**Filtration Requirements of Silicon Wafer Manufacturing Processes**

**Introduction**

Silicon wafers are the base component in the process of manufacturing an integrated, multi-layer circuited device. Continual technological advancement, diversification and device miniaturization in the industry have increased the demands on silicon wafer manufacturers. Wafers are required to be cleaner, smoother and possess a higher degree of flatness than ever before.

This Application Brief describes the impact of using effective filtration methods in wafer manufacturing and how utilizing clean process fluids are critical to producing high quality, “on-spec” wafers. The results are improved productivity, less scrap and increased profits for the wafer manufacturer.

**The Process**

The manufacturing of wafers is accomplished in several steps that are identified in the simplified process flow diagram in Figure 1. Each step plays a critical role in producing a final wafer that meets the stringent quality specifications. The fluids (coolants, etchants, slurries, and rinse waters) used in these processes require a high degree of filtration in order that particulate contaminants, that cause defects on wafer surfaces, are removed.

**Slicing**

During the slicing process, the wafer is cut from the produced silicon ingot. The wafer is typically cut to a thickness of 1-1.5 mm by an extremely fine slicing wire. The wire and ingot are cooled during the slicing process by a Glycol/DI Water coolant. The coolant plays an important role in maintaining effective wire cutting properties as well as prolonging the useful life of the wire.

![Figure 1 — Process Summary](image)

![Figure 2 — Silicon Ingot Slicing Process](image)
**Lapping**

After slicing, the wafer is mechanically lapped to remove surface roughness. A mixture of abrasive alumina (A1203) powder and water is fed to a conversely rotating base plate in the lapping tool to polish the wafer to the required thickness. Figure 3 shows the lapping process and the regeneration of the polishing slurry.

**Etching**

Lapped wafers are etched to remove any remaining micro-cracks or surface defects caused by the abrasive alumina in the lapping stage. The etchant solution, used to dissolve the wafer surface, may be a mixture of nitric acid and glacial acetic acid or it may be a concentrated caustic solution such as sodium hydroxide (NaOH). After etching, the wafer is cleaned with RO/DI water sometimes in conjunction with ultrasonics to increase the cleaning rate. Figure 4 shows the Etching process.

**Polishing**

Chemical Mechanical Polishing (CMP) is performed to achieve the final desired wafer flatness and smoothness. This process normally uses Silica powder suspended in DI water and pH controlled between 10 to 11 with potassium hydroxide. The resulting slurry is fed to a day tank which acts as a reservoir to ensure uninterrupted flow of slurry to the polishing tool. At the CMP tool, the wafer is flooded with slurry and rotated rapidly as it comes in contact with the polishing pad. Surface smoothness and flatness are controlled by the particle size distribution and type of slurry utilized, the rotation speed of the wafer, and the amount of pressure applied to the pad. Figure 5 shows the Polishing process.
Super Cleaning

The Super Cleaning process (Figure 6) is used to ensure any remaining impurities on the wafer are removed. It takes place in three steps.

1. The first step, SCI, is designed to reduce organic impurities and particles from the wafer surface. The Ammonium Hydroxide/Hydrogen Peroxide/Water (NH$_4$OH/H$_2$O$_2$/H$_2$O) solution used in this step may be aided by ultrasonics in the SC1 tank.

2. In the next step, Hydrofluoric acid rising is designed to remove any oxide or metallic impurities.

3. The third and final step, SC2, uses a mixture of hydrochloric acid and hydrogen peroxide (HCl/H$_2$O$_2$/H$_2$O) which changes the bare wafer surface to a super clean, natural oxide surface.

In all three steps, the chemicals are required to meet particle count specifications of < 10 particles/ml @ ≥ 0.16 µm. After the third cleaning step, the wafer is rinsed with high purity DI water.

The Problem

Contaminant related problems can occur throughout the wafer manufacturing process. These problems causing contaminants can be introduced into the wafer manufacturing process in a variety of ways. They are:

- With the raw materials that are used to make polishing and lapping slurries.
- By contaminated etchants, coolants, and cleaning and rinse fluids
- Agglomeration of small particles in the storage containers and day tank of CMP and Lapping Polishing Slurries.
- Formation within the Distribution system
- Generation during the various cleaning, etching and polishing processes.
- The specific problems that occur, as a result of contaminated fluids, in each step of the wafer manufacturing process are as follows:

Slicing

During the slicing process the coolant temperature must be controlled in order to minimize operating costs. Particulate contaminants present in the coolant will:

A. Cause increased friction elevating the coolant temperature.
B. Reduce the effectiveness of the cutting wire and increase the frequency of its replacement.
C. Reduce the flatness of the cut wafer and increase the problem of kerfs and bowing.

Lapping

Oversized and agglomerated slurry particles in lapping slurries can cause deep scratches or micro-cracks on the surface of the wafer if not removed. In addition, the average particle size distribution of the slurry must be maintained in order to ensure the level of surface quality is achieved.
**Etching**
Particulate contaminants in etchant chemicals will cause non-uniform etching of the wafer surface.

**Polishing**
Oversized and agglomerated slurry particles in CMP slurries create microscratches and pits on the surface of the wafer. Figure 7 shows that a wafer polished with unfiltered CMP slurry has been significantly scratched and pitted whereas the wafer polished with CMP filter to 1 μm absolute shows virtually no defects.

![Figure 7— Impact of Filtration on Wafer Surface Defects Created During Polishing with Metal CMP Slurry](image)

**Super Cleaning**
Particles present in the cleaning chemicals and rinse waters of the Super Cleaning process can create defects on the super clean oxide surface created in this final processing step. Defects will result in scrapped wafers.

Fluids used in the wafer manufacturing process that contain particulate contaminants can cause the production of defective wafers. Defective wafers must be scrapped resulting in reduced productivity and less profit for the manufacturer. As an example if a manufacturer of 8 inch wafers produces 700,000 wafers per month and experiences a scrap rate of 5%, the lost revenue resulting from the scrapped wafers is $525,000 per month! Reducing the scrap rate by only 1% equates to an increase in revenues of $175,000 per month or $2,100,000 per year as shown in Table 1.

### Table 1. Calculating Cost of Scrapped Wafers

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Price of 8 inch wafer</td>
<td>$25</td>
</tr>
<tr>
<td>B</td>
<td>If each month the maximum company produce</td>
<td>700,000 wafers</td>
</tr>
<tr>
<td>C</td>
<td>Revenue per month B X A</td>
<td>$500,000</td>
</tr>
<tr>
<td>D</td>
<td>The current scrap rate is 3%/ month i.e. B X 3%</td>
<td>21,000 wafers</td>
</tr>
<tr>
<td>E</td>
<td>Therefore the total scrap rate per month D X 25</td>
<td>$525,000</td>
</tr>
<tr>
<td>F</td>
<td>Improve scrap by one percent (E/3)</td>
<td>$175,000</td>
</tr>
<tr>
<td>G</td>
<td>Annual Revenue Increase F x 12 month</td>
<td>$2,100,000</td>
</tr>
</tbody>
</table>
The Solution

3M Purification high efficiency filtration products are effective in all wafer manufacturing processes. The specific filter recommendation for each process is as follows:

**Slicing**

The rigid, fixed pore structure of 3M Purification’s Betapure™ NT-T series depth filter cartridge is ideal for the filtration of the coolant used in the slicing operation. Betapure NT-T series will reduce the damaging particles from the coolant and will not unload them once retained. A two stage filtration system with 40 µm Betapure NT-T series acting as the prefilter to 20 µm Betapure NT-T series is recommended.

The efficient reduction of coolant contaminants by Betapure NT-T series will ensure that the cutting wire is provided maximum protection, reducing wear and ensuring the wafer is sliced to maximum flatness and without deep surface cracks.

The unique design of the Betapure NT-T series media (see Figure 8) allows for contaminants to be trapped throughout the depth of the filter media resulting in long onstream life and reduced filtration costs.

**Lapping**

Series filtration both before and after mix tank with 40 µm Betapure NT-T series followed by 20 µm Betapure NT-T series will reduce oversized or agglomerated slurry particles that can cause wafer defects. Recirculation of the slurry in the final tank with 20 µm Betapure NT-T series to control the average particle size and reduce the chance of particle agglomeration in the tank is recommended.

While Betapure NT-T series will reduce the large unwanted particles from the slurry, its structure allows that the smaller desired particles are not removed. The ability of a filter to reduce large contaminants while allowing particles to pass is called “classification”. Figure 9 shows that the classifying filter reduces essentially all particles 2 µm and larger while effectively allowing particles less than 2 µm in size to pass. Compare this with the performance of the 2 µm “Clarifying” filter that retains a large number of particles smaller than 2 µm.

Betapure NT-T series will reduce the large unwanted particles while allowing the small particles to pass thereby maintaining the average particle size and, therefore, reduce the creation of deep micro scratches on the wafer surface.

Figure 9 — Particle Reduction Efficiency of Classifying vs. Clarifying Filters

- **Classifying Filter**: Reduced nearly all 2 micron and larger particles, while allowing nearly all particles smaller than 2 microns to pass.
- **Clarifying Filter**: Reduced nearly all 2 micron and larger particles, but also removed a large number of particles smaller than 2 micron.
Etching

Clean etching fluids should be maintained during this process to ensure the desired surface roughness is obtained. High efficiency membrane filters rated at 0.1 µm absolute are recommended in this process. The filter used must not only be efficient at 0.1 µm, it must also be able to operate at high flowrates so the rapid turnover of the etchant holding tanks is accomplished. 3M Purification 0.1 µm LifeASSURE™ MFE series filter cartridges are ideal for the filtration of the etchant chemicals. The PTFE membrane of LifeASSURE MFE series provides compatibility with a wide range of chemicals. In addition, the high area construction of the cartridge allows for high flows for rapid recirculation of the chemical tanks allowing “making spec” in the shortest period of time.

Filtration of the DI rinse water with 3M Purification’s 0.1 µm LifeASSURE™ EF series filter cartridge will ensure the efficient reduction of particles present. The positively charged nylon 6,6 membrane of the LifeASSURE EF series filter media is extremely efficient and will ensure the effective reduction of damaging contaminants. Figure 10 shows how the charge allows for LifeASSURE EF series 0.1 µm media to efficiently remove 0.021 µm particles clearly much smaller than the pore size of the membrane.

The LifeASSURE EF series cartridge is also manufactured with a high area (11 sq. ft. per 10” cartridge) pleated media with low flow resistance and is, therefore, capable of high throughput. Figure 11 compares the flow capacity of LifeASSURE EF series with that of standard nylon membrane media. As seen in Figure 11, LifeASSURE EF series operates at much higher flow rates with much lower pressure drop than standard nylon membrane cartridges. This allows for longer runtimes between filter cartridge change-outs and, therefore, lower filtration costs.

Figure 10 — Electrokinetic Retention of 0.02 µm Beads by LifeASSURE™ EF Series Filters

Figure 11 — Comparative Flow Capacities: Standard Nylon Membrane vs. LifeASSURE™ EF Series Filters
Polishing (CMP)
CMP slurries are most effectively filtered by Betapure™ NT-T series rigid, depth filter cartridges. The slurry typically contains desired particles less than 0.5 µm in size. Particles and agglomerated slurry particles greater than 0.5 µm in size will be retained by the Betapure NT-T series media while particles in the desired size range will pass. Figures 12 & 13 shows that Betapure NT-T series reduces the large particles without altering the average particle size in the slurry and, as a result, it does not change the polishing rate. Betapure NT-T series 10-20 µm filters are recommended after the day tank and before the CMP tool. The mixing filters are recommended to be rated at 20-40 µm to reduce the particle load sent to the Day Tank. The circulation filter is also typically rated 20-40 µm to reduce any agglomerates created in the tank.

Super Cleaning
LifeASSURE™ EF series and LifeASSURE™ MFE series filters are recommended in the processes. As previously discussed, the LifeASSURE EF series filter cartridge is manufactured with a positively charged nylon membrane that is efficient at reducing contaminants much smaller than the filter micron rating. LifeASSURE EF series filters will provide the high efficiency needed with high throughput for long filter life and reduced filter costs. Microfluor filters provide the efficiency and chemical compatibility required for this process.

3M Purification Recommendations- A summary of specific 3M Purification recommendations are listed below in Table 2.

Table 2. 3M Purification Recommendations

<table>
<thead>
<tr>
<th>Application</th>
<th>Process fluid</th>
<th>3M Purification filter</th>
<th>Micron Rating (µm)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingot grinding</td>
<td>Coolant, Glycol</td>
<td>Betapure™ NT-T Series, Betapure™</td>
<td>20-40</td>
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<tr>
<td>Conner/Edge chamfering</td>
<td>Slurry</td>
<td>Betapure™ NT-T Series</td>
<td>50-70</td>
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<tr>
<td>Wire Slicing</td>
<td>DI water/Glycol</td>
<td>Betapure™ NT-T Series</td>
<td>20-40</td>
<td></td>
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<tr>
<td>Lapping</td>
<td>Recovery slurry</td>
<td>Betapure™ NT-T Series</td>
<td>40 &amp; 20</td>
<td>In Series</td>
</tr>
<tr>
<td>Lapping</td>
<td>After mix tank slurry</td>
<td>Betapure™ NT-T Series</td>
<td>40 &amp; 20</td>
<td>In Series</td>
</tr>
<tr>
<td>Lapping</td>
<td>Final tank circulation loop</td>
<td>Betapure™ NT-T Series</td>
<td>20</td>
<td></td>
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<tr>
<td>Etching</td>
<td>Nitric acid &amp; glacial acetic acid</td>
<td>LifeASSURE™ MFE Betafine™ PEG Series</td>
<td>0.1-1.2</td>
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<tr>
<td>Etching</td>
<td>Sodium hydroxide</td>
<td>LifeASSURE™ MFE Betafine™ PEG Series</td>
<td>0.1-1.2</td>
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<td>Polishing (CMP)</td>
<td>Post mix tank slurry</td>
<td>Betapure™ NT-T Series</td>
<td>20-40</td>
<td></td>
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<tr>
<td>Polishing (CMP)</td>
<td>Day tank circulation loop</td>
<td>Betapure™ NT-T Series</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Polishing (CMP)</td>
<td>After day tank before CMP tool</td>
<td>Betapure™ NT-T Series</td>
<td>10-20</td>
<td></td>
</tr>
<tr>
<td>RCA Cleaning</td>
<td>SC1- ammonium hydroxide/hydrogen peroxide (NH₄OH/H₂O₂/H₂O)</td>
<td>LifeASSURE™ MFE LifeASSURE™ EF</td>
<td>0.04 to 0.1</td>
<td>Check Concentration &amp; Temperature prior to recommendation</td>
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<tr>
<td>RCA Cleaning</td>
<td>Hydrofluoric acid</td>
<td>LifeASSURE™ MFE</td>
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<td>RCA Cleaning</td>
<td>SC2- Hydrochloric acid and hydrogen peroxide (HCl/H₂O₂/H₂O)</td>
<td>LifeASSURE™ MFE</td>
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<td>RCA Cleaning</td>
<td>RO/DI water at POU</td>
<td>LifeASSURE™ MFE</td>
<td>0.04/0.1</td>
<td></td>
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