Waste Minimization, Pollution Prevention and Resource Recovery at a GaAs Manufacturer

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A**bstract: This extended abstract examines strategies and technologies to minimize the environmental footprint of Compound Semiconductor Manufacturing Operations and ways to recover and recycle commodities to contain cost and secure limited resources.**

INTRODUCTION

Waste minimization, pollution prevention and resource recovery are the efforts that assist a semiconductor Fab to not only reduce their environmental impact but also to remain economically viable. A GaAs Fab uses both precious and strategic metals as well as many solvents in the manufacturing process, and their use and reclamation needs to be closely controlled and monitored in order to be viable in today's manufacturing environment. Water is a precious commodity that is many times taken for granted, but as populations grow and existing finite fresh water resources are over utilized, water needs to be a focus of conservation efforts.

GALLIUM

Gallium is a strategic metal used extensively in GaAs wafer Fab manufacturing. The total market for gallium is relatively small and subject to price and availability fluctuations. Due to the fact that gallium is relatively scarce on earth and the small volatile market, it behooves semiconductor manufacturers to closely examine all areas where gallium can be recovered or reclaimed.

The first line of gallium conservation is reuse in the production process. MBE gallium can be recovered at the end of a campaign and reused in the next campaign if the Fab can develop ways to remove the gallium, store it and then return it to the MBE without introducing contaminants that may adversely affect the production process. Reusing GaAs wafers that fail at some point in the production process instead of scrapping the wafers helps preserve natural resources. This may be as simple as re-working a wafer that was misprocessed in photo or etch or involve an outside vendor to clean up the wafer enough to reintroduce it into the manufacturing process. Even if the reworked wafer is not acceptable for production, it can be used as a dummy or mechanical wafer thereby serving a function and displacing a virgin wafer in these applications.

RFMD has partnered with a gallium reclaim vendor who has assisted us in reclaiming many sources of this metal from frozen liquid gallium reclaimed from MBE operations to low yield filter media from wastewater treatment. All the following materials are currently reclaimed for gallium content:

- Gallium metal from MBE
- Scrap wafers
- Sludge collected via centrifuge in the wastewater pre-treatment operation
- Metals scraped from MBE units during PM procedures
- GaAs dust collected in air pollution control equipment from wafer singulation
- Wastewater filter media from the wastewater pre-treatment operation

When designing a Fab or introducing new air and water pollution control equipment, make sure to work with a reclaim vendor to assure that the gallium captured in these systems can be recovered in an economically viable process. For example, the gallium reclaim vendor could not reclaim gallium from the filter system which used "depth" filters to trap GaAs particulates from the wastewater. By re-engineering the filtration system to utilize a "surface" filter we are now able to reclaim the gallium from the wastewater.

Air pollution control equipment that captures GaAs particulate from wafer processing should be designed in such a way that the GaAs powder can be collected and shipped for reclaim. A baghouse upstream on a HEPA filter can be utilized to recover GaAs powder while the HEPA controls the final air emissions of arsenic to comply with air quality standards.

PRECIOUS METALS

Precious metals are limited in availability and high in cost. With the current trend in precious metals pricing, semiconductor manufacturers need to closely scrutinize where and how they are using precious metals in the manufacturing process.

Various precious metals are used in semiconductor manufacturing but very little is left in the final product. An example is the manufacturing use of gold, where significant amounts of gold need to be purchased to plate or coat electrical contacts in the microchip. Most of the gold ends up in the form of spent plating solutions, evaporator shield contamination, spent targets, etch solutions and other forms of residues. It is critical for a Fab to have robust systems to capture and collect all forms of gold and to get them to a reputable precious metals refiner for processing.

Examine all processes that apply or remove gold. Metals liftoff is an area where the use of filters and collection devices can pay for themselves very quickly. We generate a solvent saturated filter that contains gold from solvent liftoff. We worked with a local precious metals reclaim vendor that can accept flammable solids on a hazardous waste manifest and process the material for recovery.

Gold etch and plating solutions are a source that can return significant amounts of revenue. Depending on the process, these solutions may be hazardous or nonhazardous based on the chemistry being used. Regardless, the purpose of the etch process is to remove gold and that gold can be recovered. Gold plating baths that reach a depleted state and are no longer suitable for plating still contain significant amounts of gold. A regimen of sampling all of the spent baths in the Fab will find that some baths have sufficient gold in them to warrant a collection system to allow them to be captured and shipped for reclaim.

Process Engineers need to look at the metals being used and evaluate options for using non-precious metals to achieve the same results that are obtained with the precious metals. This can lower the overall cost of manufacturing while preserving a limited natural resource.

When evaluating reclaim, do not overlook small usage items. Platinum is used in small amounts but with a value per ounce exceeding gold, there may be opportunities to capture platinum for recycle.

All targets, crucibles, scrapings should be controlled and returned to a gold refiner to recover the value. It is important to partner with a reputable gold refiner or two to assure that you are receiving the yields you should. Periodic split samples to multiple vendors can be used to gauge performance and assure high yields. Also, your Environmental and Quality personnel need to go out and physically audit the vendors that you are using. This will help assure that the possible toxic metals that go with the gold are properly managed and that their process is robust from a quality perspective to assure adequate return for the precious metals sent for reclaim.

SOLVENTS

While silicon wafer processing is acid intensive, GaAs wafer processing is a solvent intensive manufacturing process. This is due to the extensive photo-lithography steps required to produce GaAs devices. There is a wide variety of solvents used in the manufacturing process and, as such, there exist multiple opportunities to reuse and recycling.

The first line of solvent conservation is to get better utilization out of the solvents you are already using. This may be as simple as extending bath life which can be done a number of ways. Some solvent baths were historically changed on a per-day of per-shift basis. By changing the trigger point for a bath change to be indexed to production (change every x number of wafers or lots) bath life can be extended as long as there is no impact to quality. Another method is to have two baths for a solvent stripping operation in a lead lag configuration. The first bath is the “dirty” bath which removes the majority of the material that is being stripped and the second bath is for final cleaning. As the dirty or clean bath becomes saturated, the dirty bath is dumped and now the previously clean bath becomes the dirty bath and fresh chemical is used for the clean bath. By controlling this process with robust work instructions, solvent usage can be reduced.

Tooling can be modified to minimize evaporation from solvent baths and other processes. Simple condensation coils in the annular space around a bath opening or in tooling can condense the solvent and return it to the bath, reducing the need for makeup and additional solvent usage.

The next step that is critical for solvent reclaim or recycling is dedicated drain systems. Some solvents and photoresist materials can polymerize in the drain systems and cause clogging. Obviously, these materials need to be kept separate or the risk of clogged drain lines and downtime is very real. But also by segregating drain systems, solvents can be collected with minimal impurities and contamination. While these solvents cannot be readily reused in the semiconductor manufacturing process, many times they are pure enough to be reused “as is” by other industries with lower purity requirements. Expensive solvent such as NMP (n-methyl pyrrolidinone) can be captured and sold for reclamation to various solvent recovery type vendors. It is not typically feasible for an on-site solvent recovery service to work to recover solvents and then reuse them in the manufacturing process due to the quality concerns and the high purity semiconductor grade of chemicals needed for manufacturing. However there is a market for some of these solvents.

Regulatory due diligence must be pursued on all of these used solvent streams to assure conformance with State and EPA regulations. In our case, we are able to sell one solvent stream as a product because it is reused “as is” in another industry. A second solvent waste stream needs to be reprocessed before the recipient can then resell the material. Therefore, it is considered “waste” by EPA and needs to be shipped on a RCRA manifest due to its characteristic of flammability. In order to avoid potential legal and regulatory issues, make sure that your program conforms to the intent and the letter of the law as interpreted by your local enforcement agency before proceeding.

WATER

Semiconductor manufacturing requires large amounts of water and much of it has to be ultra high purity water from an RO/DI system. Ultra high purity water is expensive to produce and the purification produces wastewater from RO reject, ionic bed regeneration, media filter regeneration and other steps in the process.

The first step is to reduce usage wherever possible. High purity water has a shelf life and you do not need to produce more than is needed or at some point the treated water will have to be rejected to drain. A robust analysis of Fab needs should be used to fine tune the high purity water system to meet the needs of the Fab but not to exceed them.

The RO/DI system is a place where you can start your water conservation efforts. Every percentage point increase in the yield from the RO/DI system will be additional high purity water for the process, reduced RO reject and monetary savings for the operation. Work with your water treatment vendor to explore opportunities to increase yields in the system to reduce overall water consumption.

Every place where high purity water is used needs to be evaluated. Quick dump rinse (QDR) baths should be set to standardized overflow rates or better yet have conductivity set-points that trigger blow down. Flow meters can be very helpful to assist Production in setting these process tools to the minimum effective flow rates that preserve the process. Fixed flow meters are not necessary; there are various “strap-on” type flow meters that are available and can be used at sequential locations to assure that water is being used effectively.

Some processes may not need high purity water such as grinding. In these applications, using a lower grade of water can significantly conserve overall water consumption. Work with Production and Process Engineering to make sure that the proper grade of water is used for each application in question.

Much of semiconductor wastewater is cleaner than incoming city water which is typically laden with chlorine, fluoride, calcium, magnesium and other ions. You may want to look at the wastewater produced by different processes within the Fab and evaluate which may be conducive for re-use elsewhere in the process or even for reintroduction back into the raw water feed to the RO/DI system. For example, the discharge from a QDR may be clean enough to use for grinding or another application.

Even the RO reject water can be reused in some limited applications. Even though it is laden with ions, it can still be effectively used as cooling tower makeup water or even as makeup to acid gas scrubbers. By cascading systems with lower purity requirements off the Fab wastewater, overall water usage is reduced.

Additionally, there are some support processes that can be fine tuned to reduce water usage. Large scrubbers and point of use abatement devices can suffer in performance if they are fed too much water. An example is a packed bed wet scrubber used for air pollution control. Excess water flow into the unit can result in the flooding of the media resulting in less effective air pollution control. Make sure that these units are in the acceptable range specified by the manufacturer. In this case, more is not better.

The last avenue for the water in the Fab is discharge to the sewer typically after some sort of pre-treatment and/or final treatment. If your water recycle program is robust and you effectively control the way water is used, each gallon may have been reused several times before it is discharged.

CONCLUSION

There are many opportunities in semiconductor manufacturing to reduce the environmental footprint of the activities. By emphasizing conservation, reuse, recycle and reclaim, a semiconductor manufacturer can not only minimize its environmental impact but also reduce expenditures and maximize return for the shareholders.