

SINGLE SIDED WAFER THINNING AND HANDLING

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ABSTRACT

The increasing demand for smaller, more portable, more powerful electronics has driven an increase in the functionality of the devices that power them—more capabilities and features have to be packed in smaller spaces. Given the approaching limits of Moore's law, an alternative to shrinking feature sizes is to increase the density and functionality of the integrated circuit (IC) packages. To do so, the die size and the die thickness have been significantly reduced. Some of the main drivers behind thinner die requirements are portable communication and computing devices, memory cards, smart cards, as well as CMOS image sensors, hybrid, flexible systems-in-a-foil, LEDs, MEMS, solar, and power devices. Die thickness of 50 μm and under are common today.

Wafer thinning, as the means to reduce die thickness, is an enabling component of this endeavor. Handling the thin wafers during the manufacturing and packaging processes is just as critical.

We present field results from a new wet etch thinning technology that allows for the thinning of wafers down to 50 μm or less, with better uniformity, and at a lower cost than conventional thinning. The technology produces smooth edges without encroaching onto the non-process side. The method is intrinsically uniform throughout the entire surface, including the edges of the wafer. In contrast, conventional wet thinning technologies that spin, spray, or grind the wafers have inherent limitations on both uniformity and final thickness. The technology is compatible with virtually any material, such as silicon, germanium, glass, quartz, III-V, II-VI, among others. The etching technology presented herein makes no contact with the wafers and does not spin them; it is thus very gentle and suitable for ultrathin wafers which are very fragile and often warped or distorted.

We will also cover methods of handling ultrathin wafers without the need for carriers or any temporary bonding. Ultrathin wafers are often distorted by many millimeters in shapes and patterns that are not reproducible or predictable. Therefore, to handle freestanding ultrathin wafers the handling technology has to be capable of dealing with these issues effectively and consistently.

It is for these demanding applications that we will present technologies capable of processing and handling these ultrathin wafers and the associated devices to store, map, and align them.

We have successfully inserted into full production technologies that involve all of the above: Linear scan etching with non-contact Bernoulli handling, including very distorted wafer mapping and aligning, as well as a new side-contact chucking technology.

Keywords: Chemical Thinning, Etching, Stress Relief, WaveEtch, Linear Scan, Ultrathin Wafers, Handling, Non-contact chuck.

INTRODUCTION

Many excellent articles have been written on conventional grinding, polishing, and thinning techniques; as well as on the many methods for bonding a wafer to a carrier for handling, thinning or processing. Therefore, in this writing, we will concentrate on a new chemical thinning technology that allows for the thinning of wafers down to 50 μm or less, with better uniformity, and at a lower cost than conventional thinning. We will also discuss methods of handling thin wafers without carriers of any sort, thus dealing with the inherent issues of wafer distortion, warpage, and extreme fragility.

Wafer thinning can be performed in several ways: 1) by grinding the wafer down (usually to 100 to 150 μm), 2) by chemical mechanical polishing, which can bring the wafer thickness down to 50 μm or less, 3) by chemical etching, which thins the wafer down and removes the subsurface damage left by grinding and polishing, and 4) by plasma etching. Usually a combination of grinding and one of the other methods is the most practical route to a cost effective thin die solution.

Most thin wafer handling is performed by bonding the wafer to a temporary carrier and thus handling the wafer in much the same way as a conventional thicker wafer. There are, however, applications where, for reasons of yield, economics, process flow, or device performance, it is preferable to handle the wafer without a carrier. It is this latter case that will be addressed in this paper.

THINNING AND STRESS RELIEF

Chemical thinning is a necessary step to eliminate the subsurface damage and relieve the stress that grinding and polishing leave behind. Chemical thinning is also an alternative to polishing (following grinding) as the method

to make ultrathin wafers. It has the added benefit of completely eliminating damage or surface features that result in electrically active sites that other technologies may leave behind, which are deleterious to device performance¹.

Wet etching involves the interaction between a liquid and a solid substrate and it is often the fastest, most cost-effective way to remove material², selectively or across an entire surface, as required in packaging applications and many other steps of semiconductor fabrication.

The demand for denser, lower package heights, higher power requirements, tighter total thickness variation (TTV) specs, and the development of higher-functionality systems-in-a-package (SiP) or systems-in-a-foil (SiF) are driving the need for more robust, lower cost, higher yield thinning technologies with no end in sight^{3,4,5}.

When the substrate may be wetted on both sides, immersion is a common choice for etching and thinning. If the substrate may only be exposed to etchants on one side, spin or spray become reasonable candidates, but each has its shortcomings—such as radial and transport-induced non-uniformities. Depending on the particular package or device requirements, improved uniformity (in terms of TTV) is often an important consideration; conventional technologies have clear limitations in terms of how much material they can remove while staying within the allowed TTV requirements. These technologies often result in undesirable exposure of the non-process side to residual liquid or vapors. This is of particular importance on freestanding wafers.

A new technology, WaveEtch LinearScan etching, provides high uniformity as well as true single-sidedness on large ultrathin substrates. It addresses the main shortcomings of conventional wet processing by providing 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. Exposure of every surface element to the same chemical and transport environment makes the process intrinsically uniform (Figure 1). The solid-liquid interface (boundary layer) is not subject to speed gradients, convection, or other transport-related gradients that may cause variations in its thickness and result in a large TTV. The system eliminates virtually all transport-related and centrosymmetrical non-uniformities, which plague spin/spray and immersion processes. Figure 2 shows the uniformity of 4", 6" and 8" wafers (as TTV) after the removal of 75 μm with a WaveEtch tool. Substrates are held on their non-process side by a side-gripping or "caterpillar" non-contact chuck (or CAT chuck for its resemblance to the side motion of the namesake insect's legs), while being gently scanned over a narrow pool of etching chemicals. This novel chuck holds the ultrathin wafer by its edge and its legs retract sequentially out of the way as the wafer is scanned over the fluid meniscus (See Figure 3), making no contact with the backside (non-process

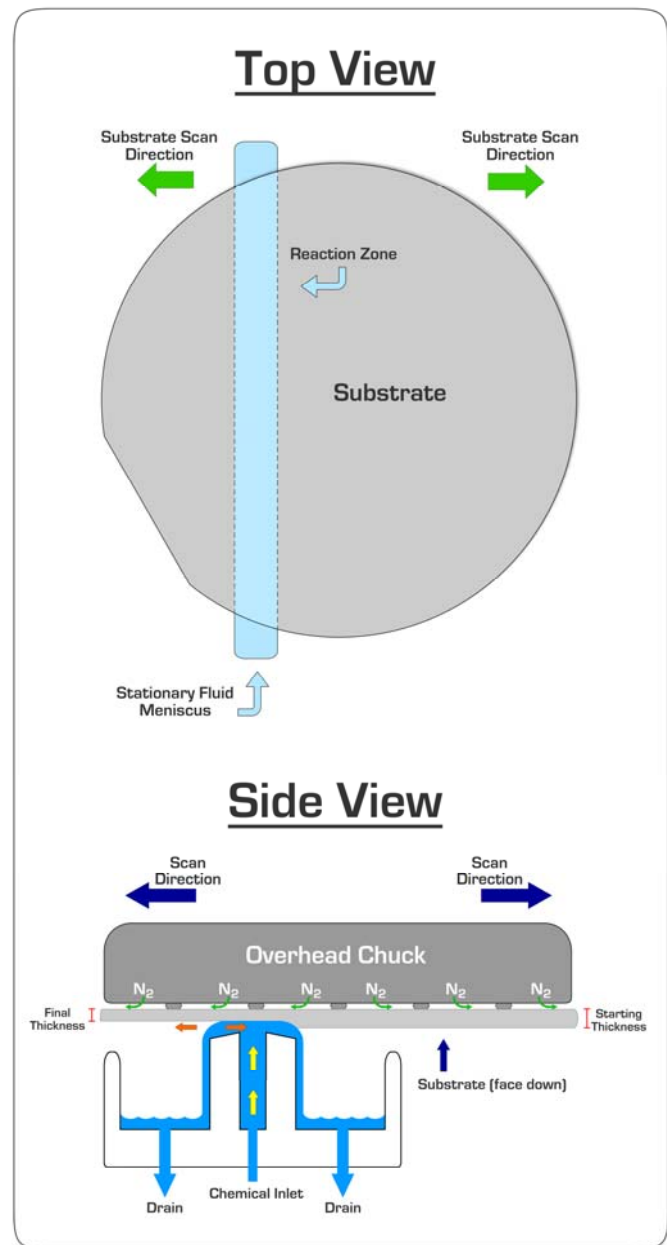


Figure 1. Schematic representation of the LinearScan process depicting the substrate material being removed by the etching process (held process side down), as well as the orthogonal paths of the reactants and the byproducts. The shaped flow of gas (DynamicConfinement), preventing the encroachment of fluid and vapors onto the non-process side (top), is also shown. Note the removal of material (etching) after the wafer has passed over the fluid meniscus and the different paths the reaction byproducts take to avoid interference with the supply of fresh reactants to the reaction zone. The top view illustrates the wafer being scanned repeatedly in alternating directions, as necessary, over the fluid meniscus showing the narrow reaction zone where thinning is in progress (wafer is being etched from below).

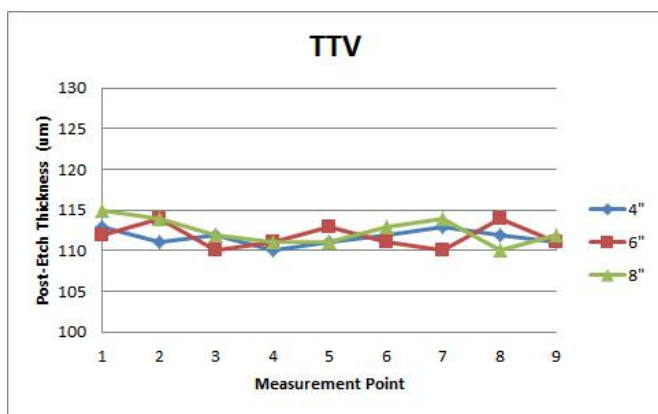


Figure 2. The material removal uniformity (Total Thickness Variation or TTV) typical of the WaveEtch LinearScan thinning process is illustrated above. TTV ranges from $\pm 1.5 \mu\text{m}$ for 4" wafers to ± 2.5 for 8" wafers after the removal of $75 \mu\text{m}$ to reach a final thickness, in this case, of $112 \mu\text{m}$.

side) of the wafer, while still protecting it from vapor or liquid encroachment.

The reactants enter the reaction zone through the bottom of the pool, while the byproducts exit in a plane parallel to the substrate surface; this delays bath saturation, extends bath life, and insures a consistent supply of fresh chemicals to the surface. The substrate is not immersed, but merely put in contact with the top of the pool's meniscus, as is also illustrated in Figure 1.

Chemicals and vapors are kept away from the non-process side by a proprietary gas sealing technology called DynamicConfinement (Figure 1), which forms a gaseous O-ring around the periphery of the substrate to prevent any liquid or vapor incursion. In this way, the non-process side is not subject to physical or chemical contact, thus eliminating the need for any kind of backside protection, such as resist or tape.

Wafer thinning and stress relief are native applications of the LinearScan etching technology. Substrate assemblies, at any point in the packaging process, of virtually any thickness, structure, and size are all compatible with the LinearScan etching process.

The final thickness for modern IC device substrates continues to decrease, with $50\mu\text{m}$ being the current state-of-the-art target for many modern devices⁶. LinearScan etching systems are particularly well suited to handle and process very thin substrates. The unique process is carried out 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. In the absence of hydrodynamic edge effects, the edges of the wafers are free of sharpness and the formation of "teeth," or

other features common in spin/spray etch systems that significantly weaken the substrates⁷.

The chemistries used in linear scan systems 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. Chemical usage reduction can range from approximately 20% to a factor of two or more, depending on the process, method, and tooling used to perform it.

Since all areas are exposed to the same chemical and transport environment, the size and shape of the substrate are largely irrelevant. A process developed for a given substrate geometry, can be readily used for other substrate geometries, making product process migration effortless and cost effective. LinearScan etching systems naturally accommodate odd, noncircular, thick substrates, and structures larger than 300mm, as well as severely distorted wafers (up to 10 mm off-plane distortion).

For cleaning applications such as those sometimes required in 3D's low standoff height structures or to remove residual polymer, the chemical process and the rinse steps may be augmented by the application of megasonics. Megasonics alter the behavior of the boundary layer, promote transport to reach crevices in complex or high aspect ratio structures⁸,



Figure 3. Image of MATECH's side-contact chuck (CAT chuck). Notice the position of the fingers that have moved out of the way to avoid contact with the etching fluid while the remaining fingers stay in contact with the sides of the thin wafer keeping it within capture range of the fluid pool. The adaptive handling allows the chuck to manage ultrathin, severely distorted wafers while making no contact with the non-process side.



Figure 4. Image showing the large amount of out-of-plane distortion and warpage typical of unsupported ultrathin wafers. In this case approximately 10 mm. Notice also the wide slots in the special cassette designed to accommodate said distortion.

and speed up the process and rinse steps. The interfacial control allowed by this technology enables unprecedented manipulation of the liquid-solid interface.

Since there is no mechanical contact with the surface of the substrate, linear scan systems are well suited for thinning and stress relief after grinding operations for packaging applications of very thin wafers. The process offers superior uniformity (Figure 2) 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 ultrathin wafers ($\leq 50\mu\text{m}$) avoiding the risk of punch through due to their superior uniformity. Intrinsic limits of grinding operations and downstream yield losses (from de-taping or de-bonding) usually prevent grinding to thicknesses below $150\mu\text{m}$. The gentle and uniform nature of linear scan wet processing can easily thin well below $50\mu\text{m}$.

ULTRA THIN WAFER HANDLING

Processes such as temporary bonding, back-grinding, metallization, etching, debonding, and dicing, all may involve some form of thin wafer handling. In general, all of these are carried out by bonding the device wafer to a temporary handle or carrier. The purpose of this operation is to handle the wafer throughout the process as a SEMI standard wafer would be handled, thus allowing use of existing equipment and facilities. To remove adhesive residue (usually by a wet process) and during packaging, the ultrathin wafers have to be detached from their carrier and handled freestanding. It is at this point that issues of breakage (i.e. yield) arise.

In these cases, thin wafers (as thin as $50\mu\text{m}$) have to be handled directly. Among the common wafer handling technologies—vacuum chucking, gripping, and Bernoulli—the latter is most suitable for ultrathin wafer handling between the cassette and the process station. The system is rugged, reliable and capable of a throughput of over 200 wafers per hour.

There are two primary challenges in handling ultrathin wafers: distortion and breakage. The deflection of a wafer, in the absence of added stress, is proportional to the square of its radius and inversely proportional to the third power of its thickness. Figure 4 shows the amount of distortion common in back end of the line freestanding ultrathin wafers. In this case the distortion is approximately 10 mm, compounded by the stress caused by additional layers deposited on them. Any method that will effectively hold and handle them must take this into account.

We used a Mechatronic Bernoulli end effector specifically designed to handle thin, distorted wafers (see Figure 5). To planarize the wafer and confine its lateral motion, the end effector has a rim of very small fluoropolymer vacuum pads which make contact in the exclusion zone. This approach to lateral confinement is preferred to other contact methods which may chip or damage the edge of the wafer, resulting in reduced strength or breakage.

To assist in accommodating the extreme distortion, it is common for the cassette slots to be double-spaced as compared to standard wafer cassettes, as seen in Figure 4. Since the wafers can take a shape that is changing and unpredictable, the loaded cassette must be scanned before any wafer is moved out of it or into it. The cassette scanner measures the position of the edges of each wafer and provides the data for the wafer handling robot end effector.



Figure 5. Bernoulli end effector effectively and consistently handles unsupported ultrathin wafers, down to $50\mu\text{m}$ thick. This image shows an 8" end effector used in conjunction with a WaveEtch system equipped with a side-contact CAT chuck. The etching system handles and processes freestanding 6" and 8" ultrathin wafers.

Similarly, the aligner, which has a Bernoulli movable chuck, makes no contact with the wafer surface. To prevent the wafers from shifting positions after alignment, the aligner chuck and the end effector perform a “handshake” whereas the vacuum hold from the chuck is not released until the hold from the end effector is in place.

The combination of Bernoulli and CAT non-contact chucks along with LinearScan wet etching makes an excellent combination for wet processing and handling ultrathin freestanding wafers. The ability to use virtually any chemistry to interact with any substrate material enables the systems to process most materials of interest, all while retaining the ability to handle ultrathin wafers with severe warpage or distortion. In addition to packaging applications, the systems are being used to etch or thin InP, Ge, GaAs, Si, polysilicon, glass, and quartz, among others. Substrates of odd shapes and within a large range of size and thickness can also be processed. These methods provide a new way to wet thin and handle ultrathin wafers in a more precise, efficient, and environmentally friendly manner.

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