CROSSING AUTOMATION

Behind the Technology: Wafer Engine™
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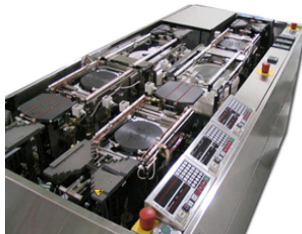


Automated wafer handling technology began with the use of tweezers and vacuum pencils in the 1970s then moved to O-ring drive systems and other specialized mechanical transfer systems in the early 1980s.

The advent of larger diameter wafers, including 150 mm and 200 mm, coupled with the requirements for backside cleanliness, random access requirements and the advent of the SEMI/MESC standards, resulted in a gradual adoption of the SCARA style folding arm robots in the late 1980s that are still prominent today. The slow adoption of standards and the poor adherence to a wafer transfer plane standard led to a multitude of tool architectures that required diverse and specialized robots with highly customized designs.

In the late 1990s the 300 mm wafer size transition began; this change was accompanied by rigorous new standards for tool loading heights and loadport interfaces for all process and metrology tools in a fab. While these standards narrowed the need for the specialized choices for wafer handling solutions, and in some cases actually reduced tool flexibility and throughput rates, positive benefits included the rapid evolution and adoption of interchangeable front opening unified pod (FOUP) loadports and the adoption of equipment front end modules (EFEMs) and factory automated material handling systems (AMHS) as an industry-wide norm for 300 mm manufacturing. These standards also played an important role for the transition to the AMHS that improved factory scheduling efficiency and removed ergonomic barriers for handling heavier wafer containers.

A fresh examination of wafer handling approaches to optimize EFEM performance was initiated in the early 2000 timeframe. At that time there was significant diversity in new wafer handling requirements, which were challenging to meet with the conventional SCARA robot designs.

These new demands included:

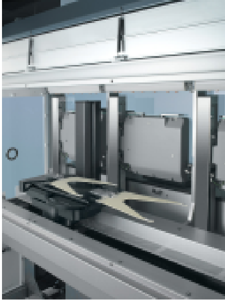
--- The ability to perform dual-swap wafer exchanges very rapidly for the higher throughput tools that were coming to market.

--- High placement accuracy to minimize the time required for pattern acquisition in certain process and metrology tool applications.

--- Flexible and/or extendable horizontal travel to support a growing number of EFEMs utilizing more than three loadports.

---Improved serviceability and access within the EFEM.

A variety of architectural approaches were analyzed and ranked in terms of their ability to measurably achieve differentiated performance relative to the existing status quo. The Wafer Engine™ approach was selected as offering the most favorable combination of attributes for the anticipated requirements of the next generation of semiconductor processing tools.



The Wafer Engine architecture is decidedly different than conventional SCARA robots in terms of how precision motion profiles are generated and controlled for the different wafer moves that are typically required in EFEMs and Sorters. Key differences include:

--- Improved Wafer exchanges to/from a FOUP: The Wafer Engine employs a light weight end effector attached to a simple single component linear ball slide. The linear motion inherently achieved by this approach enables very rapid acceleration and excellent travel path accuracy with a simple single axis servo drive. Compared with a conventional SCARA robot which typically would require two or three high mass box-section links moving in coordinated profile fashion, the linear drive system is lower in moving mass by at least one order of magnitude, easier to control, and lower in cost. Additionally, the compact physical cross-section readily enables the use of dual end effectors in a simple over-under architecture. The employment of dual end effectors can have a dramatic impact on both the wafer handling bandwidth of the wafer engine and the throughput capacity of associated EFEM elements such as pre-aligners, vacuum loadlocks , and atmospheric transfer stations such as process chucks and loadports.

Typical use cases for dual end effectors include wafer exchange at a process location and a FOUP; with a single end effector and a conventional robot, the robotic arm assemblies comprised of two or more links must travel to the process station and pick or place a wafer. These assemblies must then travel to a drop off location, drop the wafer off, pick up another wafer, and return to the process station. During the elapsed time for the transfer activities, the process station has been incapable of any value-added activity until the next wafer has been delivered. To address this inefficiency, link style robots are offered with optional dual end effectors, but this option typically requires additional pivoting links and a need to swing one link and its wafer aside in order to utilize the second link. This “fanning style” robot architecture can provide a throughput improvement over a single link design but the potential exchange time is still impeded by the need to execute multiple motion profiles for each of the fanning links during a given wafer exchange.

Conversely, with a dual end effector Wafer Engine using pure linear transfer, no incremental time is required for extra motion profiles because each end effector and slide assembly can extend or retract in its own spatial zone without contention for operating clearance. Further, both end effectors can perform simultaneous get or put operations if desired, which can further improve throughput performance for use cases such as ‘batch-transfer.’ The net performance result is that very fast wafer exchanges are achieved with a minimum of mechanical motion and path planning, which enables excellent wafer throughput rates in a wide variety of use cases.

--- Improved Airborne Particulate Management: Enabling a linear motion technology for semiconductor wafer handling required a new approach to environmental control for the linear slide mechanism in order to achieve the sub-class one atmospheric cleaniness levels required in the wafer environment. This is accomplished by equipping the wafer engine slidebody with an on-board integrated exhaust and ULPA filtered air management system. This system assures that no particulates can migrate from the isolated motion control components into the wafer handling environment under any combination of vertical, horizontal or theta motions, thus providing a superior level of airborne cleanliness performance relative to typical SCARA style robots.

---Extendable Z Travel: The folded Z axis approach enables the Z travel range to be changed with minimal impact to the Wafer Engine mechanical structure; adding incremental Z travel does not require any additional changes to the lower part of the Wafer Engine. In contrast, conventional architecture SCARA robots require that additional vertical slide travel be added to the lower canister structure on a pro-rata basis as the useful Z travel range is increased. This limits the robot's ability to access the first wafer plane for SEMI Standards compliant loadports and constrains the opportunity to fully utilize the spatial domain available in tool EFEM's for a variety of performance enhancing options such as bare-wafer buffering, integrated metrology, and elevated chamber entry ports.

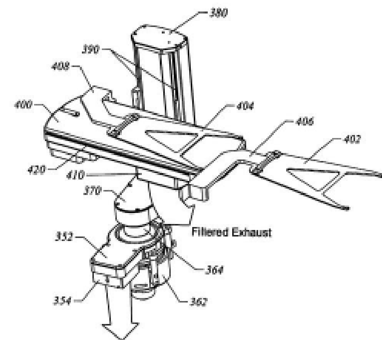
--- Extendable Horizontal (X) Travel: The Wafer Engine utilizes a precision linear ball slide in conjunction with a direct drive servo motor to achieve excellent motion planarity and velocity control over a flexibly scalable total length of travel. Accurate positioning is achieved by a choice of either rotary or linear encoders; the Wafer Engine can thus achieve accurate and consistent wafer placement for EFEM width applications ranging from two loadports to more than four loadports in total width. Additionally, the theta motion at the end of the EFEM's travel range enables easy access to accessory modules that may be located at either, or both, ends of the EFEM.

The intrinsic scalability of the X-Axis architecture is also an important attribute for enabling spatially efficient migration to a 450 mm wafer size; the length scaling does not mandate an associated increase in the EFEM depth relative to 300 mm wafer handling practice, whereas link-style robots typically require longer links with a greater swing radius as their effective X reach is extended. This increased swing radius, combined with the trend to 3, 4, or even 5 loadport wide EFEMs, will necessarily add to the EFEM depth unless the SCARA robots also adopt a linear track architecture.

--- Improved Serviceability and Access: The Wafer Engine assembly is inherently lighter in weight and more compact than a SCARA robot with an equivalent reach. Further, it is designed to be detachable from the X-motion linear slide assembly so that it can be serviced or replaced as a module by one person utilizing access from either end of an EFEM or through a BOLTS plate access zone. Additionally, with power off, the Wafer Engine can be manually positioned to any convenient X or theta position to enable service access to other EFEM or tool components. Likewise, the linear driven end effectors can be freely moved through their range of travel for end effector maintenance or replacement.

CROSSING AUTOMATION

--- Increased Opportunities for Future Wafer Engine Enhancements: The Wafer Engine's end effector slidebody architecture can enable a new range of functional possibilities for a wafer handling robot because the slidebody provides a reference platform that "travels" with the wafer in a predictable fashion. This platform can enable incorporation of wafer theta and X-Y alignment functions on the slidebody, potentially reducing the requirement for a stationary pre-aligner with its separate space consumption and the travel time associated with travel to and from the loadports and/or processing stations. Likewise, the incorporation of optical character recognition capability for reading Wafer ID's on the slidebody is also possible and would likewise save space and reduce cycle time in some applications.



An additional capability that may be achieved with the Wafer Engine is the provision of environmental isolation for the wafer while it is being handled in the EFEM; the provision of specialized containment /isolation may serve a variety of functions related to environmentally sensitive wafer surface states or associated handling requirements.

The Wafer Engine is well-suited to address many of the automation challenges facing the new generation of process tools as we continue to pursue Moore's Law. For example, plasma-based process tools must meet higher throughput requirements while at the same time make provisions for an increasing number of non-product wafers used for tool chamber cleaning and metrology. In the clean and strip sector, throughput requirements are approaching 400 wafers per hour. These requirements place great demands on the wafer handling system and pose a serious challenge for meeting the required exchange rate of FOUPs at the tool loadports. An expedient and cost-effective way to address the loadport bandwidth issue is to increase the number of loadports at a given tool from the typical two or three units to four, five, or even potentially six. This architectural change is readily accommodated by a linearly scalable wafer handling approach, because the same basic mechanisms and EFEM configuration can efficiently accommodate applications that range from two to four -- or more -- loadports in width, while preserving positional accuracy and wafer plane planarity throughout the wafer transfer zone.

Some of the described capabilities and associated technology relating to the Wafer Engine™ may be the subject of Crossing Automation USA or Foreign issued and/or filed patents.