AN EXAMPLE IN THE CURRICULUM DEVELOPMENT OF NANOTECHNOLOGY

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Abstract— *Nano-fabrication and nano-instrumentation are recently popular research topics in the development of nano-technology. Research demands come from the needs of advanced IC fabrication technology. The state-of-the-art photolithography-based IC technology, with product feature size in the range of sub-micron level, is reaching its extreme limit for a more compact microchip fabrication. Nano-technology is the chance for the realization of that purpose. STM and AFM are two key equipments currently used in the development of nano- technology. Tremendous amount of research works announced so far were focusing on the applications of STM and AFM on nano-fabrication and nano-instrumentation. Due to the fact that SPM plays a major role in the development of nano-technology, both STM and AFM were investigated in very details on their functions and working principles. Typical examples in the development of SPM-fabricated nano-structures were choused to summarize the techniques of nano-technology. The knowledge base involved was then analyzed. Based on that knowledge foundation, a comprehensive curriculum in nano-technology was possible. This research also demonstrated a feasible way in the curriculum development of nano-technology.*

Index Terms *¾ AFM, curriculum, nano-structure, nano-technology, STM*

INTRODUCTION

Nano-fabrication and nano-instrumentation are recently popular research topics in the development of nano-technology. Research demands come from the needs of advanced IC fabrication technology. The state-of-the-art photolithography-based IC technology, with product feature size in the range of sub-micron level, is reaching its extreme limit for a more compact microchip fabrication. Nano-technology is the chance for the realization of that purpose. The feature size of the nano-technology product is smaller, by a factor of one hundred, than the feature size of sub-micron technology product. The sub-micron technology is the mainstream of the current IC fabrication.

Taiwan is well known by her IC fabrication capability. IC industry plays a major role in the economy of Taiwan today. Based on the trend of IC technology, the ability in the development of nano-technology would promise a continuing prosperity of the IC industry on Taiwan. It would finally help to keep the growing momentum of the economy. The supply of high-tech human resources is certainly a key issue to the development of this new technology. A well-designed curriculum of nano- technology will surely guarantee a good start in the training of high-tech manpower. This was the goal of the research.

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STM AND AFM [1]

The tunneling effect is the foundation for STM to measure the surface structure of a specimen with the precision level up to atomic scale. Tunneling current is observed as the STM probe and the specimen are just several atoms apart. Its magnitude is proportional to the reciprocal of the distance between probe and specimen. The surface profile can thus be detected, with vertical resolution up to 0.1Å, through the detection of tunneling current. There are two ways in the measurement of surface profile, constant current spectroscopy and constant level spectroscopy.

Constant current spectroscopy: During the STM probe scanning, the tunneling current is kept at constant by adjusting vertically the probe position, based on the surface

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profile, such that a constant gap is kept between probe and the surface of the specimen. Displacement information of the probe in the vertical direction represents the surface texture of the specimen.

Constant level spectroscopy: During the STM probe scanning, the probe is kept at a constant level. The gap between probe and the specimen surface is thus varying according to the surface texture of the specimen. Tunneling current detected is also varying accordingly. This tunneling current information describes the surface texture of the specimen.

For AFM instrumentation, the probe has a physical contact with the surface of the specimen. During the scanning process, the bending motion of the probe complies with the profile of the specimen surface. A ray of laser light incident upon the top of the probe is reflected to a photocell. The output voltage of the photocell has a one-to-one correspondence with the reflection angle, i.e., the bending condition of the probe. A feedback circuit is designed to adjust vertically the position of the probe, according to the output of the photocell. Eliminate the variation of the output voltage of the photocell, due to the bending of the probe, is the purpose of the adjustment. The adjusted probe positions collected in the vertical direction describe the surface texture of the specimen.

Technology involved: instrumentation of tunneling current; servo system; application of laser diode and photocell; application of piezoelectric material at precision motion; vibration isolation; computer techniques.

EXAMPLES USED TO SUMMERIZE THE NANO-TECHNOLOGY

The research was focus on the investigation of SPM in the nano-fabrication and nano-instrumentation. Five typical examples were chose to summarize the technology involved. They are the groundwork of nano-technology.

Nano-structure via AFM lithography [2]

Nano-fabrication: A silicon dioxide layer was first formed on the surface of silicon substrate. An ODS layer, acting as an etch-resist layer, with thickness of 1.5-2 nm was then deposited via CVD on the silicon dioxide layer. The fabrication process followed with an AFM probe scanning over the ODS layer to form a nano-structure pattern. The pattern scanned, together with constant current input, by the probe and formed on the ODS, loosed its etch-resist property. A chemical etch process transferred the pattern from ODS layer into the silicon substrate. A final electroplating process formed the nano-structure with gold. The width of the golden structure line is 200 nm.

Technology involved: silicon oxidation; CVD; chemical etching; application of AFM; instrumentation of constant tunneling current; electroplating; computer techniques.

Nano-structure via STM lithography [3]

Nano-fabrication: A thin metallic layer TaIr with thickness of 10nm was deposited on the Si (100) substrate via sputtering process. Another thin layer of a-Si:H, not react to the oxygen and thus acting as a resist in the pattern development, with thickness of 25-40nm was deposited on top of the TaIr layer. STM scanned the pattern, a desired nano-structure, on top of the a-Si:H layer with Pt/Rd probe as cathode and silicon substrate as anode. A constant tunneling current was kept during the scanning process in order to eliminate the H from the scanned or patterned area of a-Si:H layer, i.e., the anti-oxidation property of the patterned area was deteriorated and a silicon-dioxide nano-structure was formed. TMAH, an etching solution with anisotropic etching rate of 10000:1 between a-Si:H and SiO_2, was used to eliminate the a-Si:H layer on the top and disclosed the lower TaIr layer to the air. The etching process left the nano-structure as a double deck structure with SiO_2 layer on the top and TaIr layer underneath. A dry etching process, Ar^+ bombardment of the substrate surface, was employed to eliminate the disclosed TaIr layer and left the TaIr nano-structure with SiO_2 on the top. After removing the SiO_2 layer, the SiO_2 pattern that was initially developed via STM was transferred successfully to form the TaIr nano-structure. The TaIr metallic line was 40nm in width.

Technology involved: application of STM; instrumentation of constant tunneling current; servo system; vibration isolation; sputtering process; silicon oxidation; chemical wet etching; plasma etching; computer techniques.

Nano-structure fabricated via AFM [4]

Nano-fabrication: The 300nm PMMA/MAA photosensitive resist layer was applied on a substrate of any kind. The substrate was then baked under the temperature of 165-170 ^{0}C for an hour. For the resist to be more dissolvable to the developer, MIBK:IPA=1:3, the substrate with the resist on the top was subjected to a full-scale e-beam exposure. Another 24nm PMMA resist layer was applied on top of the first layer, under the temperature of 496K. The process followed was that AFM scanned pattern , the nano-structure, on the second resist layer via its Si_3N_4 probe. It was then baked at 165-170 ^{0}C for 60 sec, cooled at room temperature and developed with MIBK:IPA = 1:3 for 5 sec to reveal the substrate surface under the patterned nano-structure. PVD deposition was followed to fill up the nano-structure with metal and two layers of resist released from the substrate via acetone. A metallic nano-structure with

60nm in height and 40nm in line width was fabricated.

Technology involved: application of AFM; instrumentation of constant contacting force of the probe; servo system; vibration isolation; chemical wet etching; PVD; resist application; computer techniques.

AFM as a read/write device of a very high-density data storage disk [5]

Nano-instrumentation: AFM probe was used to read data from or write data to a very high-density storage disk, with density up to 25 GB/in^2, that was transparent and made from polymer. For the data writing, AFM probe was slightly depressed into the spinning transparent disk. A laser beam, incident upon the tip of the probe from a position below the disk, heated the tip for 1μs with laser power set at 20mW such that the tip reached the glass transition temperature of the polymer. With the tip at glass transition temperature, the AFM probe cut pit, 100nm in length and 10nm in depth, on the disk as digital information. The writing speed could reach to 100KHz. For the data reading, AFM probe was also slightly depressed into the spinning transparent disk. A laser beam was incident upon the top surface of the probe, from a position above the probe. The reflection from the probe was received by a photocell and two kinds of position signals were detected due to the up and down motions of the probe. Those position information read were the digital information on the disk. The reading speed could reach to the level of one million bits per second. One pit marked on the disk stood for one bit of the digital information.

Technology involved: application of AFM; instrumentation of constant contacting force of the probe; servo system; vibration isolation; application of laser diode; application of photocell; technical skills in light focusing, light transmitting and light heating process; computer techniques.

Nano-structure fabricated via AFM (second example) [6]

Nano-fabrication: The fabrication of the nano-structure was based on the anisotropic etching rate of Si and SiO_2 to the KOH solution. The AFM probe, conductive with voltage applied to form strong electric field between the probe and the substrate, scanned and formed the SiO_2 nano-structure on the Si(100) substrate. The nano-structure scanned by the AFM probe, i.e., scanned by the strong electric field, was turned from Si into SiO_2. KOH etching was then applied. The nano-structure shaped after the KOH etching was due to the fact that SiO_2 had much slower etching rate than the Si to KOH solution. A line width of 57nm was observed.

Technology involved: application of AFM; servo system; vibration isolation; chemical wet etching; silicon oxidation through the application of electric field; computer techniques.

THE KNOWLEDGE BASE OF NANO-TECHNOLOGY

Technology involved: Based on those 5 examples described on above, techniques related to the nano-technology was synthesized and shown in below.

Application of SPM (including AFM and STM); instrumentation of constant tunneling current; servo system; application of laser diode and photocell; application of piezoelectric material at precision motion; vibration isolation; thin film deposition (including PVD and CVD); silicon oxidation (including thermal oxidation and electric field oxidation); chemical wet etching; plasma etching; electroplating; sputtering process; resist application; techniques in light focusing, light transmitting and light heating process; instrumentation of constant contacting force of the probe; computer techniques.

The knowledge base: Based on those synthesized techniques, the knowledge involved was analyzed, synthesized and shown in below. A comprehensive curriculum could be easily proposed with the research result.

Quantum mechanics (emphasis on tunneling effect); Physics (including mechanics, electricity, electromagnetism, optics and photoelectric effect); Chemistry (including models of the atom, chemical bonding; aqueous-solution reactions; electrochemistry, photochemistry); stress and strain analysis; vibrations; electronics; circuits analysis; control systems; application of microprocessor; mechatronics (including sensors, actuators, control circuit, piezoelectric actuator); IC fabrication process; programming.

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