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Final Report: EE 3940: Global Seminar: Engineering and Research in Taiwan and Hong Kong
27 June 2008

The purpose of this report is to present the technologies that I witnessed first-hand during the Global Seminar I participated in May and June of 2008.

SUMMARY OF TECHNOLOGIES

This research discovered several technologies and their useful applications. Some of the technologies encountered were wireless communication (Radio-Frequency Integrated Circuits (RFIC) and Low-Power Wireless Bio-Sensor Network (SOC)), Innovation and Synergy for Intelligent Home Technology (INSIGHT), biomedical devices (Focused Ultrasound and Infectious Disease Informatics), energy (Renew Wind and Solar Energy Control), speech recognition, chip fabrication (Dynamic Random Access Memory (DRAM), nanotechnology (MOS characteristics), flexible circuit boards, and thin film transistor liquid crystal display (TFT-LCD).

The three technologies I have chosen to focus on are nanotechnology, chip fabrication and biomedical devices. These three technologies are currently being researched and developed into products.

Nanotechnology

First, I'd like to discuss nanotechnology. Dr. Siddheswar Maikap of Chang Gung University is the principal researcher for making improvements to MOS nanotechnology devices. With the progress of complementary metal-oxide semiconductors (CMOS) into nano sizes, there is a high demand for alternative gate dielectrics with high dielectric constants (high-k) such as HfO, ZrO, Al O, their silicates, and nitrides since the conventional SiO2 gate dielectric leaks excess current in the nano-size. A solution to this problem that is currently being researched is the use of a material such as HfO for the gate dielectric. This provides several advantages, for example, it yields better thermodynamic stability when connected to Si. This still does not solve the problem, however, since it leads to Coulomb scattering, which reduces the channel mobility. To enhance the channel mobility, compressively strained Si_{1-x} Ge_x layers have become the best option to use (I).

The research being done on this is investigating the reliability characteristics of HfO films on SiGe/Si heterostructure, focusing interfacial layer (IL) with different post-deposition annealing (PDA) temperatures and the Hf-silicate gate stacks on strained-SiGe MOSFETs, which hasn't been adequately researched as of now (I).

In conclusion, the reliability characteristics are improved with increasing the PDA temperatures, but more degradation can be found at the elevated temperature due to more crystallization of HfO_2 film with the bulk traps. This investigation on the reliability characteristics will be helpful for fabricating the most promising Si_{1-x} Ge_x MOSFET devices with Hf-based gate dielectrics for the new generation of CMOS technology.

Chip Fabrication

The second technology I will focus on is chip fabrication. We visited Nanya Technologies, which designs and manufactures DRAM. The process of making DRAM is just like making any semiconductor chip. Silicon is melted and grown into silicon crystal (ingot), which is sliced into wafers (about 8 inches to 12 inches diameter). The wafer is polished (normally the stage that Nanya will get its wafers). To start making DRAM, Nanya will grow SiO_2 on the wafer by exposing it to oxygen at high temperature or by a chemical vapor deposition (CVD), where Si and O_2 are combined and coated on the surface of the wafer. The wafer is then coated with a light-sensitive chemical called *photoresist* and light is shone through a pattern onto the wafer to form a mask. As a result of the light exposure, some portions of the wafer harden and become resistant to certain chemicals, while the non-hardened part is washed with chemicals leaving a three dimensional pattern of the mask behind. To control the electricity through the chip, certain areas of the wafer are exposed to chemicals that change the capability to conduct electricity. It is also at this stage that doping is done as needed. This is achieved by exposing the wafer to chemicals and also by heating forcing the Silicon atoms to be displaced that of the dopants. An alternative method is the use of ion implantation, where ions are shot to sections of the silicon to displace the silicon atoms. The next step is to electro-plate copper to the entire wafer surface and again to unwanted portions of the metal is etched away with chemicals to leave lines of metal interconnects. Next, the wafer sort is done, where each chip on a completed wafer is test for electrical sanity. Failed chips are discarded and good chips are mounted on the circuit boards and once packaged they are tested again (IV, V). The above processes described above are facilitated with an automatic line, which utilizes an automated overhead hoist transport, made up of an overhead shuttle (OHS) and overhead transport (OHT).

Nanya's plant in Taoyuan is currently running most of its DRAM production on 110nm process technology, based on a trench capacitor cell exhibiting the best area efficiency in the DRAM industry. This area efficiency advantage translates into comparably small die sizes and a high number of chips per processed wafer and consequently reduced production costs. DRAM technology faces enormous challenges when reducing the memory cell geometries, as the substrate doping level has to be increased to overcome short channel effects. On the other hand, data retention is strongly impacted by the electric field across the device junction connected to the DRAM storage capacitor. The dependence of data retention time on increasing electric field is widely reported and basically originates from increasing junction leakage with higher doping concentration. Various solutions have been proposed, including vertical access transistors in deep trench technology or recessed devices in stack capacitor technology. The basic idea behind these concepts is to increase the array transistor channel length by extending it into the silicon surface. This enables lower doping concentrations at the expense, however, of the device drive current (III). Nanya is moving towards the stack technology as demand for small size DRAM increases.

Biomedical Research

The final piece of research that was most interesting to me was the biomedical research of Dr Hao-Li Liu of Chang Gung University and that is why it is the technology I will discuss in detail. His work is on focused ultrasound. The focused ultrasound is one of the more recent technologies, as it is just 50 years old. The focused ultrasound is very useful in conducting localized tissue thermal ablation reversible/ temporal blood-brain barrier disruption. By driving the focused energy in continuous-wave delivered mode, the ultrasound energy can be sharply focused into soft tissues and due to tissue viscous and ultrasonic-energy absorptive nature, the sharp focus can then induce a localized temperature elevation in about 30 – 55 degree Celsius in a few seconds. The rise in temperature can cause irreversible tissue *necrosis* at the target region while keeping surrounding tissues undamaged. Hence, this will be for destroying deep-seated tumors or brain disorder site, by using the focused ultrasonic energy to thermally destroy the target without damaging the intervening brain tissues (II).

There is another important usefulness when in the burst-tone driving mode, the current focused ultrasound can temporarily induce reversible blood-brain barrier (BBB) permeability in brain tissue. By doing so the localized BBB disruption can serve as a new way to delivery drug to the brain (II).

DETAILED TECHNICAL ANALYSIS: FOCUSED ULTRASOUND

Introduction:

Exposure of body tissue to Ultrasound results in two phenomena. One is a non-thermal effect called cavitation and the other is thermal (heating) effect. Cavitation occurs when the tensile strength of pure water is very large, on the order of 100 MPa, so that cavitation is almost always initiated at a preferential site for liquid rupture. However, the mammalian living systems circulate blood through a variety of filters (i.e., lung, kidneys, liver, etc), the cavitation threshold in blood is higher than in water, and even higher in tissue. Typical values of the threshold are: Water—0.5 MPa; Blood—2.5 MPa; and Tissue—5.0 MPa (II).

Also high-intensity focused ultrasound (HIFU) is a non-invasive technique for heating tumors. The principle is based on the physical effect of ultrasound beam on tissues. The main goal of HIFU is to maintain a temperature between 50 and 100 °C for a few seconds (typically less than 10 s), in order to cause tissue necrosis. Typically, focal peak intensity between 1000 and 10,000 W/cm2 is used with pulse duration between 1 and 10 s and a frequency of 1 to 5 MHz (II).

According to the vascular characteristics of tumor, however, the vascular supply and blood flow in tumors are markedly different from those in normal tissues. Generally, the blood perfusion in tumors is poorer than that in the host's normal organs or tissues. In addition, blood flow is distinctly higher in the tumor periphery than in the tumor center where often tumor tissue is necrosis due to insufficient nutriment. In Dr Liu’s study, instead of heating all total tumor volume, they propose a novel heating only on the tumor periphery by using HIFU.

Formulations and Methods:

The acoustic pressure field, which induced by the spherically curved transducer (10-cm diameter, 10-cm radius of curvature), was based on the numerical solution of the Rayleigh–Sommerfeld diffraction integral. The integral relates the velocity u normal to a radiating surface S, to the acoustic velocity potential by:

$$\psi_p = \iint_S \frac{u.e^{-ikr}}{2\pi r} dS \qquad [1]$$

$$p^2 = (k\rho_t c)^2 |\psi_p|^2 \qquad [2]$$

$$q = \frac{\alpha}{\rho_t c} P^2 \qquad [3]$$

Where ρ is the density of tissue, and c is the speed of ultrasound in tissue.

The speed of ultrasound has an average magnitude of 1550m/s in most soft tissues. Due to the emitted ultrasound power, the absorbed power density in tissue, q, is give by [3], where α is the attenuation coefficient. Ultrasound attenuation in tissue is the sum of losses due to absorption and scattering.

A precise temperature model is essential for the thermal treatment. Generally, the Pennes bioheat transfer equation, as shown, is used to solve the temperature distribution in living tissue for a given absorbed power deposition during thermal therapies:

$$\rho_t c_t \frac{\partial T}{\partial T} = k_t \nabla^2 T + W_b c_b (T_a - T) + Q_m + q \qquad [4]$$

Where ρ_t is the density of tissue, c_t is the specific heat of tissue, W_b is the blood perfusion rate, c_b is the specific heat of blood, T_a is the arterial temperature 37 °C, T is the tissue temperature, Q_m is the metabolic heat, and q is the absorbed ultrasound power density. Due to metabolism, the heat generation term Q_m is neglected, that is, its value is very small about 0.0001-cal/cm3 s. And the geometry of the heating system is shown in **Fig. 1**.

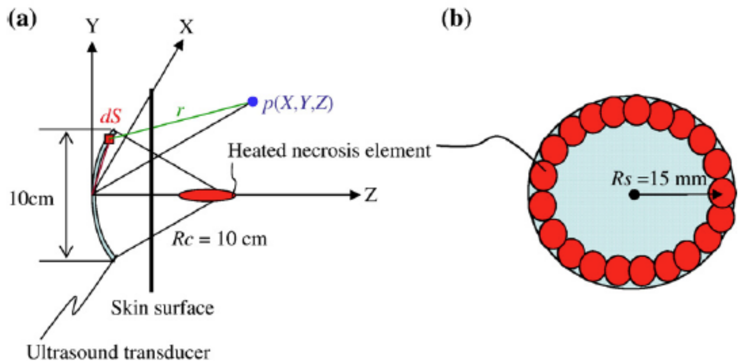

Fig. 1. Schematic diagram of the geometry of the heating system. (a) Spherically curved piezoelectric transducer with diameter 10 cm and the radius of curvature Rc = 10 cm and the frequency 1 MHz was used for simulation. The power of the HIFU transducer is 80 W and the heating time is 60 s. (b) The heated necrosis element induced by HIFU was moved with a radius Rs 15 mm on the tumor periphery.

A single necrosis volume by one exposure of HIFU is named "heated necrosis element." Ablating a tumor is usually just the result of covering the whole tumor by the heated necrosis element. However, in his study they used high intensity focused ultrasound to rotate with a radius R_s 15 mm and to heat the blood perfusion tumor periphery demonstrates that the core and shell domains of tumors were used in the study. In addition, the blood perfusion rates of different sites are used for simulations. The thermal dose or equivalent-minutes at a reference temperature of 43 °C at a given location (X, Y, Z) and at time t, is calculated as:

$$EM_{43}(\text{min.}) = \int_{t_0}^{t_f} R^{[T(X,Y,Z,t)-T_r]}\, dt \qquad [5]$$

Where R=2 for $T \geq 43$ °C R=4 for 37 °C$\leq T \leq$43 °C, t_0 is the initial time, t_f is the final time, T is temperature and the reference temperature T_r equals to 43 °C. In this study the threshold value of thermal dose for tissue necrosis is 300 min. 3 (II).

Results:

Results and discussion **Fig. 2** demonstrates the maximum temperature within the tumor changes for the six different blood perfusion rate cases. Due to the high heating power (i.e., heating power 80Wand heating duration 10 s), the blood perfusion does not significantly affect on the maximum temperature. On the other hand, the temperature is almost independent of the blood perfusion for rapid heating.

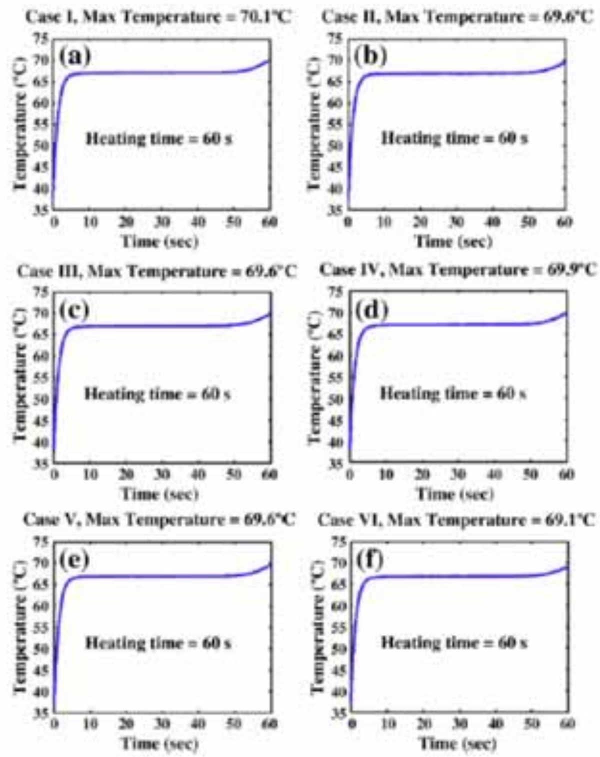

Fig. 2. Transient temperature profiles of the six heating cases by using a HIFU transducer for the power 80 W and the heating time 60 s. (a) Case I, (b) Case II, (c) Case III, (d) Case IV, (e) Case V, and (f) Case VI.

Solid tumors induce tumor *angiogensis*, in other words, tumor *neovascularization*, with extensive and rapid growth. Generally, the blood perfusion in the tumor periphery is higher than in the tumor core. On the other hand, the use of heat by HIFU could destroy the periphery tissue of tumor (II).

Conclusions:

The thermal lesion induced by high-intensity focused ultrasound can fully cover the tumor periphery cites with a high blood perfusion. Thus, the heating to tumor periphery by HIFU may offer an approach to destruction of solid tumors. The modality of heating on the tumor periphery by using high intensity focused ultrasound may provide an approach to eradication of solid tumors (II). I foresee that in about five years, this technology will be widely used in hospitals to both deliver drug to the brain and also kill tumor. This is currently being tested in the Chang Gung Memorial Hospital.

The detailed analysis of the Ultrasound is just one example of how the research being done can help people all around the world. The Global Seminar provided me with a deeper understanding of the new technologies being developed in Taiwan and Hong Kong, along with their real-world applications.

ACKNOWLEDGMENT

The authors thank Dr. Shey-Shi Li, Dr. Siddeswar Maikap, Dr. Yung-An Kao, Dr. Hsiao-Lung Chan, Dr. Hao-Li Liu, Dr. Woei-Luen Chen, Dr. Guan-Wu (Jeff) Chen, Dr. Ren-Yuan (Tarzan) Lyu, Iris Chang, Dr Jin Lu, Dr James Fok and Prof. Gerald Sobelman for the presentation and the insight that was given to the various technologies.

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