White Paper

Optimizing High-Purity Fluid Containers for Semiconductor Fabs

Selection Guide for Stable Polymers in Rotomolded Tanks

The semiconductor industry's growth and production levels are critically reliant on reducing contamination during manufacturing processes, especially considering the number and variety of fluids the wafers encounter. The goal is to create clean, viable components while maintaining the highest purity levels, regardless of the platform where the work is conducted. This minimizes potential contamination and promotes safety. Which processing method supplies the most reliable, efficient, and economical tanks/containers for fluid handling? Discover the critical factors that make rotationally molded vessels a superior choice for semiconductor fabrication.

Figure 1: Mold preparation for a high-purity PFA tank

Semiconductor industry size

Semiconductors form the building blocks for all forms of modern technology. As its basic function, a semiconductor controls and manages electric current flow in electronic equipment and devices. This activity is enabled by transistors on the chip. Transistor sizes have shrunk dramatically — close to the size of an atom — due to advances in lithographic technology. This allows high-production yields and enables today's smart technologies.

Consumers' seemingly insatiable appetite for smart technologies and industrial modernization have combined to drive increased demand for semiconductor chips. Electronic goods often rely on multiple chips for their performance. For example, a single electronic vehicle contains anywhere from 2,000 to 3,000 chips. As a result, a record 1.15 trillion semiconductor units were shipped worldwide in 2021.

Potential for contamination

With their miniscule size and delicate circuitry, semiconductor chips must avoid any undesirable chemical exposure or interactions during manufacturing. Chemical exposure or interactions with containment vessels can introduce or extract metals, ions particles, or organic materials from a formerly clean surface. Proper material selection and manufacturing methods must be applied to every component utilized in the manufacturing stream to produce parts that are both hygroscopic and resistant to chemical reactions, which helps minimize contamination. These controls improve quality and help fabs reduce the number of wafer defects.

According to a statement by Farhang Shadman, Ph.D., director of the semiconductor research facility at the University of Arizona, in a talk with tech magazine IEEE Spectrum, any contaminants are harmful to the silicon wafer. For example, even miniscule amounts of bacteria, whether alive or dead, can carry trace elements of phosphorus or carbon, which "change the electrical properties of the silicon wafer."

Stages in production requiring fluid containment

While semiconductor plants are known as "thirsty" facilities, using millions of gallons per day of ultrapure water (UPW), there are many other fluids used during production — where purity is equally as important. In addition to multiple cleaning and washing steps, fabrication involves etching, chemical-mechanical polishing or planarization, spin coating, and electrochemical deposition, among other processes.

Consider the following examples of semiconductor fluid containment vessel types:

Figure 2: PFA tank

- **Tanks.** The process of planarization, or chemical polishing, uses orbital action to polish the wafer smooth and is intermediated with a chemical slurry. Rotomolded tanks can contain the chemical slurry and be fitted with or without lids.

  When the chemical is mostly inert, or if it is a fine grain polishing compound, a company could select high density polyethylene HDPE as a solution for mixing operations. HDPE offers good impact- and abrasion-resistance. Depending on the grit, HDPE supplies greater resistance to abrasion than stainless steel.

- **Rotomolded cylinders or squared-off containers.** These appear on various platforms used to wet clean and etch wafers. Rotomolded canisters for etching and cleaning also serve multiple platforms. Cleaning and etching involve a harsh chemical bath. Due to the harshness and the high purity of the chemical, the container must be able to withstand the chemical attack and any elevated temperatures. Perfluoroalkoxy (PFA) would be the material of choice for this process.

- **Bottles.** Bottles in diverse sizes (3, 6, and 10 liters) find applications in the electrochemical deposition phase for advanced wafer level packaging and through-silicon via structure applications. At this stage, copper and other metals are deposited to create the electrical connections that power mobile electronics.

The bottles are threaded to accommodate caps. Often rotomolded out of polypropylene, these bottles are used to monitor and measure the volume of chemicals being used. They often have fluid-level sensors welded on with sensor lead lines on the side to route around the bottle and keep the wire clean, monitoring fluid levels.

Figure 3: Welding dosing bottle with accessories

Whether utilizing UPW, caustics, or bases, all these manufacturing processes must control potential contaminants to protect the integrity of the component while maintaining safety standards by avoiding leaks.

High-performance polymers provide best containment strategy

There are several material options for containers used to confine these fluids at the various stages of the semiconductor manufacturing process. Companies can choose stainless steel, metal alloys, glass, quartz, or polymers. High-performance polymers supply an economical and effective option as containment material for UPW and chemical substances for a variety of reasons. Other materials are known to have flaws.

Stainless steel, for example, requires special coatings to prevent corrosion. However, these coatings can and do flake off, contaminating fluids and exposing the vulnerable metal surface underneath. This can compromise the component's durability, longevity, product and process quality, and worker safety. Metal alloys supply corrosion resistance but add to the expense. Glass and quartz containers can pit, chip, or shatter. In the semiconductor industry, metal and anionic contaminants can lead to component failure.

A high-performance polymer, such as polyvinylidene fluoride (PVDF), is considered a "clean polymer" because it does not require the use of stabilizers, plasticizers, lubricants, or flame-retardant additives. High-performance polymers used for high-purity fluid containment offer a winning trifecta of cost-effectiveness combined with corrosion resistance and hydrophobic characteristics. Next in line of importance is the method used to form these polymers into containers, bottles, and vessels used for fluid containment. The manufacturing method has an enormous impact on potential contamination.

The process of rotational molding

Rotational molding leverages the characteristics of high-performance resins to provide high-purity containment for the semiconductor industry, offering unique advantages over blow molding or injection molding. RMB Products focuses on PVDF, PFA, and HDPE, as they are the resins most specified for semiconductor fluid container applications. RMB can also provide high-purity fittings for the tanks that are compatible with the tank itself.

The process of rotational molding is like that used for rotolining larger vessels. RMB selects the appropriate polymer resin, melts it, and rotates the mold biaxially to create the container. This processing method can also be used to create recessed fittings or different geometries with curvature or contours. These variations can help accommodate customer requirements for cabling, mounting devices, and other features on the containers. Or they can be used for level sensors or other peripherals.

Figure 4: PFA tank molds held on machine arm prior to molding process

Compared to blow molding or injection molding, rotomolding supplies several advantages related to the method of manufacture using the same type of high-purity polymers. The differences allow operators to:

- **Retain every drop of liquid.** Rotomolding produces a container without an interior seam. The parting line is on the container's exterior, not interior. This contrasts with blow molding and injection molding, which has seams that can disrupt the flow or capture of fluids from the container. Rotomolding enables complete fluid recovery.

- **Protect against bacterial or sedimentary buildup.** This seamless interior provides no hidden corners, lines, or cracks for bacteria or other sediment to accumulate, helping increase the container's suitability for high-purity operations and protect against contamination.

- **Avoid leaks or container failure.** The main point of failure for welded containers is the welded seam. Seams are man-made and prone to quality problems. A container without seams, the result of rotational molding, helps eliminate the chance of leakage.

- **Extend useful lifespan.** Seamless construction creates tanks and bottles that are mechanically stronger than vessels with seams, making them better able to withstand the rigors of processing or unintentional bumps and drops.

- **Expedite project completion timelines.** Rotational molding shortens the timeframe to set up a mold by hundreds of hours, if not weeks, compared to alternative molding technologies. An existing mold or mold modifications makes the timeline even shorter.

Compared to other technologies, rotational molding is a very low-pressure process that is both quick and simple. Other methods, such as injection or blow molding, involve much higher pressures and could require thousands of hours of machining to create the molds. The mold-making process for these alternative technologies also might require cooling jackets or other accessories, adding to the cost.

Processes and material characteristics optimized for high-purity applications

RMB takes every possible step to ensure its final product will provide the cleanliness and purity required in the semiconductor industry. For example:

1. **Virgin, certified resins.** RMB restricts its material usage for rotomolding processes to virgin, certified resins. It works with all the multinational providers, sourcing materials from Chemours, Daikin, Arkema, or AGC, Inc. The materials contain no other monomers or polymers, with the sole ingredient being the polymer requested by the end user.

2. **Purity and traceability.** RMB maintains lot traceability and follows it through the rotomolding process to guarantee the material remains pure. When installed in the customer's system, at whatever stage of the semiconductor manufacturing process, the material will be as pure as when RMB first purchased it.

3. **No regrinding or recycling.** RMB does not recycle or regrind its polymers. Any excess material or drop from the manufacturing processes is sent to a secondary firm for reuse at a different facility. The material is not wasted, but it also is not used for high-purity rotomolded products.

Figure 5: Inside view of RMB's clean room

Figure 6: Rotomolded PFA tank with sloped bottom and drain

4. **Strong shapes.** RMB creates cylindrical or spherical tank shapes, which are easier to mold than to fabricate. The radius of a cylinder or sphere is inherently stronger than a container with a squared-off, 90-degree angle at the bottom. A rotationally molded sphere or cylinder helps increase the container's strength.

5. **Dedicated clean room.** The final cleaning and bagging occur in the dedicated clean room at RMB. This is standard operating procedure for any high-purity product manufactured by the company. In the clean room, every product surface is wiped with isopropyl alcohol, and all products are placed in certified bags. The bags are tied off prior to moving them through the airlock to shipping.

Why the emphasis on pure, original polymer resins

The emphasis on 100% virgin resin material is one key to ensuring contaminant-free components. When polymers are reground and recycled, it increases the risk of contamination and/or component failure. Consider two examples:

- A secondary grind of recycled resin presents an opportunity to introduce a contaminant into a material being prepared for molding. If the grinders aren't completely clean or dedicated to grinding a single material, cross contamination can easily occur.

- Ground resins are similar in appearance and can easily be mixed into a batch of a different polymer type, despite traceability efforts. When the materials are mixed, it changes the chemical resistance characteristics and mechanical properties.

In addition, a material that is processed more than once, or is ground and then recycled, increases the potential of oxidation or damaged polymer chains. These might degrade the plastic's physical and mechanical characteristics, leading to component failure in a critical process.

Prime considerations for selecting the right polymer

Among high-purity polymer resins, PFA is the material most often requested for semiconductor applications due to its chemical compatibilities and thermal processing limits.

PFA has an extremely high processing temperature. It is stable and can be used in applications that experience temperatures greater than 400° F while maintaining its chemical compatibility. It is well-known for its resistance to acids and bases. Although PFA exhibits ideal properties for high-purity containment, particularly for caustics and bases, the material itself is difficult to process. In fact, there are few companies that can claim PFA molding expertise.

RMB works on a daily basis on projects that specify PFA. Fittings that are used to measure liquid levels are a common feature of chemical processing applications. These fittings must be installed using a welding process. RMB tries to ensure that all fittings are welded from the outside in a manner that does not produce any internal seams.

RMB relies on the expertise of certified PFA welders, who must obtain annual qualification. Welders seeking certification must produce samples for testing at an independent lab. The lab tests and certifies the weld strengths against desired standards. Weld strength is vital to preventing mechanical failures or lost fittings that could ultimately result in downtime for the processes utilizing PFA tanks or the containers that incorporate welded fittings, a common feature in chemical processing.

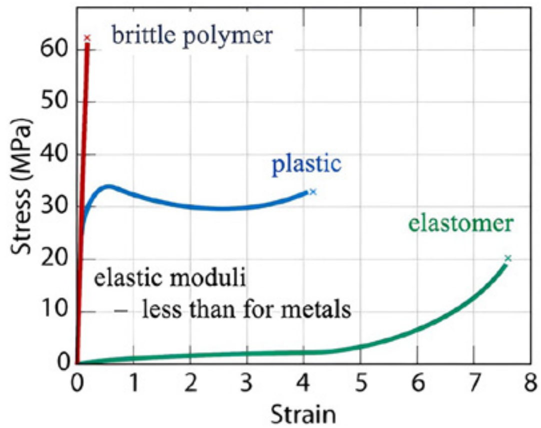
In addition, RMB conducts all its weld fitting operations within the clean room environment, which is ISO rated for air impurities.

Customers will often specify their preferred polymer resin for rotolining. When unsure, the engineering staff at RMB is available for consultation. Here are some considerations for engineering properties to keep in mind when specifying the polymer for a semiconductor or high-purity application:

- **Specific heat of the material.** This is the amount of energy per unit volume required to raise the temperature of a material one degree. RMB can help specify the heat energy for any given polymer and advise which material and size tank will work best in the process when there are high thermal requirements.

- **Material strength.** Look for materials that have high strength characteristics, or a large area of application potential according to the stress/strain curve. While a polymer's ultimate tensile strength may be higher or lower than alternative materials, these alternatives can fail abruptly. Failure, such as a glass container breaking into shards, can instantly ruin whatever batch or single wafer is in production in that vessel.

Mechanical Properties of Polymers:
Stress-Strain Behavior



Note that the area under the stress/strain curve displays the amount of energy required to create failures in the material. Polymers that are rotationally molded offer high strength characteristics, or a large area of application according to the curve.

- **Ductility.** Rotomolded polymers are very ductile. Once rotomolded into a bottle, tank, or vessel, they will not fail or become brittle. Upon impact, the polymers will not break or chip like glass would, thus contaminating the contents of the processing. In contrast, glass has no stretching or percent elongation. Many of the polymers utilized by RMB for rotational molding can stretch from three to nine times their original length before reaching a fracture point.

- **Surface energy.** Thermoplastic polymers have varying degrees of surface energy, which characterizes their bonding capabilities. High surface energy allows easy bonding whereas low surface energy does not. The lower the surface energy, the greater the resistance to bonding, equaling a greater capacity to repel liquids as diverse as oil and water, among other substances. The surface energy of PFA, for example, prevents anything from sticking to it. It aids with fluid recuperation as well as the ease of flushing foreign or unwanted objects from its surface to prevent contamination.

This quality, combined with a seamless tank interior from rotomolding, helps promote the high-purity atmosphere required for semiconductor manufacturing — regardless of phase or processing step.

Quantifying a specialized design ethos

RMB incorporates design ethos into its process. This means moving beyond client specifications and using preferred methods to achieve an end product that exceeds expectations. For example, when a container requires welded-in fittings, RMB's design will ensure that the fittings are welded from the outside to reduce or eliminate the possibility of internal welded seams. As discussed earlier, this helps prevent contamination.

Design applies to sizing containers as well. Rotational molding of bottles or tanks starts at the 120-milliliter mark and can produce containers that hold up to 200 liters. Size should factor into decision making related to contamination potential. Larger vessels or containers have a stronger correlation to contamination due to their greater surface area. Keeping them within a given size range helps manufacturers better adhere to stringent purity and cleanliness standards.

Proportions matter as well, or the aspect ratio, for a freestanding cylindrical tank. Containers should remain within a 1:1 or 1:1.5 ratio. In a 1:1 ratio, the diameter and height are equal, whereas in a 1:1.5 ratio, the height is 1.5 times taller than the diameter.

Semiconductor project planning, consultations, and timelines

Throughout the semiconductor processing stages, rotomolded containers are already in use on various platforms for fluid containment or have potential to offer superior properties compared to other technologies and materials. The areas of use can include wet stations, spin processors, and polymer removal stations; annealing, measurement, surface preparation, inspection, and test systems; and scrubbers.

Trust rotomolded containment vessels from RMB for semiconductor fabrication processes, such as:

- Atomic layer deposition
- Chemical mechanical planarization
- Chemical vapor deposition
- Cleaning
- Coating/developing
- Electro chemical deposition
- Epitaxy (the process of growing a crystal)
- Etching
- Ion implantation
- Lithography
- Physical vapor deposition
- Rapid thermal processing
- Stripping
- Wafer bonding/debonding

RMB manages the entire rotational molding process in-house, from design to shipping. Its in-house capabilities are fully integrated to quickly support new mold designs and new projects. However, the best time to initiate a discussion with an RMB engineer is at the start of the project. That way customers can avoid delays, lost productivity and work, and costly redesigns.

As an ISO 9001-certified company that regularly supplies equipment to meet military, government, and aerospace requirements, RMB's quality is top-notch. Count on the highest level of quality and service for your next semiconductor application for high-purity fluid containment. Contact RMB today.

ABOUT THE AUTHOR

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Phillip Velazquez is a mechanical design engineer at RMB Products. He designs rotationally molded products that support semiconductor and pharmaceutical industries as well as rotationally lined pressure piping and pressure vessels that support the chemical industry. He prides himself on shop floor involvement and uses it to improve the manufacturability of his design work. Velazquez earned his bachelor's degree in mechanical engineering from the University of Colorado.

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