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Topic Hub: Semiconductor Manufacturing **Subsection : P2 Opportunities**

The semiconductor industry is characterized by innovation and rapid product and process evolution compared to other industries. As with other industries, however, there continue to be prospects for reducing pollution and inefficiencies. Opportunities exist for reducing energy, water, and materials, as well as the wastes, effluents, and emissions generated.

Notes:
1. Some opportunities listed below may already be the norm for some fabs.
2. Suggestions may require trials prior to implementation, to maintain wafer quality.
3. Available opportunities for fabs may differ depending on whether the fab is being built from the ground up, or whether an existing fab is being retrofitted.

Energy Efficiency

Cost savings in energy and electricity generation and purchase is not the only reason to design and implement energy efficiency. Generally, energy conservation and efficiency results in a more reliable facility due to less wear on filters, pumps, and motors, reduced maintenance and operating costs, and reduced greenhouse gas generation. Additionally, an energy-efficient facility has lower pressures and slower airflow, which improves filtration efficiency for these systems. The end result is reduced particle contamination on the semiconductor, generating improved product yields and product quality.

According to a 2005 study by the International SEMATECH Manufacturing Initiative (ISMI), the global semiconductor industry could save nearly $500 million per year in energy costs, or enough electricity to power a small city, by making only modest improvements to its tools and facility support systems [1].

The amount of energy and fixed consumables used in the fab is related to the number of mask layers. In turn, the number of mask layers reflects process complexity [2]. The continued increase in functional complexity achieved with each semiconductor generation has been accompanied by steady decreases in the size of the die itself. This reduction in die size allows for improved resource efficiency because not only are more die capable of being produced on each wafer, but also less energy is required by the integrated circuit during its useful life.

The 2005 article in HPAC Engineering titled, Measuring and Managing Energy Use in Cleanrooms presents additional suggestions [3] details many aspects of efficient energy design for fabs, some of which are listed below, along along with suggestions from several other citations.

- "Right-size" energy systems for the facility as a whole, e.g. upsizing cooling towers, while downsizing certain other components, especially heating, ventilation, and air-conditioning (HVAC) systems [3].
- Design and operate redundant air handlers, scrubbers, and cooling tower units in parallel to reduce pressure drop and power requirements, yet provide backup capacity when needed [3].
- Sequence chillers for maximum efficiency.
- Install variable-frequency drives on fan motors (supply and exhaust), and other motors across the plant.
- Use more high-efficiency, point-of-use, and variable-speed capability pumps with stand-by mode, especially with fabs that may operate up to 700 vacuum pumps. They use less than half the electrical power of current versions and can be idled during non-productive periods to save an additional 30 percent of consumption [1]. (Targets for variable-speed include hot water pumps, chillers, primary loop-chilled water pumps, secondary loop-chilled water pumps, condenser water pumps, and cooling tower fans, to control and balance water flows).
- Place vacuum pumps as close as possible to the supported equipment.
- Size the boiler plant to minimize energy use while idle and eliminate boiler reheat requirements through heat recovery. Different sized boilers with integrated, intelligent seasonal switchover control minimizes idle energy use during low-load periods [3].

- If payback justifies, install economizers and heat exchangers on boilers.
- Minimize pressure drop in air delivery system with low-pressure-drop filters and lower face velocity unit coils.
- Upsize passive components (e.g. ducts and pipes) to allow use of smaller fans and pumps [3].
- Minimize sharp turns and 90-degree elbows in air ducting to provide lowest-resistance air flow.
- Reduce cleanroom airflow velocity. The ISMI successfully demonstrated at several fabs that lower velocities through HEPA filters, as much as 30-40% lower, did not impact product yield. Studies have also shown that lowering HEPA velocities can result in improved pressure differentials, improved parallelism of the flow, reduced particles, and no impact on cleanroom temperature or relative humidity [4].
- Optimize air-change rates (ACR), the single largest factor in determining fan and motor sizing for a recirculation air handling system. Reducing ACR by 30%, yields 66% power reduction, may improve cleanliness by minimizing turbulence, and may allow downsizing of fans and motors. Current recommendations are not based on scientific findings, and there is no clear consensus on the optimum [3].
- Use variable ACR systems and controls (manual, timer, occupancy sensor, or real-time particle counts) [3].
- Minimize total exhaust volumes through variable-flow control, exhaust optimization for the process equipment, design approaches to maintain proper stack exit velocity with optimal bypass/dilution airflow, and by eliminating pressure drop bottlenecks in the exhaust ductwork system [1,3].
- For idled tools, rebalance exhaust and shut off utilities.
- Minimize exhaust by using direct (face velocity) measurements of containment to set the exhaust rate. Manufacturers' suggested exhaust quantities may be overstated [3].
- If significant heat output comes from process tools or boilers, use heat recovery system(s).
- Collect solvent vapors for heat generation, possible with a thermal oxidation unit.
- Use mini-environments for better contamination control and process integration by controlling pressure differences or using unidirectional airflows [3].
- Install the most energy-efficient heaters and RF generators.
- Optimize recirculation air systems - most systems demonstrate energy savings from lower pressure drop design [3].
- Integrate sensible cooling devices with the air-recirculation system [3].
- Use a medium-temperature loop to expand the potential for waterside free cooling [3].
- Use a low-approach temperature on the cooling tower [3].
- Use a chilled water reset to increase the chilled water supply setpoint when lower-temperature chilled water is not required to meet cooling needs and, conveniently, when the cooling towers are able to produce the lowest temperature free cooling water [3].
- Institute an energy management program with risk management, cost control, quality assurance, employee recognition, and training.
- Optimize nitrogen use and right-size the on-site nitrogen generation by rewheeling compressors, sealing equipment openings, and replacing nitrogen with clean dry air in non-process applications.
- Do not use air compressors to heat or cool air for cleanrooms.
- Explore ways to reduce use of deionized (DI) water and ultrapure water (UPW) - less water production means less energy consumption.
- Can the temperature of "hot DI" water be reduced at all?
- For onsite reverse osmosis water production, install pressure recovery turbines.
- If vending machines are provided, (common for shifts that run around the clock), install vendormisers and pull the lamps and ballasts from the machines.
- Make it company policy to unplug cell phone/blackberry/radio chargers when batteries or devices are not being charged.
- Consolidate refrigerators and refrigerated chemical storage areas.
- Install motion detector lights.
- Implement leak detection for compressed air, vacuums, and any specialty gas delivery systems.
- Replace incandescent "exit" signs with LED lighting.

Note: Although beyond the scope of this document, a few ideas for reducing energy in silicon production are listed at the Energy Efficient Cleanroom Information Site.

Water Use & Efficiency

The largest water conservation opportunities for fabs are reduction and reuse of UPW and DI water. About 1,500 gallons of city water is needed to produce 1,000 gallons of UPW or DI water, according to a 2002 abstract by Klusewitz & Viegh.

The industry is taking steps to significantly lower the use of UPW through equipment and process optimization. One example is the replacement of wet stations by Automated Wet Benches (AWB) for many wet etching processing steps. The two main differences between these systems involve container sizes and wafer drying methods. As a result, the AWB can use smaller tanks, less chemicals and smaller exhaust systems. These redesigned wetbenches with the reduced-volume rinse tanks have resulted in water use reductions of approximately 40 percent [5]. Another opportunity is to convert wet processes to dry processes.

Additional conservation prospects involve reductions in facility water use, and make-up water for equipment such as water towers and chillers. Projections indicate that 30-50% of fab water can be reused [5]. Other specific suggestions follow:

- Reduce point-of-use water consumption by optimizing rinse processes. Detailed evaluation and implementation steps with actual case studies are available at Rinse Optimization For Reduction of Point-of-Use Ultrapure Water Consumption in High Technology Manufacturing [7].
- Recover and reuse water from UPW or DI production and fab processes. In some cases, this water can be used without treatment. Potential uses, depending on the characteristics of the reclaimed water, include cooling tower make-up, water-cooled packaged air conditioners, scrubbers, acid waste drains, irrigation, and non-wafer-contact processing, such as tool cleaning, quartz sputtering, and glass cleaning; and finally, in fab humidification systems [4]. Numerous online case studies and articles *(See Complete Set of Links)* illustrate the gamut of water recovery possibilities.
- Use reject brine from reverse-osmosis UPW production for reintroduction into the reverse-osmosis input feedwater [8].
- Recycle or reclaim spent rinse waters. A sampling of semiconductor plants in Texas showed a return on investment of between five and seven months for water recycling systems [8]. Numerous systems are available, including electrodeionization (EDI) (a primary ion-exchange process).
- Where possible, replace wet-etch tools with dry-etch tools.
- Implement leak detection.
- Use timers on sinks to time wafer etch cycles instead of running dump rinsers without wafers in them.
- Evaluate whether the idle flow rate on the post-etch dump rinser, which operates with continuous water overflow (to prevent particles and bacteria growth), can be reduced without impacting quality [4,5].
- Recycle the water (with arsenic) from the grinding process for reuse at the front end of the process. Adequate filtration is imperative [9].
- Consider alternative sampling for bacteria so the constant-flow sample lines of DI or UPW water can be reduced or turned off at times [10].
- Install orifice restrictors upstream of the idle-flow valve on the bottom fill of the dump rinsers [8].
- Routinely calibrate resistivity probes in DI tanks to minimize unnecessary dumping or overflowing.
- Optimize wet-bench process recipes by replacing overflow rinses with quick-dump rinses (for non-HF rinses) and stopping overflow rinses when baseline resistivity is met [4].
- Minimize the number of dumps in the sink dump rinsers [10].
- If the internal air compressors are water-cooled, consider outsourcing the production of compressed air. (This saves Fairchild about 13 million gallons of water per year [10]).
- During downtimes or product conversions, work with wet tool manufacturers to design water-efficient tools, e.g., reduce idle and process flows, segregate drains to maximize water reuse.
- Reduce tank size and configuration to improve water flow past the wafers. Add flow meters to track flow rates and ensure optimal flows are maintained [10].
- Extend bath life by recirculating buffered oxide etch (BOE) to remove particulates and other contaminants.
- Make bath changes based on data rather than a set time period. Data indicators include conductivity, pH, or number of wafers processed.
- Replace wet-sink spray tools with diffusion cleaners. This also reduces use of chemicals [9].
- Decrease the slurry flowrate during polish and pad cushioning.
- Collect rainwater and/or stormwater for irrigation.

Solvents, Chemicals and Gases: Use and Wastes

- Implement a chemical management system, vendor-managed if possible.
- Continue to work toward reduction in use of perfluorocarbons (PFC), potent greenhouse gases,

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that may be used for chamber cleaning in vapor deposition tools, or as etch gases. Current strategies include alternative chemistries; process optimization; recovery/recycle; and various forms of destruction or decomposition such as combustion, plasma dissociation, thermal chemical absorption, and catalytic conversion) [4].

  - PFC reduction program: Semiconductor Industry Association (SIA) companies forged a voluntary agreement with the US Environmental Protection Agency which enabled the industry to continue its use of PFCs, while committing to a reduction program which targets the reduction of PFC emissions by 2010 to a level 10% below the level of emissions in 1995. Currently, SIA members are working with the Intergovernmental Panel on Climate Change (IPCC) to update the PFC emission inventory process to better reflect methods underway to reduce PFC emissions.
  - Alternative Chemistry: The global warming potential (GWP) of many PFCs used in semiconductor manufacturing is listed in Uses and Emissions of Liquid PFC Heat Transfer Fluids from the Electronics Sector (page 4). If possible, convert to a chemistry with a lower GWP. A paper given by Forth-Rite at the SEMATECH AEC/APC meeting in October 2007 documented their transition from C2F6 chemistry (with a GWP of ~9,200), to C3F8 (GWP of ~7,000).
- Install newer wet benches that reduce use of sulfuric acid (and UPW).
- Purchase high-precision and/or auto-dispense pumps for photoresist and sulfuric acid in cleaning sinks.
- Replace wet hydrofluoric acid immersion process with a wet spray process.
- Use aqueous slurry blast cleaning instead of solvent to clean dry-etch tools.
- Minimize water contamination of solvent wastes and acid wastes.
- Try incrementally more dilute bath chemistries.
- Review and optimize bath dump frequencies.
- Segregate N-methylpyrrolidinone (NMP) and other photoresist strippers for reuse and recycling. (In-house recycling may require investment in dedicated equipment.)
- Install separate piping and tank collection systems for spent isopropyl alcohol (IPA), sulfuric acid, and phosphoric acid to reduce chemical waste and maximize recycling [11].
- Replace wax with tape as a masking during mesa etch to reduce the solvent cleanup of wax [9].
- In solvent sink cup cleaning, install automatic in-place cup wash to extend the cup cleaning cycle [9].
- Use vent fog jet gun(s) to dispense solvents [9].
- Spin dry certain components instead of using IPA [9].
- When possible, use deionized water wipedown instead of IPA or acetone [9].

Other Fab & Facility Processes

- Extend polish pad life with a programmable conditioning unit that controls the pad uniformly [10].
- Use dry pumps on vacuum equipment to eliminate use of oil.
- Depending on the Class rating for the cleanroom, research whether cleanroom paper is really needed. (If standard paper can replace cleanroom paper, it costs less and may be recyclable).

Solid Waste & Recycling

- Maximize recycling of spent metal targets.
- If Tyvek clean suits are used, consider replacing with suits that can be laundered and reused, or search online for Tyvek recycling companies.
- See if there are other local uses for nitrile gloves from cleanrooms, such as auto shops. Nitrile gloves also contain a high Btu value, and incineration for energy may be a better option than landfilling.
- Although an emerging opportunity, there are ways to recycle silicon wafer scrap into usable mateiral for solar panels [12].
- Evaluate opportunities with suppliers to take back packaging materials, and/or implement reusable packaging systems with suppliers.
- Search material exchanges for companies who may want dewatered fluoride cakes, sulfuric acid, and phosphoric acid - these may be valuble feedstocks for another company. Post these streams on a material waste exchange for the region.
- Recycle plastic packaging (e.g., shrink wrap, packaging for laundered clean-room suits).

Fab Decommissioning and Decontamination

Consider hiring a qualified and experienced consultant or contractor to-

- Find recycling or reuse opportunities for as much building material, equipment, metals, inventory, wastes, and other materials as possible, by applying effective cleaning techniques, defensible verification sampling and analysis protocols, sound disassembly, and segregation. Ensure the contractor will comply with all regulations and will verify suitability of the final destination(s) of any reclaimed materials.
- Reduce the volume of unusable waste by dewatering, compressing, or other means.

The Future ....

What new techniques and technologies are required to enable the next wave of roadmap technology advances and environmental improvements?

The International Technology Roadmap for Semiconductors (ITRS) is an assessment of semiconductor technology requirements. The objective of the ITRS is to ensure advancements in the performance of integrated circuits. This assessment, called roadmapping, is a cooperative effort of the global industry manufacturers and suppliers, government organizations, consortia, and universities. In their roadmap, they report a list of challenges and needs for the industry, including environmental, health, and safety needs.

The Engineering Research Center for Environmentally Benign Semiconductor Manufacturing (ERC) is a multi-university research center leading the way to environmentally friendly semiconductor manufacturing.

The Semiconductor Industry Association's (SIA) Environment Committee is focusing on chemical issues with global significance. Several initiatives SIA is supporting - on behalf of the US semiconductor industry - include:

- Lead-free solder requirements and alternatives to leaded solder;
- Working to reduce greenhouse gas emissions;
- The European Chemicals Policy (REACH) and its potential impact on products sold in Europe;
- Adopted a Materials Composition Declaration Guideline in 2005 to standardize requirements posed to the industry with respect to hazardous constituents in semiconductor products, through the use of a uniform materials declaration;
- Participating in activities related to the potential regulation of PFAS and perfluorooctanoic acid and its salts (PFOA);
- Taking a leadership role in a new program to support China's State Environmental Protection Administration (SEPA) efforts to bring existing worldwide regulatory standards to China's electronics industry.

These groups, along with SEMATECH and various manufacturers, look toward the future working on new ways to improve efficiency and reduce wastes. For example, semiconductor processing in supercritical carbon dioxide (SCCO2) shows considerable promise for photoresist cleaning applications below 65 nm. And, Intel is exploring use of compound semiconductors with some materials (e.g., indium antimony), giving vastly better performance than silicon and reducing voltage.

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