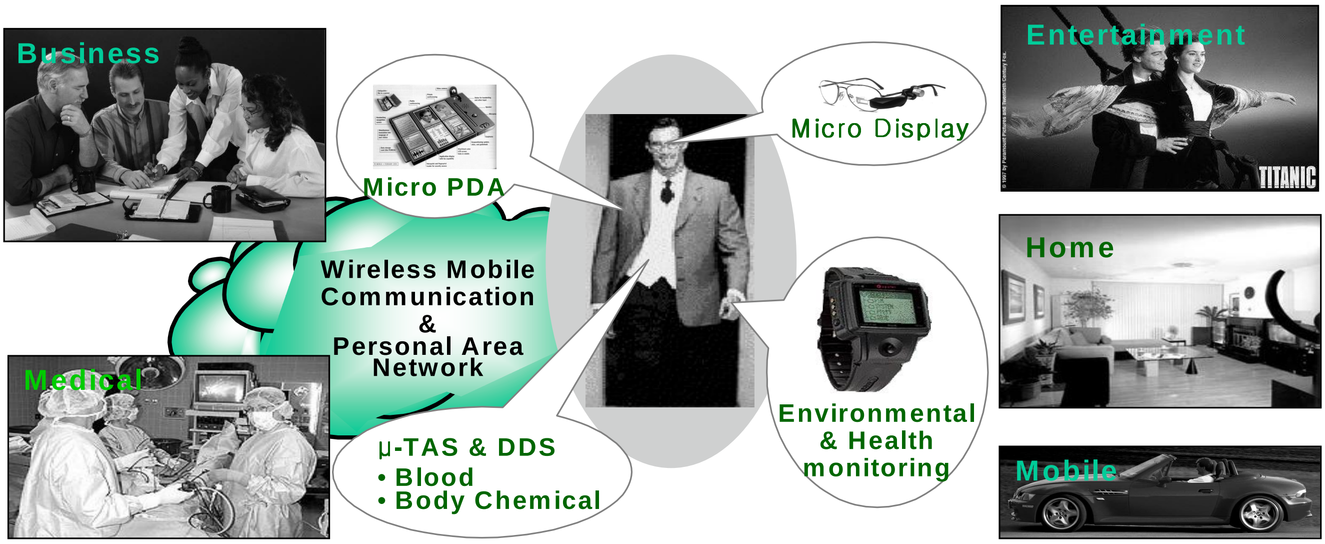

Fig. 1. Toward mobile/wireless and health conscious society.

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longer and healthier lives. With the emergence of digital convergence where communications, computing, entertainment and healthcare is crossing traditional service and business boundaries, future hardware platforms will require integration of multifunctional capabilities to meet or even to create new market demands. It is in this respect, the MEMS technology will play a dominant role in miniaturizing and integrating mechanical, optical, fluidic and biochemical functions that are required in the future platforms. In this paper, some of the technological issues related to the future electronics devices such as inertial sensors, mass storage, IC chip cooling and medical diagnostic systems that can be addressed with MEMS technology are discussed. With the mobility of hardware platforms comes the need for position sensing and various motion sensing input devices. MEMS micro gyros, being both very compact and low cost, can be used extensively for this purpose. With the wireless connection to the internet, the future mobile communications and computing devices will require massive amount of storage for storing moving picture files requiring fast read and write speed, compact size and high reliability. MEMS based nanoelectromechanical system (NEMS) utilizing scanning probe microscope (SPM) is conceived to be the most feasible one to realize higher areal density than the current magnetic hard disk media enabling nano-bit writing and high-speed readout. At the same time, future computing devices are facing thermal engineering challenges from both the high heat generation with rapid performance improvement and the reduction of the available heat removal surface area. MEMS microfluidics technology can provide efficient and compact cooling system for reliable operation of the microelectronic devices. MEMS microfluidics can also be applied in developing lab-on-a-chip devices that will perform most or all of traditional lab functions such as immunoassays, DNA and protein identification on a chip. In the following sections, some of the research work that are being conducted at SAIT in MEMS and NEMS area in anticipation of fore-mentioned market and technology demands are introduced.

2. MICRO INERTIAL SENSORS

Gyroscopic devices for measuring angular rate have been the subjects of extensive research and development over the past several decades. As electronic devices become smaller and more mobile, the need to sense the motion and position of these devices becomes increasingly important. There has been a considerable interest in the development of a low-cost and small sized gyroscope, since many applications, such as navigation systems for automobiles or sensors for recognizing handwriting motion for computer input exist for these devices. As representative micro inertial sensors, silicon based gyroscope is being considered as the next mass-product mechanical sensors after silicon pressure sensors and accelerometers. This section will introduce the recent advances in the research and development of silicon based vibratory micro gyroscopes at Samsung. Recently, several works on micro mechanical gyroscope have been reported, and most of these sensors are vibratory type. This vibratory gyroscope is driven in a resonant state by electrostatic force and detected the output due to a capacitance change between the mass plate and the bottom electrode. The Coriolis motion arising from the angular rate causes the capacitance change and is converted to voltage change [1][2]. Figure 2a shows the SEM photograph of the SOG(silicon on glass) processed gyroscope [3]. It is very simple to fabricate the gyroscope with a total chip size of 3x3.5x1 ㎣ using only one mask. The gyroscope structure is fabricated on an anodic bonded 40 μm-thick silicon on glass. After the top silicon is etched using a deep RIE, a part of the glass under the silicon structure is etched by HF for releasing the top silicon structure. Since the depth of the etched glass under the silicon structure is about 20~30μm, the damping and the stiction between the structure and the glass substrate are minimized. The minimum gap and the aspect ratio of this structure are 2 and 20 μm, respectively.

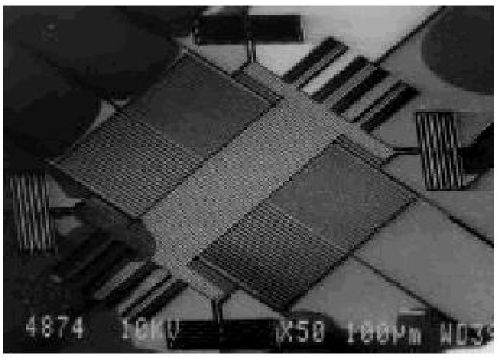

Figure 2a. Silicon-on-Glass processed gyroscope.

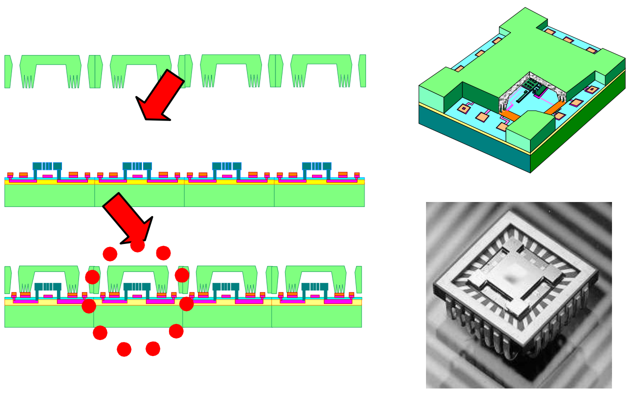

Figure 2b. Wafer-level vacuum packaged micro gyroscope

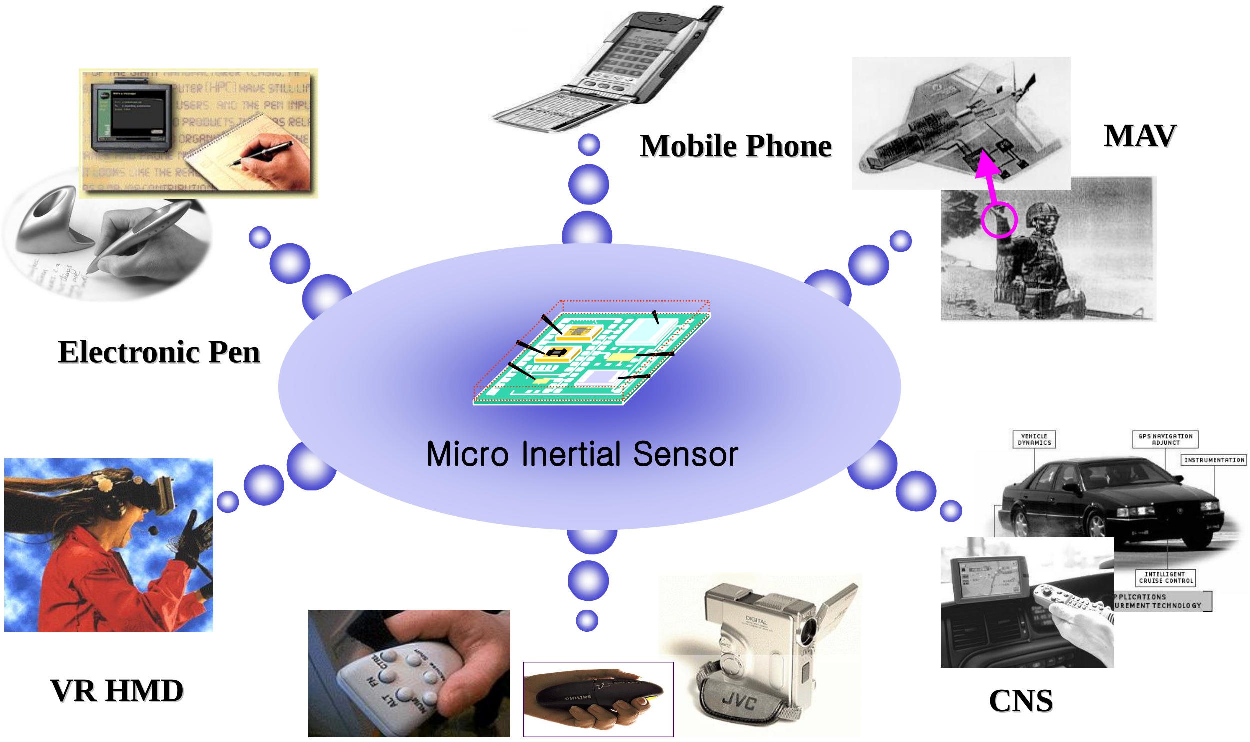

Figure 3. Various applications of micro inertial sensors.

Without an additional frequency tuning method, it is demonstrated that the difference between the two frequencies is about 85Hz, and the noise equivalent rate is 0.05deg/sec at 50mTorr pressure. Various applications to mobile systems as shown in Figure 3 require small form factor as well as highly reliable packaging for optimal performance and low cost mass production [4]. A wafer-level vacuum packaged micro gyroscope is shown in Figure 2b. Samsung micro gyroscopes are currently in production at the Samsung Electromechanics Company. SAIT is continuing the R&D effort in integrating multi-axis angular rate and acceleration sensors for one-chip type inertial measurement unit.

3. NANO STORAGE

With the wireless connection to the internet, the future mobile communications and computing devices will require ultra-high areal density (greater than 100 Gbits/in^2), fast read and write speed, compact size and high reliability. A system utilizing scanning probe microscope (SPM), as shown in Figure 4, is conceived to be the most feasible one to realize higher areal density than the current magnetic hard disk media enabling nano-bit writing and high-speed readout. Many researchers have proposed the application of SPMs, such as scanning tunneling microscopy (STM), atomic force microscopy (AFM), magnetic force microscopy (MFM), and scanning near-field optical microscopy (SNOM), as future ultra-high density data storage systems. It has been proposed that employing ferroelectric thin films [5] as recording media inherently has several advantages: 1) the recorded data are non-volatile, 2) the recording density can be ultra high because of narrow domain wall thickness (1~2 nm in case of 180° domains), 3) the ferroelectric domains can have fast switching speed, 4) information bits can be written and read electrically. The electrostatic force gradient between the tip and the sample can be detected by the shifts of the resonant frequency and therefore induces a variation in the vibration amplitudes and phases of the cantilever. It is often called a dynamic non-contact (NC) mode of electrostatic force microscopy (EFM). The ability to image non-uniform charge distributions and variations in the surface work function has been exhibited as shown in Figure 5. Understanding the detection mechanism of the EFM provides clear insights of the image of spontaneous polarized domain as well as complex nature of the domain switching kinetics.

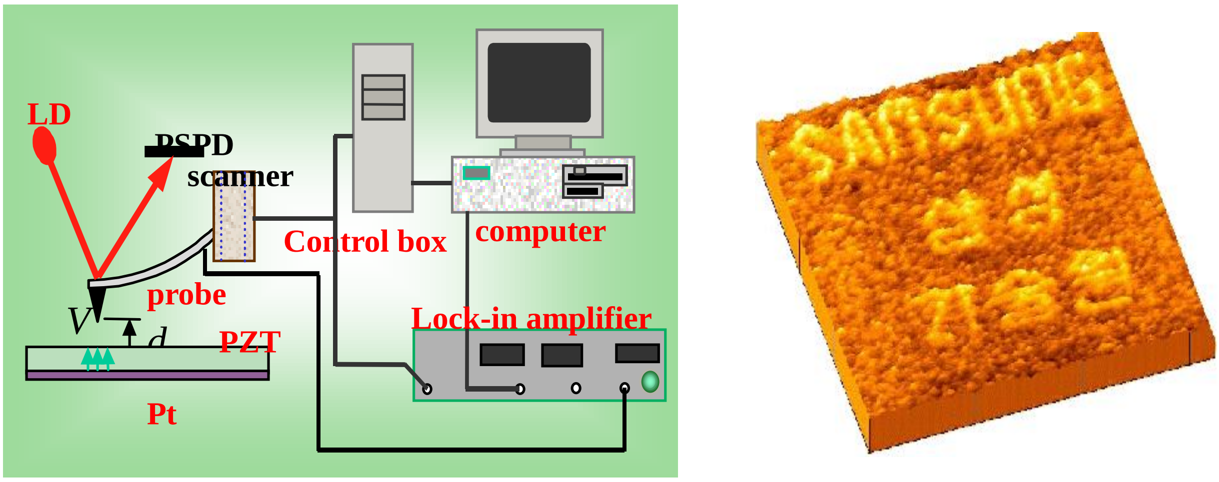

Figure 4. Use of electrostatic force microscope in writing high density data on thin PZT film.

We have demonstrated the possibility of utilizing PZT films as high-density data storage media using EFM and also investigate the exact nature of EFM imaging. Retention loss of polarized domains is observed as well. However, commercially available SPM apparatuses are quite bulky, hence, cannot be used as a portable data storage device. In order to miniaturize the SPM system, a nano-precision X-Y stage is required as shown in Figure 5. The micro XY-stage is a very focused device in the field of two-dimensional sub-micrometer position control of nano-tools. Recently, IBM has developed stages for probe based mass storae system [6]. Some important issues on this field include: large displacement [7,8], high precision, high natural frequency [9], low mechanical interference and so on. Thus, most fabrication processes are focused on the improvement of these mechanical characteristics and tend to be complex, especially in the releasing of free structure including central stage. We have fabricated the micro XY-stage with a large area central stage (5 ㎜× 5 ㎜) in the shuttle using simple release technique.

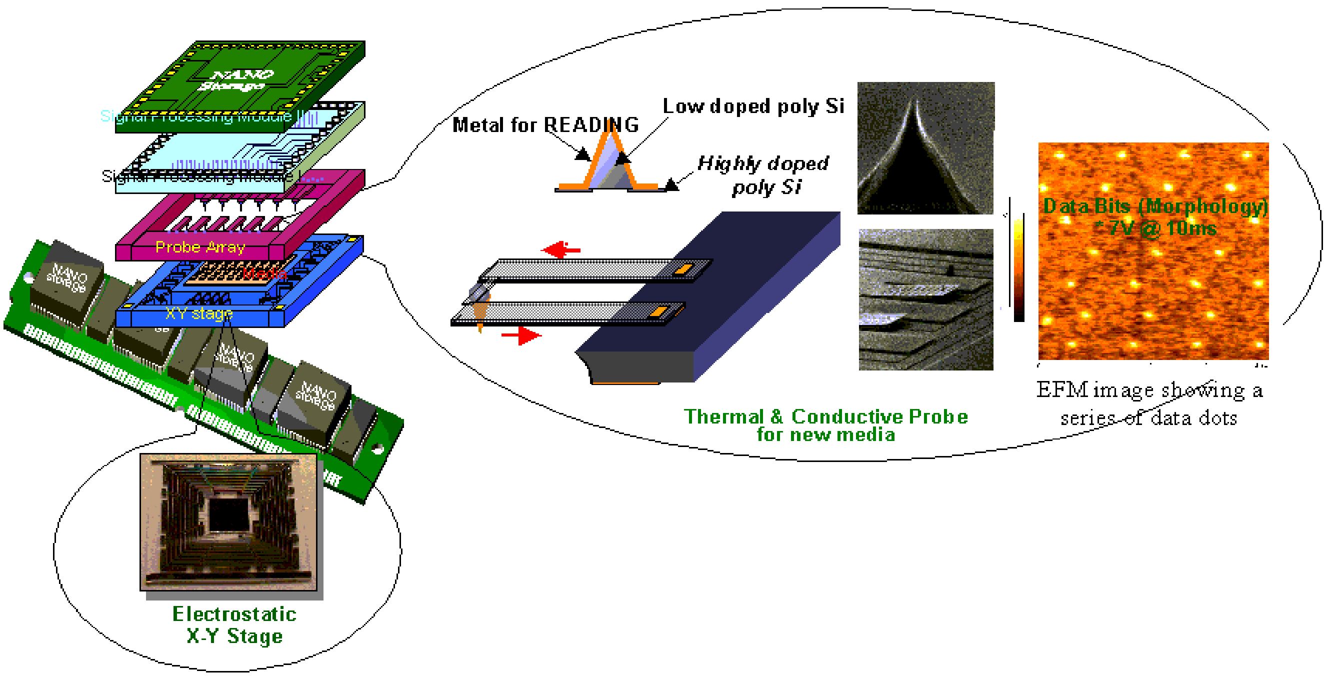

Figure 5. Next generation mobile/micro storage system.

The large central stage area is beneficial for the nano-structure array with limited integrate density or high density data recording media. The proposed device has the simple structure of four identical comb actuators that are arranged perpendicular to each other. Each comb drive actuator has only pulling mode and the specific location of the shuttle is determined by the vector sum of two effective driving actuators. The maximum travel range is designed up to 50 ㎛ under the applied voltage less than 25V (including DC bias voltage). The depth of spring has the same value as that of electrode for maintaining high z-stiffness. MEMS-based nano-precision X-Y stage will enable miniaturization and integration of SPM read-write mechanism for the development of nail-sized SPM data storage system [10].

4. MICROFLUIDICS

4.1 Micro Cooling System

With the rapid development of the wireless telecommunication technology, the use of compact and mobile computing systems has increased exponentially. The consumer's demand for the high performance computers leads to the high clock speed and the large circuit integration for multifunction. As a result, the heat generation at the electronic modules has been remarkably increased [11]. In addition, the compact size for portability and large packaging density have reduced the overall size of the mobile computing system [12] resulting in the decrease of the available cooling surface area. In the absence of the sufficient heat removal, the working temperature of the electronic modules may exceed the desired temperature level. The elevated temperature also causes increase in the system failure rate. Therefore, the employment of the high performance and portable computing systems require the efficient and compact cooling technology to provide a reliable system operation. Current method of using fin/fan combination or heat pipes will not be able handle the heat flux generated by high performance chips in the upwards of 50 Watts or more. In anticipation of this problem, SAIT has developed a micro capillary pumped loop (CPL) cooling system as shown in Figure 6, where micro channeled evaporator over a heat source evaporates the coolant which then moves through a vapor line to a condenser to be condensed back to the liquid state. Hence, the heat is removed by condensing vapor back to liquid state. Capillary action at the micro scale wick structures of the micro channels circulates the coolant, circumventing the use of pumps, resulting in a noise-free compact CPU cooler. In order to improve the heat removing capability of the condenser, we developed a novel heat transfer enhancement method in the laminar flow regime by using the hydrodynamic mixing. We fabricated the bulk-micromachined microfin array heat sink as shown in Figure 7, and use the flow-induced vibration of the microfin array for heat transfer enhancement. Thermal performance of the microfin array heat sink is experimentally evaluated to have 25% better heat removal capability than that of the plain-wall heat sink fabricated with the same material [13].

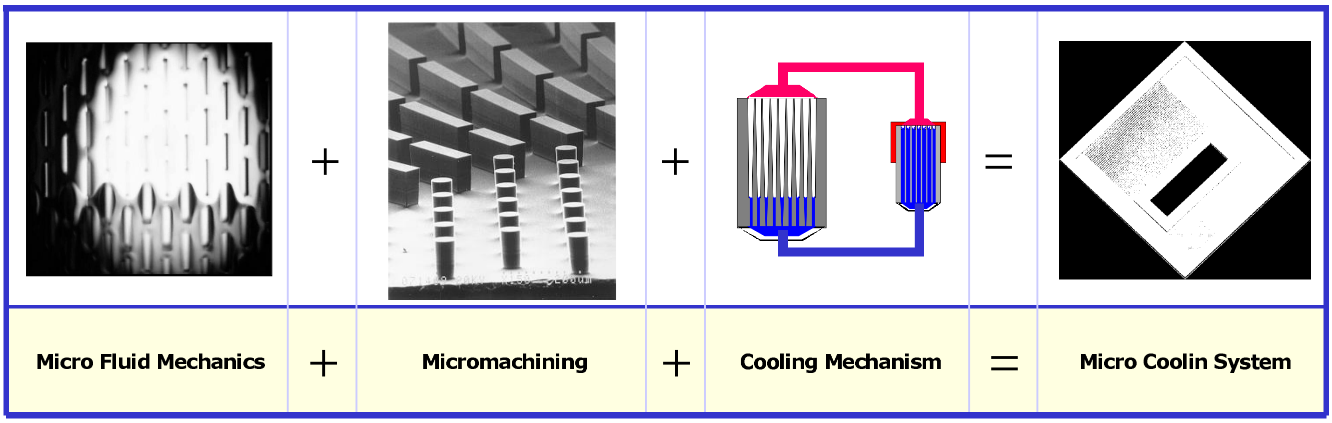

Figure. 6. Micro capillary pumped loop (CPL) cooling system.

Figure. 7a. Bulk micromachined microfin array.

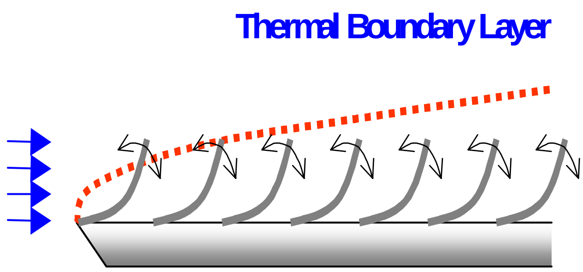

Figure 7b. Breaking up of the thermal boundary layer.

4.2 BioMEMS

The completion of the Human Genome Project is opening a new era in the practice of medicine where, through DNA testing, an early diagnosis of disease can take place for better prevention and treatment of diseases. Although commercially available DNA chips are currently being used for testing of genetic diseases, current methods still require sample preparation on laboratory instruments that are bulky, expensive and time consuming. BioMEMS will play a significant role in providing faster and more economical diagnostic services with lab-on-a-chip devices replacing the current diagnostic instruments. MEMS and microfluidics are key technologies in the development of these miniaturized diagnostic chips. Eventually, these portable diagnostic devices will communicate wirelessly with the medical data banks enabling proper medical diagnosis to be made right in the doctors' offices or at home. The emergence of biotechnology with information technology is expected to have great social and economic impact in the health-conscious society to come.

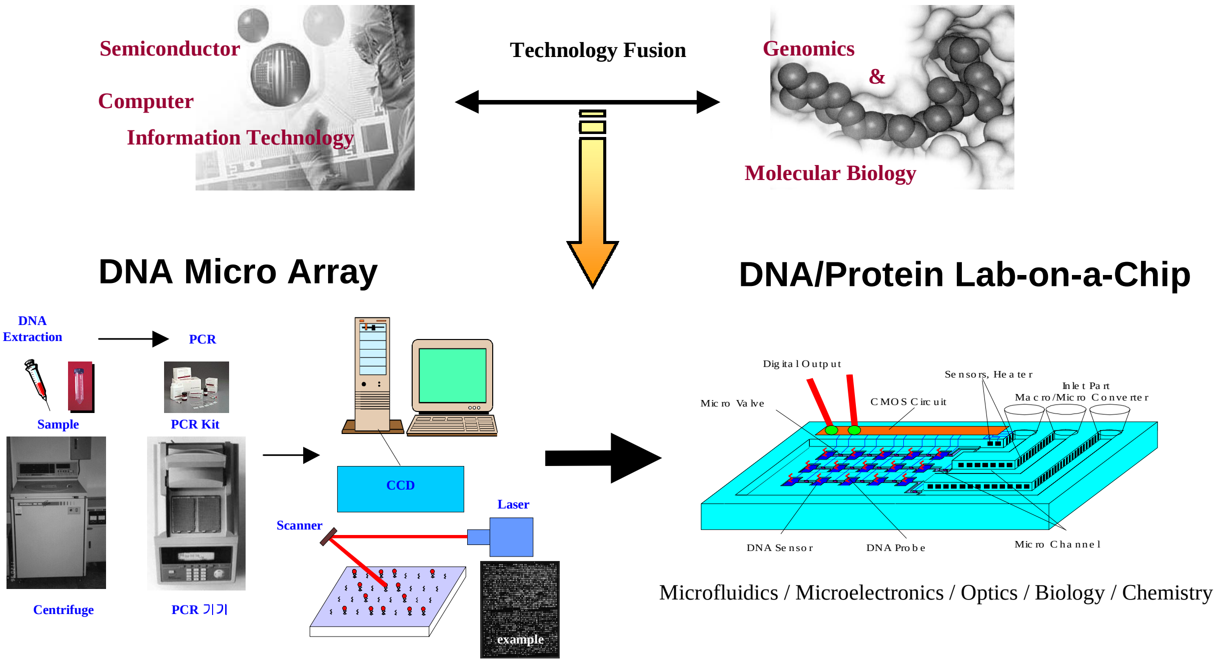

Figure 8. Emergence of information and biotechnology.

CONCLUDING REMARKS

SAIT has a very active research program in MEMS sensors, actuators, microfluidics, RF MEMS and BioMEMS areas. A few representative projects have been introduced in this paper. It is expected that MEMS will play a significant role for the future electronic devices that are continually being miniaturized with multi-functional capabilities. Samsung as an electronics company is preparing for the proliferation of MEMS applications by building the state-of-the-art fabrication facility devoted totally to MEMS R&D efforts. We are also making conscious effort to improve design and analysis capability for the robust manufacturability of MEMS devices. In this regard, Coventor's (formally named Microcosm) MEMCAD software tool is implemented to establish infrastructure for the design capability. It is envisioned that the multidisciplinary and concurrent engineering approach, as shown in Figure 10, along with state-of-the-art infrastructure will bring competitiveness in the commercialization of microsystems.

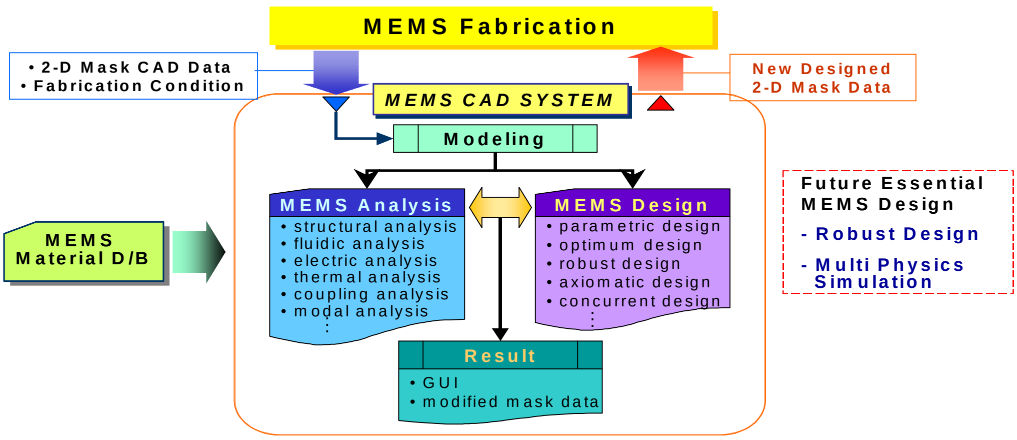

Figure 10. Concurrent Engineering CAD System for MEMS

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