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Extending process flexibility for single-wafer wet etch

Despite the success of some dry-etching processes, wet etching remains a staple in semiconductor device fabrication, as well as in many other related technologies, such as MEMS and photovoltaics manufacturing. Wet etch processes are common both in device formation as well as in the metallization and packaging areas of the semiconductor process line.

Wet etching relies on the chemical reaction between a liquid and a solid substrate and is often the fastest and most cost-effective way to remove material, selectively or across an entire surface, as is required in many steps of semiconductor fabrication. Oxide removal after a photolithographic step, stress relief after wafer grinding, wafer thinning, and surface texturing are some important manufacturing steps that rely on wet-etch processes.

There are many ways to bring a liquid into contact with a solid substrate for wet etching to take place. The choice of method depended on the requirements of the process. If the substrate can be wetted on both sides, immersion is a common choice. If the substrate can only be exposed to the chemicals on one side, spin or spray become good candidates. Depending on the aggressiveness of the process and device requirements, uniformity (in terms of total thickness variation, or TTV) is often also an important consideration.

Immersion etching usually takes place by processing cassettes full of substrates in chemical baths in a wet bench. Spin- or spray-etching processes may work on single wafers or batches in cassettes, and may etch one or both sides depending on the tool. New device manufacturing techniques are becoming more demanding, which typically mandates the use of single-wafer, single-sided processing. In addition, thin wafer processing, tighter TTV specs, and the push for increased functionality are driving this trend with no end in sight.

Wet etching transport phenomena

Most relevant features in the outcome of wet processes are controlled by transport phenomena. The given chemical mixture and the substrate material surface determine the ultimate outcome of a series of reactions, but the rate at which this happens is usually limited by the supply of reactants to the reaction zone and the capability to rid it of chemical byproducts. The reaction zone is generally contained within the "boundary layer," thus the reactants and byproducts must all diffuse

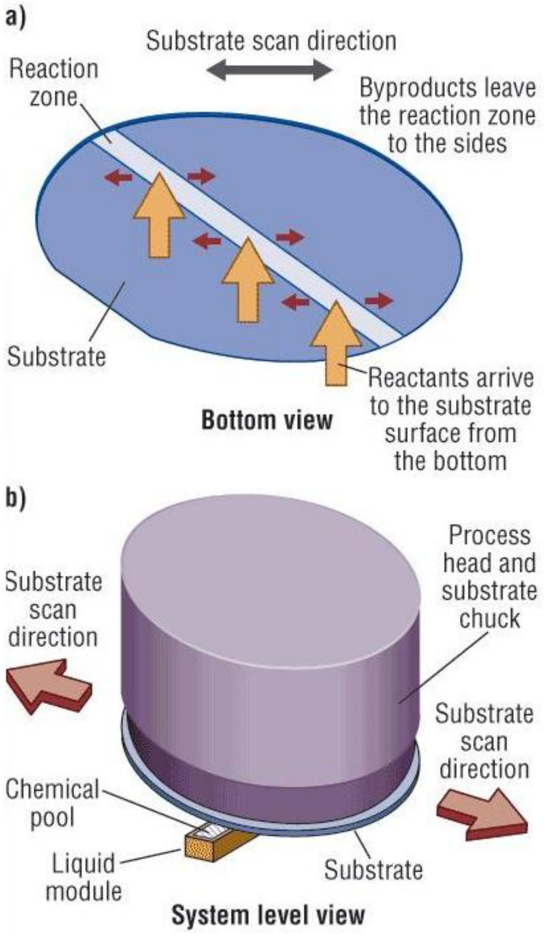

Figure 1. LinearScan technology allows for the paths of reactants and byproducts to be along orthogonal planes. a) The reactants arrive to the reaction zone from the bottom, and the byproducts exit to the sides, while b) the process head holds the substrate process-side down using a contact or noncontact chucking method while scanning it through the meniscus of the reactants, thus effectively decoupling transport from chemical phenomena.

across it. As a consequence, boundary layer properties, such as thickness and uniformity, are very important in determining the outcome of a wet process.

The boundary layer's thickness and other characteristics vary depending on the chemical's flow properties, the nature of the chemical reaction, the wetting behavior of the interface, and the temperature. In general, for a wet process to be uniform, the thickness of the boundary layer has to be uniform. Boundary layer thickness is affected by agitation and shear forces imposed by fluid flows across the surface being processed. Therefore, convection and surface speed gradients are determinants of the uniformity of immersion and spin/spray processes, respectively.

Physical limitations of agitation schemes and gas evolution pose constraints on the best uniformity achievable by an immersion process. Similarly, speed gradients across the substrate in spin or spray processes pose a uniformity limit on the process for any given substrate diameter; large nonuniformities may be seen in larger diameter substrates targeting significant material removal by a spin process.

Recently, many critical manufacturing steps have also become "single-sided," such that the substrate can only be exposed to the chemical on one side. This requirement is often brought about by the presence of devices or structures on the nonprocess side, or the more general requirement that the nonprocess surface is left in the current state while etching is performed on the opposite site. Vapor damage to the nonprocess side also has to be avoided.

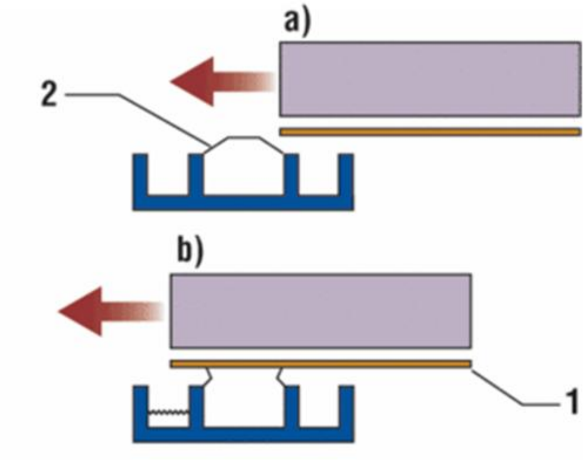

Figure 2. Side-view schematic of the LinearScan process. The substrate (1) moves over a chemical meniscus (2) that extends the width of the substrate (in and out of the page). As the substrate is scanned, every area element of its surface is exposed to the same chemical environment as any other in the substrate .

New immersion etching

New WaveEtch LinearScan etching technology provides high uniformity as well as single-sidedness on ultra-thin large substrates. It also provides a consistent and uniform supply of chemicals throughout the liquid-solid interface while making available an orthogonal path for the byproducts, such as gases and vapors (Fig. 1a). The fact that every surface element is exposed to the same chemical and transport environment makes the process intrinsically uniform. The boundary layer is not subject to speed gradients, convection, or other transport-related gradients that may cause variations in its thickness and its concomitant impact on uniformity. The system eliminates virtually all transport-related and centrosymmetrical nonuniformities, which plague spin/spray or immersion processes.

The substrate is held on the nonprocess side by conventional vacuum or noncontact chucking alternatives, while it is gently scanned over a narrow pool of chemicals (Fig. 1b). The reactants enter the reaction zone through the bottom, and the byproducts exit in a plane parallel to the substrate surface. The substrate is not immersed, but merely put in contact with the top of the pool's meniscus (Fig. 2). The chemicals and vapors are kept away from the nonprocess side by a proprietary technology called Dynamic Confinement, which forms a virtual gaseous o-ring around the periphery of the substrate to prevent any liquid or vapor incursion. In this way, the nonprocess side is not subject to physical or chemical contact.

Because the system enables material removal uniformity, it allows more chemical material removal while staying within the uniformity budget. One such typical step is subsurface damage removal after grinding. For a given final thickness, the substrate can be ground to a thicker state and more material removed chemically while still staying within the uniformity budget. Grinding to a greater thickness increases the yield and reduces the overall cost of the operation.

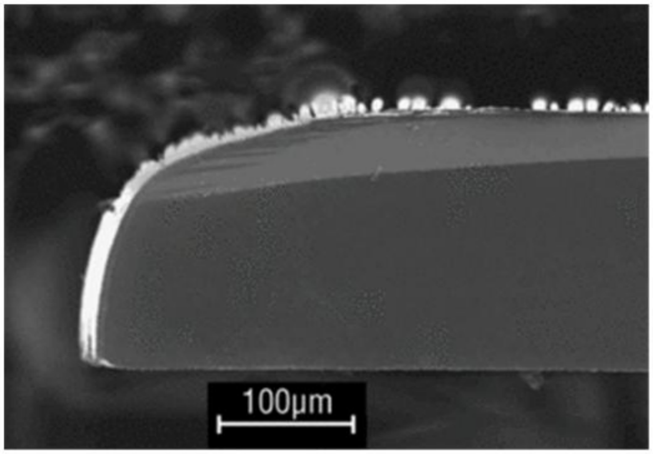

Figure 3. Cross-section of a Si wafer edge after removing 50µm of surface material off the bottom surface showing confinement of the etching process to the lower surface (process-side), as indicated by the lack of rounding off of the lower edge.

The final thickness for modern IC devices continues to decrease, with 50µm being the current state-of-the-art target for many modern devices. The described etching systems are particularly well suited to handle and process very thin wafers. The unique chucking and etching occurs with no violent spinning, no need for lateral confinement by pins or other hard devices that may damage the wafer's edge, and no dynamic loading due to high rotational speeds.

The technology also allows for flexible tools for chemical surface treatments. Since there is no need to tailor the chemistries to stabilize the boundary layer over the large radial speed gradients present in spin/spray systems, there is a lot of freedom in chemistry choice. A given chemistry is only chosen for its desired surface interaction and not for any other ancillary reason, which typically conflicts with, or hinders the achievement of, the desired results.

Flexible chemical choice and the absence of large surface flow speeds, which tend to delete preexisting surface features, allow multiple chemical steps to be superimposed to achieve additive surface features. For instance, nano-roughness can be superimposed over a micro-rough surface, which then provides an excellent surface for metal adhesion and other processes.

In the absence of hydrodynamic edge effects, the edges of the wafers are free of edge sharpness and the formation of "teeth," features common in spin/spray etch systems that significantly weaken the substrates (Fig. 3). Also, the chemistries used do not require surfactants and are used in smaller volumes at lower flow rates, allowing for more efficient chemical usage. Chemicals can be used to a process-dictated end-point without regard to surfactant depletion. Together, these features lower chemical usage and its associated purchase and disposal costs, as well as often easing environmental regulatory compliance, resulting in overall production and costs-of-ownership reduction.

These technology processes are size-independent. Since all areas are exposed to the same chemical and transport environment, the size and shape of the substrate are largely irrelevant. The same process that is developed for a given wafer size, can be readily used for another wafer size, thus making product process migration effortless and cost effective. Substrates of odd shapes, of noncircular shapes, and larger than 300mm can be accommodated by the system.

Figure 4 depicts the main components of the tool. Features include: a load station that transfers the substrate from the robotic handler to the process head, with either a vacuum or a noncontact chuck; a process station that scans the substrate back and forth until the desired etch results are obtained; a rinse station to eliminate any chemical residues; and a dry station, which may use a variety of methods including vacuum, dry nitrogen injection, and Marangoni-like systems.

The rinse is usually a rapid step since the rinse water flow under the substrate is concentrated in a small area, and the contaminated rinse water exits the rinse module immediately, without being diluted

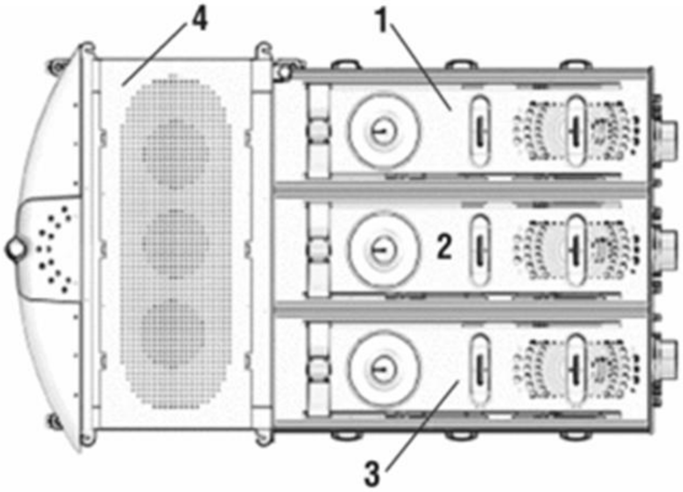

Figure 4. Schematic of the single-sided etcher showing three wet processors, each with independent chemical handling (1−3). They share a robotic wafer loader that services all installed modules (4).

into the incoming fresh rinse water. Also, to best take advantage of the tool's chemical flexibility, each process module has a full-function chemical handling unit that precisely meters, mixes, stores, ages, and monitors up to three different chemicals prepared within the tool from relatively inexpensive bulk or bottled sources (as opposed to more expensive pre-mixed proprietary formulations).

Thin wafer etching

As mentioned above, the systems are well suited to thinning and stress relief after grinding operations. The systems offer superior uniformity and thus the ability to tune grinding operations for optimum yield, picking up more chemical removal if necessary, while staying within the TTV budget and lowering the cost of the whole operation. The systems can handle the single-sided wet etching of ultra-thin wafers (≤50µm), due to superior uniformity avoiding the risk of punch through.

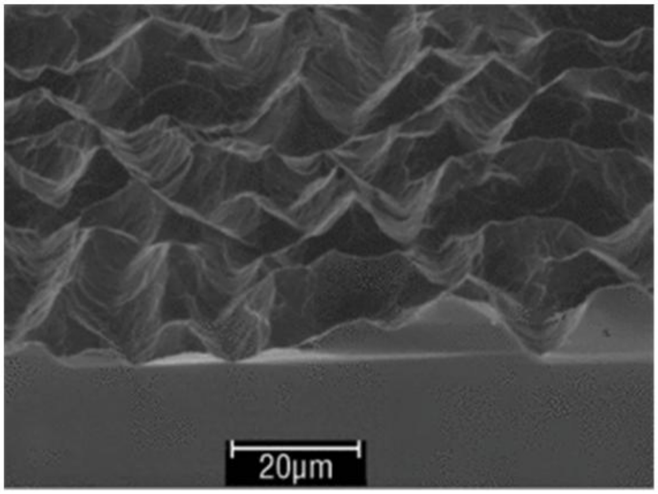

Figure 5. Nano-roughness superimposed on a 20µm rough surface, showing process flexibility of the linear-scan wet etcher.

A new application enabled by this technology is compound surface texturing. The total freedom to choose the chemistry based in its intended interaction with the surface and the absence of high speed flow over the surface, allows for the engineering of surfaces with desired characteristics by superimposing etch steps. The previous step's texture is not deleted by the next step texture, thus creating optimal surfaces for applications like improved metal adhesion, interfacial fatigue hardening, and optical surface engineering. Figure 5 shows nanometer-scale roughness superimposed over 3−4 orders of magnitude greater micro-roughness.

The technology has important applications in photovoltaic or solar cell manufacturing, from thinning the solar cell substrate once the metallization is in place (single-sided etching), to raw substrate thinning in a pre-manufacturing step. The ability to use virtually any chemistry to interact with any substrate material enables the systems to process any material of interest, just as long as a chemistry will work with it. The systems are being used to etch InP, Ge, GaAs, Si, polysilicon, glass, and quartz, among others. Substrates of odd shapes and within a large range of sizes are also being processed: 50mm InP wafers, 200mm polysilicon squares, glass rectangular shapes, and round 300mm Si wafers. The technology provides a new way to do wet processing.

Acknowledgments

WaveEtch, LinearScan, and Dynamic Confinement are trademarks of Materials and Technologies Corp. (MATECH).

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