ADVANCED ANALYTICAL MEASUREMENT AND METROLOGY ENABLES LEADING EDGE SEMICONDUCTOR MANUFACTURING

Establishing a National Center for Advanced Analytical Measurement & Metrology for Semiconductor Fabrication

I. Summary

The CHiPS and Science Act was enacted to be transformative for the domestic semiconductor industry. The effective application and continued development of next generation analytical measurement and metrology systems and techniques in the semiconductor industry will be critical to enable the continued development of future semiconductor technologies for both advanced logic and memory devices. The establishment of a *National Center for Advanced Analytical Measurement & Metrology for Semiconductor Fabrication* will benefit industry participants across the entire supply chain including semiconductor device producers, wafer fab equipment suppliers, key component suppliers, and chemical and materials suppliers. Such a center can leverage existing government (NIST) capabilities and networks and be the basis novel government-industry partnership models into the future.

II. The Need for a National Center for Advanced Analytical Measurement & Metrology for Semiconductor Fabrication

The challenges and associated developments the semiconductor industry faces as it continues to implement and develop next generation technologies over the next 5 to 15 years continues to increase. These increasingly complex challenges need to be proactively solved at higher velocities. Successful solutions to these problems will enable the timeline for the implementation of advanced node manufacturing to be accelerated. A key to enabling this is through extensive interdisciplinary collaboration among the semiconductor ecosystem partners, including device producers, equipment suppliers, component suppliers and chemical and materials suppliers.

The continuation of Moore's Law is further driving scale reduction, and the implementation of new processes and materials, continue to drive improvements in performance, power, form factor, while maintaining cost effectiveness and time to market. Semiconductor producers, as well as other value chain participants, in the USA need to compete effectively with the existing production bases that have seen a greater amount of investment in key infrastructure over the last several decades. Developments in advanced analytical measurement and metrology are "MUST" to

solve many newly developing challenges as rapidly as possible to help enable <10nm technology node devices and fabs that are being planned for the USA.

The advanced node roadmap requires increasing levels of design innovation as non-traditional scaling continues and 2D-3D mixed architectural structures are being utilized. While at the same time, many new processes and materials are being added, with little or no integration and yield history. One of the key challenges to high volume manufacturing (HVM) is elevated process and device defect sensitivity as well as new defect drivers, both which greatly affect yield. Yield and integration challenges are exacerbated with an increasing number of manufacturing process steps, as well as heightened process sensitivity and complexity. Approaches to enhancing yield enable cost competitiveness for the next generation of semiconductor devices and for the entirety of the semiconductor ecosystem. Under the current environment, this is a huge challenge (financially and technologically) for the entire semiconductor ecosystem.

III. Basis of the Problem that a National Center for Advanced Analytical Metrology for Semiconductor Fabrication Can Address

Due to the increasing number of new materials, complex device architectures, and chemical formulations, the severity of interactive process defects is rising. Defects can remain undetected without early intervention (through advanced analytical measurement and metrology) or other safeguards in place. These "New Strains of Interactive Process Defectivity" are caused by various types of complex chemistries and chemical processes and process interactions through the entire life cycles of the chemistry, from production through the semiconductor HVM environment.

Complex fab chemistry, equipment, parts, and process steps create new types of interactive compatibility issues, more defects, and new defect sources. Thus, the supply chain needs to deal with unprecedented purity and consistency requirements. These "New Strains of Interactive Process Defectivity" are significant "Yield Limiters" for <10nm technology readiness and can have a severe negative economic impact. Reactive/Task Force modes of operation are often employed to root out these yield limiters. These operations cost the semiconductor producers (and the whole supply chain) hundreds of millions of dollars per year due to non-recovered yield losses as well as quality control measures to manage excursions. In addition, chemicals and materials inventory shortage (due to forced stringent restrictions) can also impact costs.

At this point, the semiconductor industry's advanced analytical measurement and metrology techniques are challenged for leading edge nodes. The physics and sensitivity to detect, identify and correlate the killer defects sources, and to keep all the materials (including chemicals, gases, vapor phase materials, water systems, fab environment) and processes excursion free with reduced costs of manufacturing and maintenance are being pushed to their fundamental limits.

While the advanced semiconductor producers routinely invest in the most sensitive analytic measurement and metrology tools available for on wafer (on silicon) defect detection, supplier infrastructures are still substantially lacking access to advanced defect detection & characterization capabilities. Standardized analytical methodologies which were many years ago developed and agreed upon by suppliers and the semiconductor manufacturers are now quite dated and in need of refinement to meet the more stringent requirements in the production of leading edge semiconductors. Furthermore, the IRDS Roadmap is lacking significant guidance to create control limits, standards, and specifications, in large part because the ecosystem partners lack understanding of which parameters are most important to measure, monitor and control for next generation nodes' process yields.

These yield limiters significantly impact semiconductor producers' fab operations, especially at <10nm technology nodes, and ability to meet the business deadlines. The establishment of a National Center for Advanced Analytical Metrology for Semiconductor Fabrication can help to develop proactive mitigation paths for the entire industry supply chain.

IV. The Needs a National Center for Advanced Analytical Metrology for Semiconductor Fabrication Can Address

A National Center for Advanced Analytical Metrology for Semiconductor Fabrication can enable the novel analytical measurement and metrology approaches required to help solve some of the industry's most pressing challenges. Based on the complex nature of the interactive defects (which could include, for example, metallic, non-metallic, organometallic nanoparticles, dissolved organics molecules, or particle precursors in origin of <10nm, and significantly smaller than underlying node dimensions), which ultimately end as yield limiters on wafer/device, one single type of advanced analytics/metrology is no longer sufficient to identify, measure or control such defects and/or defect sources.

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The supply chain for manufacturing at advanced semiconductor nodes cannot afford individual investment(s) and development activities in all such these different types of expensive, novel, pathfinding, advanced scientific and engineered metrologies, equipment and emerging nanotechnologies. In addition, many of these technologies are novel for semiconductor industry applications, and require maximum collaborative effort among the scientific and research community (university research labs, nanotech labs), semiconductor producer and supply chain expertise to enable these technologies for HVM readiness over next 5 to 15 years.

The semiconductor industry / supply chain ecosystem would need to heavily invest in R&D and Process Quality improvement beyond today's state of the art systems of quality control, which translates into investment in advanced analytical measurement and metrology platforms. A major roadblock is that the suppliers and sub-suppliers are already severely lacking the R&D resources to set up such novel pathfinding and expensive advanced analytical measurement and metrology technologies at their manufacturing and development facilities and thus are highly dependent on their semiconductor manufacturing partners to develop the final defect free/compatible products. That puts the maximum burden on each individual semiconductor producer's technology development organizations and HVM factories.

Semiconductor producers and their supply chain partners need to divert the essential engineering resources and time while incurring substantial costs (taking away from device technology development and manufacturing) to help individual supplier(s) development, qualification and quality improvement for individual products (be it chemical, gas or equipment, chemical delivery systems, filtration or advanced packaging being used for next generation processes/products). This is not a sustaining cost-effective model to follow through for HVM Yield readiness for IDMs or for supply chain partners to meet process maturity goals in time, as this needs to happen much faster and at a cost-competitive environment in comparison to current practices of today.

Thus, the semiconductor industry needs to take a more holistic (and novel) approach to advanced analytical measurement and metrology using multiple different types of advanced scientific, analytical, and emerging AI-dependent metrology techniques to mitigate complex defects or sources of contamination to improve the yield of every critical manufacturing processes. A dedicated center can also invent best practices that can be employed across the industry. These approaches can also be applied upstream or downstream of semiconductor wafer fabrication operations.

V. Proposed Approach for a National Center for Advanced Analytical Metrology for Semiconductor Fabrication to Enhance Competitiveness

To address the aforementioned analytical measurement and metrology challenges the semiconductor industry needs a National Center for Advanced Analytical Metrology for Semiconductor Fabrication. Utilizing funding from the CHIPS Act this center could be established as a part of NIST as it expands its role to support the growth of the semiconductor industry technology in the US with the possibility to utilize 9902 Congressional funding package dedicated to Improve and Accelerate Technology Growth in US with partners, such as Intel, TSMC, AMD, Samsung, Micron, as well as critical semiconductor supply chain partners, including equipment suppliers, component suppliers and chemical and materials suppliers.

The mission of a National Center for Advanced Analytical Metrology for Semiconductor Fabrication would be to:

- Enable device manufacturers, equipment suppliers, material and component suppliers to collaborate with analytical instrumentation companies, universities, and government laboratories to explore and develop new measurement technologies
- Collaboratively identify, develop, validate and implement advanced analytical metrology and AI solutions for defect control in advanced semiconductor manufacturing.

The center will be structured to enhance semiconductor industry learning, development, and support for manufacturing growth. The goals of this center are envisioned as follows:

- Create a center that fosters pre-competitive collaborations to explore metrology options that could address key challenges the semiconductor industry has identified
- Development of pathfinding metrology for advanced semiconductor manufacturing
- To Serve for Supplier-IDM Collaborative Quality Development, with Proactive Challenge Management
- Development of more advanced standards to assist the industry with improving detection limits, as well as the precision and accuracy of the measurement techniques

Collaboration and innovation at such a center would be extended to all US based IDM fabs, supply chain partners, novel and existing metrology partners, OEM partners, NIST, SEMI, SRC, nanotech industry and research labs, as well as university research labs. This center and the platforms can be developed based on the existing infrastructure (such as SUNY Albany Nanotech center and other university Nanotech centers such as Purdue University or the University of Missouri).

VI. Conclusions

Disruptive technologies for advanced semiconductor node manufacturing demand increased defect sensitivity, and therefore require an essential need for detection, and mitigation capability. These factors can severely challenge HVM Yield Ramp at leading edge semiconductor producers. Some categories of nano-defects may be "detectable" with advanced "on wafer metrology" at a semiconductor producer but not necessarily at the key supply chain partners manufacturing facilities, thus adding an onerous, impactful, expensive and time-consuming burden of next generation defect mitigation on the entire supply chain. New techniques and approaches will be required to identify other types of latent defects. Developing new techniques and accessing wafer techniques adds enormous costs for the entire supply chain R&D investment and increases the cost of ownership for both IDMs and supply chain partners.

This center will enable the timely re-establishment of the US manufacturing base for semiconductors. It will also ensure the ability of the entire supply chain to identify and control key defects and quickly ramp advanced manufacturing solutions with leading degrees of process stability across the entire supply chain. The center will provide a more collaborative, cost-effective (and affordable) solution that can help to ensure the future success of the US semiconductor industry and its supply chain.

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