Facing the Challenge of Measurement Interoperability: Taiwan's Experience in Establishment of a National Measurement System

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Abstract

Taiwan has been recognized as an important base for product development with flexible manufacture and dynamic design in a global product value chain. Characteristics of Taiwan industry are analyzed, and special attentions are paid to electronics and IC industries having a short life cycle of products. The national measurement system is introduced briefly, including CMS-NML and CNLA. Besides primary calibrations, CMS-NML is strongly requested by the government and Taiwan industry to apply the standards-based technologies to promote the competitiveness of Taiwan companies. Examples are given to demonstrate the supports of CMS-NML to electronics, petroleum and emerging industries. The following challenges of NMS in implementation of measurement interoperability are discussed: (i) meeting the dynamic demands from fast-growing industries; (ii) facing the impact by the westbound movement of Taiwan companies to mainland China.

1 Metrology Infrastructure in Support of World Manufacture Base

1.1 Characteristics of Taiwan industry

As the National Metrology Laboratory in Taiwan, Center for Measurement Standards (CMS) has been established to support by metrology techniques the safety, health, environment and trade (S.H.E.T.) aspects of Taiwan industry and society. In other words, CMS-NML aims to promote the living quality of Taiwan society and to enhance the competitiveness of Taiwan industry via metrology standards and relating developed technologies.

Taiwan economy is characterized by its flexible and dynamic features, with a cluster of small-medium companies having the average market capital of $500 million (in contrast, a threshold for a company to be considered in the A list of Forbes is at least $5 billion in sales or

market capitalization). From the point of view of global value chain of products, Taiwan plays an important and indispensable role in manufacture, especially in production of electronics and integrated circuits.

In review of Taiwan industry, it is found that manufacture industry sector has a contribution of more than 25% to Taiwan gross domestic product (GDP). In addition, electronics industry has a dominant 46.5% contribution in terms of revenues of all Taiwan industries in 2001. The indispensability of manufacture of Taiwan industry to the global economy can be explained in the following paragraphs.

Taiwan companies are key suppliers to the global economy by producing a wide variety of hardware and software of information and communication. For instance, primary information hardware electronics made in Taiwan range from notebook and desktop personal computers and mother boards to CRT and LCD displays.

Every one of two notebook PCs in the global market of 2001 was manufactured in Taiwan, although they may be in the brands of Dell, Toshiba, Compaq and IBM. In addition, each computer has a motherboard inside, which is the main body containing a CPU, memories and peripherals. More than 85% of motherboards from world top 10 PC companies were contracted to make in Taiwan in 2001.

Integrated circuits (IC) are core elements of electronics, such as rice to food processing. IC manufacture is the core of IC industry. IC foundry plays an important role in Taiwan IC manufacture industry. IC foundry companies (contract-chip producers) are dedicated to provide IC fabrication services to integrated device manufacturers (IDMs), such as Intel and Motorola, and IC design companies. However, IC foundry companies themselves do not produce any brands of electronic commodities.

The top two IC foundry companies are all located in Taiwan; those are Taiwan Semiconductor Manufacturing Co. (TSMC) and Union Microelectronics Co. (UMC). TSMC is ranked as the most profitable computer hardware company of 2001 by the Forbes magazine. The market values of TSMC and UMC are estimated to be over 20% of Taiwan stocks market.

1.2 National measurement system in Taiwan

The National Measurement System (NMS) in Taiwan consists of a national metrology institute,

CMS-NML, and an accreditation body, Chinese National Laboratory Accreditation (CNLA). The former maintains the primary measurement standards at Taiwan and the comparability with those of other NMIs; the latter manages the routine conformity of accredited labs to ISO 17025, including proficiency testing between the accredited labs and their fulfillment of traceability to CMS-NML or SI units.

CMS-NML has been founded since 1987, and is a contract agent in operation of national metrology institute by project in Taiwan in 15 measuring fields, including most of primary standards for the realization of SI units, except time and frequency standards [1]. To date, 103 measurement systems have been established and provide about 4000 primary calibrations annually to Taiwan industry. To achieve the requests from MRA of NMIs [2], CMS-NML has applied for third-party accreditation via CNLA. The accreditation consists of assessment of the quality system at CMS-NML, and the technical assessment of measurement capability with the helps of assessors from other NMIs. In principle, at least one assessor is from the country members of APMP, and at least one from the countries outside APMP. The assessment of 15 fields of measurement standards shall be completed by the end of 2002.

CNLA is the member of International Laboratory Accreditation Cooperation and Asia-Pacific Laboratory Accreditation Cooperation. CNLA performs laboratory accreditation in the domain of 15 testing fields and 10 items in the field of calibration. 663 laboratories are accredited by CNLA with ISO/IEC 17025 (revision of Guide 25).

2 Application of Standards-based Technologies to Raise the Competitiveness of Taiwan Industry

2.1 Technical support to electronics industry

The fabrication process of semiconductors is extremely sensitive to the vibration of environments. In the south of Taiwan, a planned high-speed railway will pass through a science-based industrial park, where a cluster of ICs and optoelectronics companies are located. Especially several advanced 305-mm (12-inch) wafer production lines are scheduled to operate in the science park. The influence of vibration caused by high-speed trains to the production lines becomes a noteworthy topic, which leads to disputes in the aspects of technology, economy and even politics.

A giant IC-maker asked CMS-NML to evaluate the influence of vibration at the same scale that a

high-speed train may cause to the production equipment. In other words, the testing results will provide the maker with valuable information to the decision of specifications of IC equipment. The IC maker is a primary customer of CMS-NML in shop-floor vibration testing service, which is an essential test before precision manufacture or measuring equipment are installed in the production line.

A newly–designed amplitude generator was used to emulate the vibration conditions at a frequency range less than 12.5 Hz that are expected to occur when high-speed trains pass by. The generator was installed and operated near by a production line and the vibration impact to the process equipment, such as scanners and SEMs, along the production line was tested. The testing layout is shown in Figure 1.

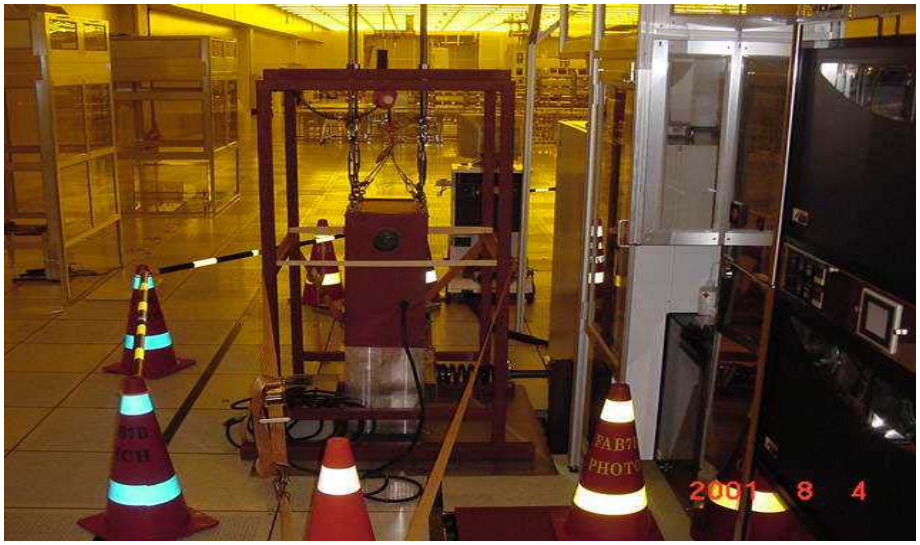

Figure 1. Test of vibration influence to IC manufacture process.

The CMS-NML evaluation report on the vibration influence due to high-speed train movement has a significant contribution to the re-start investment of semiconductor fabs by IC makers. The investment includes 6 production lines of 305-mm (12-inch) wafers, amounting to $20 billion.

2.2 Establishment of satellite calibration laboratories

To enhance the effectiveness of NMS and to relieve the burden of CMS-NML due to budget and space limitations, CMS-NML helps some key companies, including instrument makers, wholesalers and distributors to set up calibration laboratories and urges them to apply for the accreditation of CNLA.

Chinese Petroleum Corporation (CPC) is the top company among 1000 Taiwan manufacture companies in terms of sales capitalization. With the helps from CMS-NML, CPC has launched a project to establish a standards lab for calibration of flow meters in liquid petroleum gas (LPG). CMS-NML is responsible for the overall design and layout of the LPG calibration lab, with a budget of a half million. The lab is designed to calibrate the flow meters having a diameter of 50 to 300 mm with a flow rate from 20 to 4000 m^3/h. The CPC case is a CMS-NML contribution in implementation of satellite calibration laboratories. The strategy for establishment of key satellite labs is especially necessary to apply to those fields requiring large facilities and heavy equipment.

2.3 Measurement traceability for emerging industries

CMS-NML is also strongly requested by the government to provide measurement traceability for emerging industries, such as nanotechnology, communication and biotechnology, which are normally the core investments of government to create new industries or to promote the competitiveness of traditional industries by new technologies.

Nanotechnology is related to research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 - 100 nanometer range, to provide a fundamental understanding of phenomena and materials at the nanoscale and to create and use structures, devices and systems that have novel properties and functions because of their small and/or intermediate size. Nanotechnology research and development includes manipulation under control of the nanoscale structures and their integration into larger material components, systems and architectures [3]. Characteristics of objects ranging from 1 to 100 nm (extent between isolated atoms and bulk materials) are substantially different from those by either atoms or bulk materials.

Calibration and quality assurance analysis for nanosystems are important subjects in nanotechnology research. Scanning probe microscopes are important investigative tools in nanotechnology. The SPMs measure local properties with nanometer-scale spatial resolution by bringing a sharp tip in proximity to a solid surface. Thus calibration of scanning probe microscopes (SPMs) is essential to achieve measurement traceability of SPMs, and accordingly within the research scopes of NMIs. The traceability of SPMs is achieved via reference materials, as shown in Figure 2.

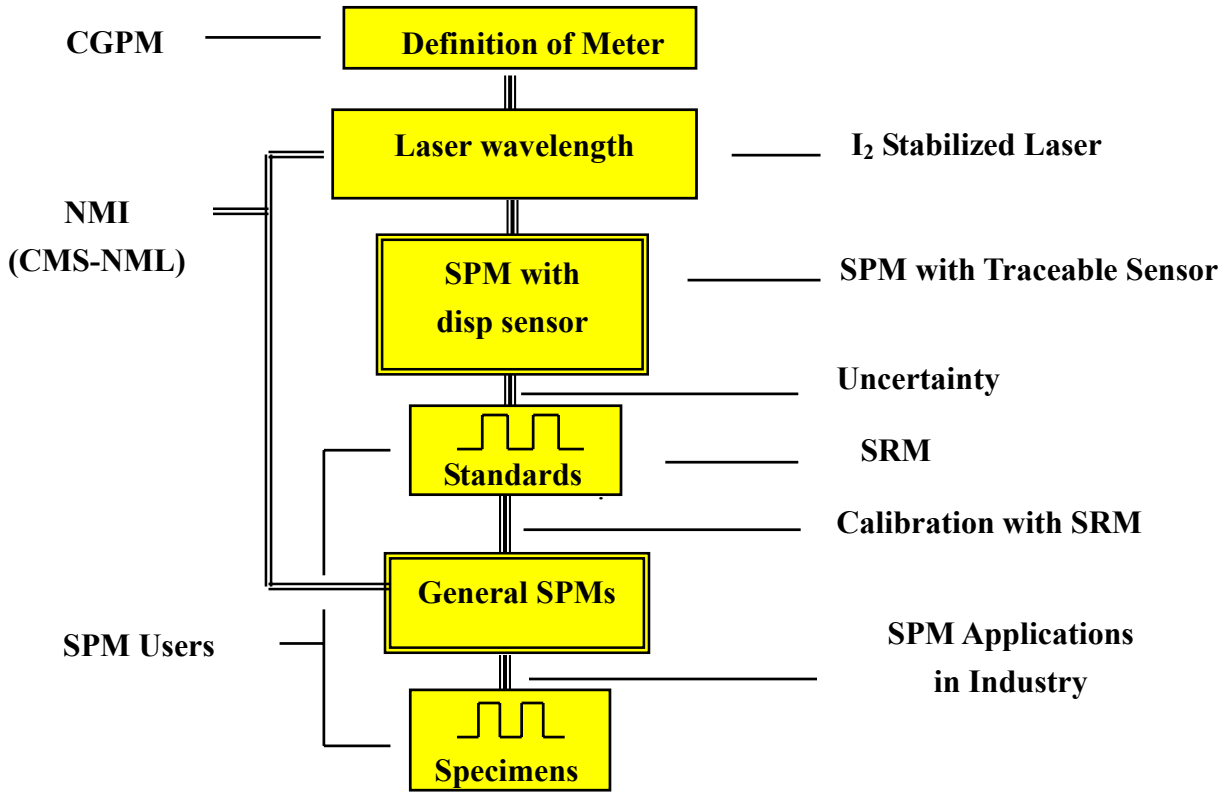

Figure 2. Traceability chain of SPMs.

In addition, a metrological SPM can be made by addition of measuring scales, either laser interferometers or capacitance sensors along three axes. Figure 3 is a metrological SPM home made by CMS-NML.

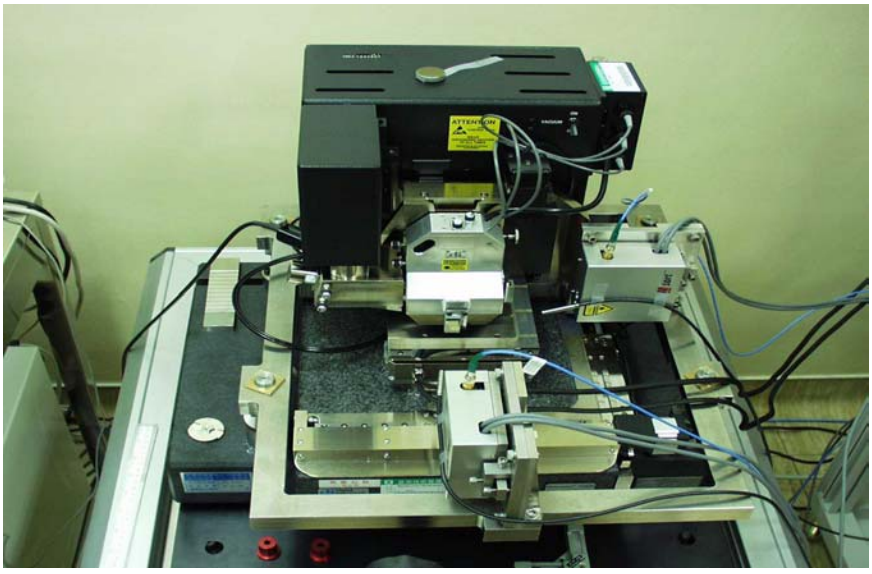

Figure 3. Metrological SPM of CMS-NML.

CMS-NML has drafted a new proposal of "Metrology Standards for Nanotechnolgy Project" in line with the National Nanotechnology Program (NNP), which is launched this year by the Taiwan government to promote new technology-based industries. The government investment of about $500 million in five years in the NNP will be carried out jointly by key research laboratories from academia and industry.

3 Challenges of the National Measurement System

3.1 Beyond Moore's law: challenges from electronics industry

As described in analysis of characteristics of Taiwan industry, most of them have a very short life cycle of products. For instance, performance of computer electronics will be double in less than 18 months (Moore's law). The fast-growing advance of manufacture capability leads to great pressure to electronics companies in terms of investment of equipment, capitals and human resources. This also brings tremendous pressure to the timely offer of supportive instruments of inspection and related traceable metrology infrastructure.

The investment of a 305-mm (12-inch) wafer fab may be as high as $3 billion, with accompanied sales up to $7.2 billion. Thus, it is estimated that less than 10 companies in the world can afford to invest a 305-mm (12-inch) wafer fab. In terms of speed, it is reported that TSMC will carry out 90 nm IC process technology into mass production by the end of 2002, even faster than the prediction by Moore's law. In establishment of metrology infrastructure, CMS-NML has just completed in three years a series of standards systems for line-width, line-spacing and thickness of IC thin films for a nominal process of 300 nm. This reveals obviously the awkward situation of CMS-NML in catching up the demands from microelectronics industry.

Instead of developing measurement standards alone, especially in consideration of expensive facilities like clean rooms, CMS-NML is seeking the cooperation of IC makers in fabricating semiconductor reference standards of new generation.

3.2 Westbound movement of Taiwan companies

With the fast-growth of new economy of mainland China, many Taiwan companies, either traditional or high-tech, have move westbound across the Taiwan Strait into the south-east provinces of the Continent. It is reported that at least 600 thousand Taiwanese stay at Shanghai

city. The “cluster-effect” is reproduced in the mainland, that means the lower and upper stream companies of an industry are gathered together in some spots of science parks. During the personal visit to Shanghai and neighboring cities, the author was much impressed by the “cluster-effect”. It was found that nearly all Taiwan companies with brands have a corresponding branch company in the mainland. The impact of the westbound movement to Taiwan economy is rather difficult to estimate.

Taiwanese companies in the mainland have responded their demands of measurement traceability and the difficulty in obtaining local support. In general, the technical level of local accredited labs is competent, however, the calibration capability and timely service seem to be enhanced. Many companies still transport their instruments back to Taiwan for recalibration. Fortunately, both accreditation bodies across the Strait are the members of APLAC, and accordingly mutual recognition of calibration reports is in principle available in the near future.

4 Conclusion

The National Measurement System in Taiwan has been established since 1987. The establishment of 103 primary systems in 15 measurement fields by CMS-NML has satisfied 93% demands (unweighted) from Taiwan industry. However, with the fast advance of heavy-weight electronics and IC technologies, the national metrology infrastructure has faced severe challenges from industry in terms of technical specification and timely offer. Advanced technology forecast and working closely with industry may alleviate the difficulty of CMS-NML in enhancement of the metrology infrastructure. In addition, the implementation of mutual recognition may also improve the satisfaction of metrology demands from Taiwanese companies around the world, especially in mainland China.

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