Developing a Nano-electronic fabrication Laboratory to enthuse Entrepreneurship

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Abstract

Manifestations of the famous bathtub curve effect have shown that in the field of electronics, miniaturization makes the cost of electronic technology reduce dramatically. In the first few years, on the introduction of a new technology, it costs more than usual till when it gets into a manufacturing phase, and after that again cost goes up due to its obsolescence, whence further miniaturization has to set in. Financing is very different in the field of nano-engineering and difficult for an entrepreneur, as the financier or the funding agency wants to see what is the end product, after seeing what is going on. The lack of nano-engineering education-so called design fundamentals; knowledge of design tools and manufacturing processes is one of the major drawbacks. To add to it there is a lack of depository knowledge and infrastructure for selection of microfabrication processes and assembly. These deficiencies can be met, if during graduation from an undergraduate or a masters program, a broad based knowledge of nano-electronic fabrication technique is provided. This paper sets the limits and gives an overview of such a laboratory for a nano-technology research and infrastructure. This education can develop a technician-training program and ultimately leads to the capabilities of building proto-type pilot projects. Since upcoming initiatives are so demanding, newer systems prevent professors to form a company or participate with new entrepreneurs. One of the greatest examples is the long-standing demand of interconnections to nano-electronic components. Giving the right training and objectivity, a new generation of entrepreneurs can be enthused amongst our students. This would help our State develop fundamental research in nano-technology. Our effort of building a nano-engineering laboratory is to develop novel integrated Complementary Metal Oxide Semiconductor-CMOS gas sensors, SOI inertial sensors and piezoelectric tactile sensors based on piezo-resonance. The equipment proposed will be finally used for nano-interconnect technology

Introduction

At the present time, the number of sensors employed in automotive, aerospace, biomedical and robotic devices and systems are increasing in the same proportion as the use of high aspect ratio micro-electromechanical systems (MEMS) and the integration of nano-electronic technology to produce them smaller and denser. Sensors are trying to match MEMS in to inevitable, usable economic systems for future use of the common man. MEMS and nano-technologically produced sensors and actuators are going to be fabricated in future mainstream endeavors. With the knowledge of Si processing in the ongoing VLSI era most of these sensors are fabricated with relatively conventional CMOS processing techniques using a suitable blending of bulk and surface micro- machining. Moreover, there are big national laboratory facilities, such as the Center for Advanced Microstructures and Devices (CAMD), at Baton Rouge and many similar types, which induce such processing experiments to become a reality for entrepreneurs.

The next step is to produce such entrepreneurs from the graduating students who are anxious to take up high paying jobs on the first opportunity. Little more can be said to emphasize the help in getting them trained in CMOS processing techniques to provide basic skills at various vendors and OEM companies to get to a flavor of making a proto-type during a summer internship or a co-op assignment. One is up against the impossible, and experience makes the difference. All universities promise a lot to give, the widest range of experience and the most innovative design experiences, but only state of the art laboratory and people who have experienced this difference in the field of business are the right resources dedicated to help in such electronic ventures. In building up a business in 50 years from now requires a small business to excel with his product. It should be a perfect innovation with proven performance at a competitive price and should be usable in related services anywhere in the world. A new fabrication technology with the utmost state of the art technology will improve the productivity and performance using the path of least resistance. Better equipment will achieve higher yield of nano-systems and performance through commercial applications of micro and nano-systems.

New technology and processing

The discovery of transistor, and later on a metal oxide semiconductor field effect transistor-MOSFET circuit has led the way to most industrial and household consumer electronics that are on the market. More sophistication is brought in by micro-electromechanical systems by including sensors to release electronic information in wherever-whenever mode from one place to another. It has been felt that the new information technology will advance itself to an extent that information conveyed will not be electronic. MEMS related technologies would lead to enabling developments that would use smart mechanical, chemical and biological systems. These sensors will be "smart dust" types of sensors and the actuators will provide the sensors a way to actively interact with the world. The information conveyed may be as small as 32 bit-processed signals, but it will be instantaneous, efficient and reliable. Just as in very large scale and ultra large-scale integration (ULSI) processing, photolithography and X-ray lithographic techniques control the patterning of thin films, and the deposition of dopants is used to make transistor source and drains and metal contacts for gates etc. using a complementary metal-oxide semiconductor type processing. MEMS and nanoelectronic processing use similar techniques to process and fabricate structural components that are of micrometer and nanometer size. The problems mostly come to the fore in their post-fabrication processing and packaging in order to become workable and reliable devices.

Fundamentally, most of nanotechnology and MEMS technology can be bifurcated into two branches bulk and surface micromachining or fabrication. MEMS' processing usually involves bulk micromachining and selectively etches away portions of the substrate, like chiseling out a fine structure within a solid silicon or metal block. The remainder of the silicon structure remains as the final device. Whereas in surface micromachining, structures are fabricated on the top of the wafer using thin sacrificial films deposited through various standard processes familiar in CMOS fabrication process flow. It is still a problem to integrate mechanical and electrical components with surface or bulk micromachining though people are trying to hybridize these components.[1] So a compromise is used to marry standard CMOS process to fabricate electrical and mechanical parts with wet etches such as potassium hydroxide (KOH) or ethylene-diamine-pyrocatechol (EDP), to remove materials, anisotropically, at different rates along different crystal planes. Since KOH is incompatible with CMOS processing and metal ion and hydroxyl ion diffusion contaminates dielectric oxides, this etch is only used for non-active electronic devices. One must not forget that focus is shifting towards the fabrication of new nano-devices based on these thin electronic oxide materials and there are many new integration challenges in oxide based nano-electronics. For example, poly-silicon based surface micro-machining processes now typically use sacrificial oxide spacer layers that are etched to render free poly-silicon structures employed as a gas chromatic device or a meander gas flow regulator. Some bulk micro-machined sensor capable of measuring differential pressure across a thin silicon membrane due to strain in a piezo-resistive element can be used as a pressure sensor or an airbag micro-switch. Similar are such low cost accelerometers with heightened sensitivity in the vertical direction, detecting acceleration of the center of mass or in another manner the height itself. Real breakthrough of the micro-machining and nano-lithography comes in the fields of atomic force and scanning tunneling microscopy (AFM & STM) as tips are exclusively micro-machined using silicon nitride as a beam holding a fine nano-metric tip. Micro machining and nano-technology can produce new enabling technologies by giving a new approach to existing problems. Recently, Texas Instrument has produced a micro-fabrication process to produce large arrays of digitally controlled mirrors in a single chip along with its dsp-digital signal processing hardware. These mirror arrays are needed for projection displays, rear projection television and higher than 600 dpi color printers.

In a recent graduating class of ELEN418-Device Processing, I asked the students, "What field they would choose to develop if compelled to be an entrepreneur?" Most of them replied they would like to form a sales company but only some said they would form a manufacturing company. The choice for a pioneering future in a sales type of venture was to produce Low-K dielectrics and solutions. The manufacturing oriented ones went for resist processing, wafer cleaning, advanced interconnect processing using copper and defect reduction in volume manufacturing, not to process technology to fabricate Nano- or MEMS products. The simple reason being they have not seen that door is open and it is time to go. They feel it is important to become an MBA engineer, as it would round off their skills better and make them savvier in how to deal with business-related issues[2] and open their eyes to the way the rest of business is run. However, salary paid to them only gets about 5% higher than they would get with a basic engineering degree.

Developing an early stage laboratory

We have enormous help from a national laboratory supported by the State of Louisiana, known as the Center for Advanced Microstructures and Devices-CAMD. This laboratory has given us summer refresher courses, non-traditional training, and research experiences on many occasions. Short wavelength X-rays from CAMD, used for micromachining by a process called X-ray lithography, has allowed us to study, design and fabricate sub-micron devices. Since X-ray lithography has the ability to produce microscopic devices of 0.09nm feature size, nano-metric structures can also be made possible by X-ray lithography. In Southern University, researchers are exploring every possible development in MEMS. We are looking forward to encouraging students in silicon micro-machined device elements for chemical industries in Louisiana. This enables us to take off in the right direction and efforts to combine these structures with other processing circuits[3] all on the same die. This makes these total sensors. Its concept is rapidly gaining momentum in our students.

Some of the general areas of interest in nano-structured materials that can give rise to new ventures can be listed as: 1) semiconductor and metal nano-particles and metal semiconductor nano-composites; 2) size-quantization effects in semiconductor nano-particles; 3) surface modification and characterization including tunneling and atomic force microscopies of nano-clusters; 4) photo induced charge separation and interfacial charge transfer; 5) dye sensitization of semiconductors; 6) photo-electrochemistry of nano-structured films; 7) photo-catalysis and environmental applications; 8) metal polymer nano-composites and membranes; 9) nano-structured sensor surfaces and biological applications of nano-materials; 10) nano-structured catalysts for fuel cells; 11) sensors; 12) electrosynthesis of nano-materials, including nano-tubes, nano-wires or quantum dots; 13) characterization of nano-structured electrode materials; 14) studies of electrochemical or photo-chemical phenomenon or materials, or other probes with nano-meter resolution; 15) semiconductor dye interfaces for solar energy conversion/stage; 16) catalytic modification of electrode surfaces and ; 17) hydrogen generation and storage. Since the field of MEMS is experiencing phenomenal growth (see Fig. 1) in communication applications let us compare how investment in conventional commercially available communication applications compares with optical communication applications, such as wavelength division multiplexing (WDM) technology.

In comparison to conventional (series 1), Dense-WDM technology (series 2) is having an exponential growth. It is being used for communication between computing systems for massively parallel processing to avoid shrinkage of processing power (teraflops) due to communication congestion that arises in electrical interconnects for inter-and intra nodal information exchange.[4]

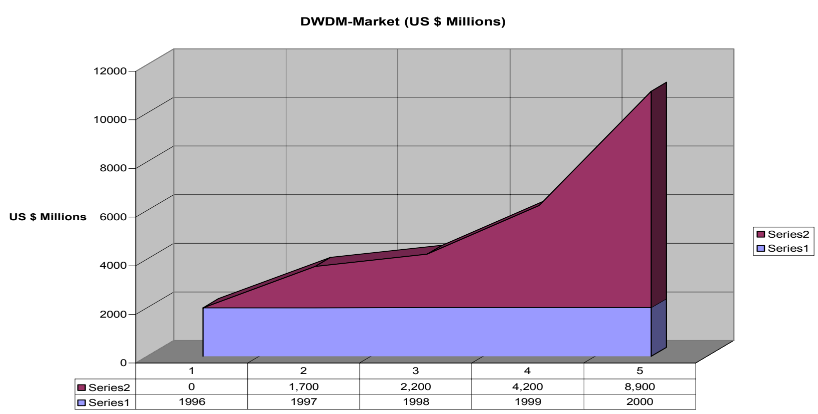

Figure 1 Comparison of yearly investment on different technologies, conventional and DWDM.

When using MEMS one can also develop single photon counting micro-arrays which consists of shallow-junction Geiger-mode avalanche photodiode (APD) detectors using CMOS -compatible fabrication steps.[5] Such sensors capable of counting single photons or charged particles are required for astronomy and various security applications. A laboratory, which has the following MEMS processing capabilities, will be able to prototype and process any marketable system.

MEMS PROCESSING CAPABILITY	
Dry Etching	
Plasma Therm 770	Deep Silicon Etching
LAM 490	Oxide, Nitride RIE
Plasma Therm 720	PZT Reactive Ion Etching
Commonwealth Scientific	Argon Ion Milling
Deposition	
Plasma Therm 790	PECVD Oxide, Nitride
Varian 3190	Sputtering Pt, Ta, Al -1%Cu
BTU Furnaces (8 -Tubes)	LPCVD, Poly -Si, Nitride, Wet & Dry Thermal Oxidation, Annealing, Alloying, Drive, Bonding
Photolithography	
Karl Suss Aligner MA -6	Front -to -Back, Alignment & Wafers bonding
Branson (Photoresist Asher)	Photoresist stripper
Tempress Wafer Cleaner	Masks and wafers cleaner
Preparation & Characterization	
Labconco Glove Box	PZT Sol -gel preparation
Rapid Thermal Anneal (RTA)	PZT crystallization, electrodes annealing
Tencor Stress Gauge FLX2908	Thin Film Stress, RT to 900 °C
Ellipsometer	Thickness and Refractive Index
Tencor α-Step	Step height measurement
4 -Point Probe	Sheet resistance, thickness measurement

Fig. 2 A typical list of equipment used for PZT type sensors and similar devices.

Shortcomings of conventional training

The laboratory experience students get from master's level training has the following shortcomings. They cannot imagine how miniaturization makes the cost reduce to zero. Lack of engineering education - so called design fundamentals, design tools and manufacturing processes such as lithography leads to difficulties in economic evaluations. Lack of metrics, standards and specifications add up to a lack of a large enough depository of knowledge, thereby making it difficult to select the most suitable microfabrication foundry. Most of the small enterprises lack the capability of making a pilot plant to produce many prototypes. And above all university systems prevent professors to form a company with their conflict of interest regulations. Thus, even though fundamental research and research infrastructure can help an upcoming initiative by a graduate or post-graduate entrepreneur, nano-manufacturing processing and micro-scale application is still a difficult project to realize as an SBIR (small business innovative and research) venture. In 1992, the venture capital fund at Rowan University started with a mandatory eight semester engineering clinic sequence wherein multidisciplinary student teams engage in semester long design project[6] showed that students engaged in entrepreneurial projects have a better understanding of the technical aspects and societal impact of their projects. This is not so in the case of commercial applications of materials and nano-technologies, investment dollars are limited and research is expensive. On the other hand engineers are cheap rent is cheap. Businesses finally became focused and became lean. They need quite a thorough business plan. They focus on profitability in the short term.

Toward meeting future challenges successfully

Our experience says you have to have enough money in the bank as starting a business is a job and a half, and one has to do the very best to make it happen. One should still have time be early in putting a prototype. Though it may happen, do not let any body say your baby is ugly. Remember that no venture firm is interested in the product if you have no patents. One can invest in patents and then pay if it becomes profitable. Our experience has shown that, while many students have ideas for original inventions, the majority of the students are not motivated to restructure these ideas into a good proposal. Faculty members are needed to help encourage invention within their traditional coursework and be willing to supervise students if they propose original inventions. Ultimately, entrepreneurship cannot be successful without a cadre of faculty willing to buy in their concept, and a good infrastructure facility back up the prototype stage of the project.

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