Entegris

Chasing the Perfect Pattern

Employing the science of innovation to create repeatable and predictable lithography patterns

Introduction

While drinking a cup of coffee, have you ever wondered how the patterns in the veins of a leaf, the stripes of a zebra, or the spots on a peacock were created? Alan Turing did, and he answered the question when, in 1952, he mathematically defined the reaction-diffusion system. He defined the system as having components that could locally influence one another to create patterns that diffuse into a larger system. His model defined that patterns are both predictable *and* unique. While Turing is renowned for his pioneering work in computer science, this study outside his field of expertise formed the basis for applying logic to predict patterns in the natural world.[1]

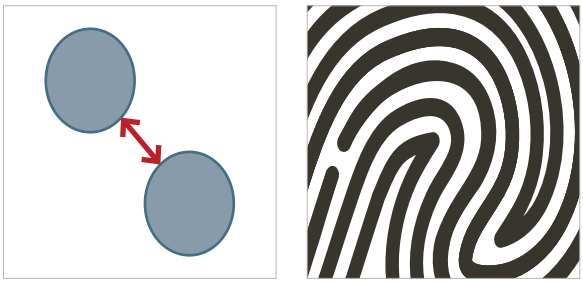


Figure 1. Turing patterns and the reaction-diffusion system.[2]

The human fingerprint is an extraordinary example of a natural pattern. Our fingerprints are formed by both a chemical and mechanical reaction to produce a completely unique identifier that lasts a lifetime. These unique patterns are both difficult to form and difficult to destroy. Unlike these natural patterns, photolithography patterns are more fallible. Modern semiconductor process engineers agonize over what might ruin their patterns, degrading performance or functionality of the circuit powering a smartphone, medical device, autonomous vehicle, or other device. This is particularly true as manufacturing processes become increasingly complex, transitioning from traditional lithography to double, triple, and quadruple patterning to extreme ultraviolet (EUV) lithography and directed self-assembly (DSA) pattern fabrication techniques.

Lithographers spend years evaluating patterning materials, pattern formation techniques, and process variables to precisely transfer designs into circuits that ultimately enhance and expand our lives. Control of these variables in the integrated circuit (IC) fab influence the quality of the pattern, and thus the potential impact and effectiveness of all electronic devices (Figure 2).

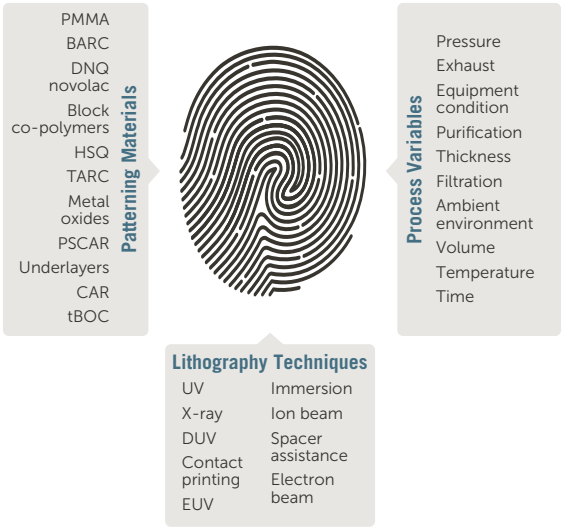


Figure 2. Aspects of photolithography pattern formation.

Optimizing for any of these variables is risky because there are complex chemical interactions at every step that can be interrupted by the smallest contaminants.

Pattern Flaw Sources

Semiconductor fabs lose yield to interruptions in their photolithography processes. These pattern flaws come from unexpected interactions between materials, such as a residue left behind from a previous process, atmospheric contamination, particularly if there is a process delay that leads to prolonged exposure, or a ripple effect from a buried material flaw, which leads to a flawed surface topology.

With 30 or more photolithography steps to produce a single device there are many, many opportunities for interruptions to show up. That is why fabs are constantly chasing after the process that will always produce a flawless, "perfect" pattern.

This process must account for each of the factors that can lead to unexpected patterns:

- Gas purity
- Liquid purity
- Tool cleanliness
- Ambient temperature and humidity
- Interactions between patterning materials
- Component compatibility

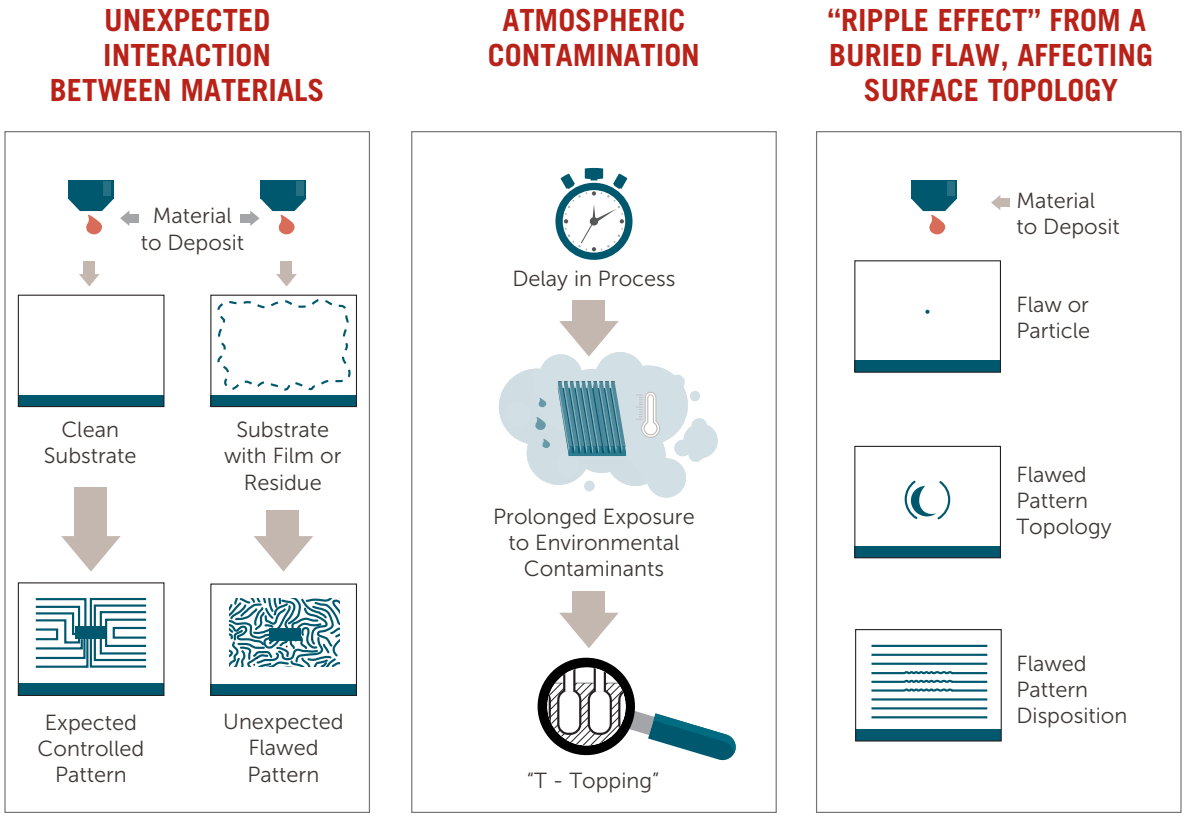


Figure 3. Sources of pattern flaws.

Contamination Control

Like all supply chains that rely on keeping a product whole, keeping a chemistry pristine from its manufacture until it contacts a wafer surface is practically impossible. Once a chemistry is bottled it must withstand air, land, and sea travel, not to mention a final journey through meters of tubing. Contamination of the chemistry can occur at any point in this journey.

To prevent contamination from transferring to the pattern, it is essential to combine purification and filtration techniques. Filtering for contaminants takes place during the many dispense steps of photostack materials. Purifying developer and rinse materials removes dissolved contaminants. The interdependencies of other process steps also play a major role in pattern quality. For example, a particle not removed in the CMP process may create a microscratch that creates a puddle at the next metal level, resulting in a shorted pattern.

It is essential to understand the chemical and physical processing variables that affect lithographic performance, and provide contamination-controlled solutions to help manage them. This is where Entegris can help.

Pattern Integrity Improvement Solutions

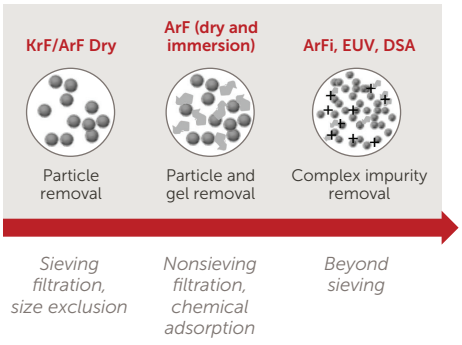
For more than 50 years, Entegris has developed broad capabilities in contamination control, high-purity materials, and materials handling. Entegris is a leader in controlling contaminants found in photoresists, solvents, process gases, air, and water that threaten integrated circuit yield, performance, and reliability. Our wide range of solutions help solve the challenges facing the lithography community by enabling lithographers to control system, material, and process variables.

OKTOLEX™ TAILORED MEMBRANE TECHNOLOGY

Oktolex™ membrane technology improves yield in ArF, KrF, and EUV lithography for Advanced Logic, DRAM, and 3D NAND Devices. Each Oktolex membrane is tailored to target the specific defect-causing contaminants of each unique photoresist or photochemical without having a negative impact on the chemical composition.

The Oktolex membrane technology is an effective tool to improve membrane wetting properties, filtration efficiency, and contaminant selectivity using both size exclusion and adsoprtion retention mechanisms.

This technology can be applied to various filters to achieve maximum contaminant removal and increase electronic device performance.



AZORA™ PHOTOCHEMICAL FILTERS

Azora™ photochemical filters offer best-in-class, contamination control in advanced photochemical and photo solvent applications. The unique, cage-like morphology from the polyimide material reduces on-wafer defectivity while providing superior flow rate. This filter technology innovation will enable users to meet critical process demands at sub-10 nm technology nodes.

PURASOL™ SN/SP SOLVENT PURIFIERS

Purasol SP/SN solvent purifiers can be especially effective at removing both dissolved and colloidal metal contaminants from a variety of ultrapure, polar, and nonpolar solvents used in photoresist applications. Using uniquely tailored membrane technology, these versatile purifiers reduce defects in critical process streams.

IMPACT® POINT-OF-DISPENSE PHOTOCHEMICAL FILTERS

Entegris offers best-in-class, ultraclean point-of-use Impact 8G photochemical filters for use in <28 nm lithography nodes, as well as robust, Impact 2 V2 filters ideal in 28 to 250 nm lithography nodes. Impact filters are optimized for various photoresists and solvents including ArF, KrF, BARC, top coat and pre-thinner, that deliver superior flow rate performance and reduced microbubble formation.

OPTIMIZER® PHOTOCHEMICAL FILTERS

Entegris offers various Optimizer point-of-dispense and point-of-tool filtration solutions specially design for organic solvent and aggressive solvent applications, as well as DI water, and aqueous developers. These advanced, ultraclean filters have superior contamination control capabilities at <20 to 250 nm lithography nodes.

INTELLIGEN® PHOTOCHEMICAL DISPENSE SYSTEMS

IntelliGen® photochemical dispense systems use state-of-the-art, two-stage dispense technology with a built-in Impact® 8G filter manifold to enable independent filtration and dispense. We offer dispense systems for low-, medium-, and high-viscosity fluids. Communication systems enable you to network your pumps for efficient process monitoring.

NOWPAK® LINER-BASED SYSTEM

Chemicals can be susceptible to particle contamination that may be introduced during chemical transport or transfer from bulk chemical containers to smaller drums or transportation packs. Mitigate this risk with our clean, contamination-controlled NOWPak liner-based bottle and canister system that helps protect valuable materials throughout the filling, transporting, and dispensing operations.

The NOWPak liner-based bottle system is designed for applications that require containment and safe transport of liquids that have high-purity requirements and/or are sensitive to the environment.

Deliver your critical process materials safely and efficiently with our NOWPak liner-based canister system. The pressurizable, reusable canister system promotes ultraclean chemical dispensing without direct contact between the chemical and drive gas, minimizing the risk of microbubbles and wafer defects.

EXTREME ULTRAVIOLET (EUV) RETICLE PODS

Without introducing unwanted contamination or physical damage, our EUV reticle pods provide reticles used for EUV lithography safe storage and protection during lithographic patterning, inspection, cleaning, and repair.

The dual-pod design offers an inner and outer pod to maintain a contamination-free environment. The EUV pod is compatible with lithography equipment and maintains a clean, dry atmosphere for the reticles both with and without pellicles.

GATEKEEPER® GAS PURIFIERS

GateKeeper® automatic regeneration gas purification systems remove gaseous contaminants down to the part-per-trillion level. They provide a cost-effective way to manage gas supply purity and prevent contamination in your process without damaging tools.

AIRBORNE MOLECULAR CONTAMINATION (AMC)

Control contaminants in the entire fab and protect both process equipment and wafers from the damaging effects of AMC with VaporSorb™ filters. Designed from the ground up for gas-phase contamination removal and low outgassing, these chemically-clean filters enable the latest technology nodes.

Why Entegris?

Lithographers in semiconductor manufacturing are tasked with the challenge of creating circuit patterns that meet production yield goals, parametric performance targets, and long-term reliability requirements in the electronic devices our digital lives depend upon. The same chip design that was manufactured a year ago may have different performance requirements today, as well as new process variables. Fab engineers must stay ahead of the game by continuously considering variables and changes to their process area that can impact the entire manufacturing system. Without controls in place, defects that occur during the patterning process can lead to device failures, impacting yield and the bottom line.

With our broad portfolio of microcontamination control, advanced materials handling, specialty chemicals, and engineered materials, we are uniquely positioned to help customers face industry challenges and meet consumer and business demands at lower costs. Ongoing investments in technology, robust manufacturing, and supply-chain capabilities make us a proven, trusted partner. Our global infrastructure, technology portfolio, and operational excellence are unmatched by the competition. Investments in newer and purer materials enable us to provide the cleanest most reliable polymer solutions to protect your overall process quality and efficiency.

Proven Quality and Performance

At Entegris, we have a relentless commitment to operational excellence. Our desire to be a relevant, trusted, technology partner drives us to identify complex problems critical to our customers, quickly develop a working solution, and move from pilot to high volume manufacture (HVM) seamlessly in record time. In our pursuit to be the best performing operational platform in our market, we have aligned our Quality systems to industry requirements and provide capabilities to meet/exceed customer expectations.

Motivated to supply consistent and predictable product performance to customers, reduce quality excursions, and minimize scrap, we have invested in advanced statistical process control (SPC) systems across all our manufacturing sites around the world. Integrated SPC provides immediate recognition of special variation causes enabling faster problem resolution, providing early quality alerts, and allowing easier decision-making to ensure process consistency and minimize product variation.

Customer requirements are demanding so we are always striving for practical, quantifiable, sustainable continuous improvement. By employing lean Six Sigma techniques and tools, we identify and remove the causes of process defects that enable us to improve quality. By minimizing variability in manufacturing and business processes, our defective parts per million (DPPM) performance has also dramatically improved.

Ensuring product performance standards are met, proven techniques such as ISO 9001 certified manufacturing sites, documentation control, and quality testing are utilized. Each manufacturing capability has been developed, tested, and improved to create pure, durable, consistent, and reliable products.

With nearly 2,000 issued U.S. and foreign patents, we have the expertise to develop process knowledge and products that enable innovation and efficiencies. Combining advanced engineering and design expertise with tools such as Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD), and MoldFlow® analysis and modeling enables us to optimize product design and speed technological advancements. In addition to innovative design, we also use R&D and quality lab analysis and testing capabilities to develop dependable solutions.

QUALITY TESTING

- Vibration and shock
- Safety and industry standardization
- Trace metals
- Electrostatic charge

PERFORMANCE TESTING

- Particle testing
- Flow rate optimization
- Ion chromatography
- Failure analysis

We are dedicated to developing the purest products that assist in your goal for zero defects, and gain you the greatest operational efficiency.

Sales and Applications Support

Entegris continually invests in expanding analytical and technology center capability globally. Our global direct sales team, sales channel partners, local applications engineers, and world-class customer service give you the support and expertise to solve your most difficult problems. This intimacy allows us to better understand your needs through direct feedback and roadmap sharing. By aligning our materials science, engineering, and R&D initiatives, we can develop indispensable contamination-control and high-performance solutions to solve your roadmap challenges.

eCommerce

Entegris has deployed an online purchasing and transaction management system that provides full eCommerce capabilities for our customers. For us, eCommerce is more than just a shopping cart, but rather a robust technology platform designed to deepen customer engagement and deliver value at every touchpoint. Driven by our customers' desire for lower costs, improved accuracy, and overall increased satisfaction, we have implemented state-of-the-art tools and full integration with our back-end systems to allow automated access to information, accelerated and easier transactions, and a convenient means to collaborate and do business.

Logistics Expertise

To support your logistics requirements, we manage the infrastructure and service provider partnerships, offering broad capabilities to ensure your supply chain door to door. Providing import processing, insurance, and transportation, we bring expertise in air, ocean, LTL, intermodal, small package, and hazardous shipments. You will receive in-house, regional logistic support in the U.S., Germany, Israel, South Korea, Japan, Taiwan, Malaysia, Singapore, and China. And our top-ranked freight partners provide import processing services and transportation to all the remaining locations around the globe.

Our global infrastructure with local R&D, manufacturing, and support focuses on specific customer needs throughout the world.

Corporate Social Responsibility

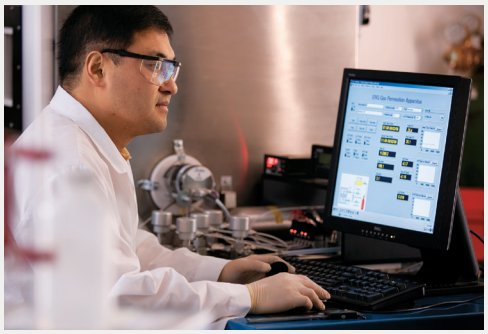
Entegris has a strong commitment to Corporate Social Responsibility and seeks to create value responsibly. We balance the demands of doing business with the need to protect the environment and its resources and to ensure the health and safety of our employees, customers, and the communities in which we work and live.

We are committed to applying these principles to product stewardship, environmental protection, employee health and safety, and plant security. In addition, we are committed to aligning our operations with the Electronic Industry Code of Conduct (EICC). Our new product development process is mindful of Department for Education (DfE) principles to ensure new designs meet customer and governmental material content restrictions, such as PFOA elimination, conflict minerals, and banned substances. We also work on developing strong relationships with our suppliers to ensure their commitment to EICC principles and product material content.

Experience You Can Count On

Contamination control is critical to your manufacturing processes and has a direct impact on production yields, product reliability, and operational efficiency. We focus on understanding your processes, sources of contamination, and on developing material-enabled solutions to ensure the cleanliness and integrity of those processes. We invest in identifying where impurities may be introduced, and take corrective actions to prevent them, which is a critical first step in contamination reduction efforts.

Trust us to support your vital applications and goal for zero defects by providing the highest purity, highest quality, and most robust products. Our reliable, cost-effective liquid filters and purifiers provide a line of defense to prevent defect-causing contaminants in current and new technology nodes.



Our ability to innovate new technologies is based on our deep knowledge of materials science and analytics.

References

[1] B. Keim, *Alan Turing's Patterns in Nature, and Beyond*, Wired, Science Section, Feb. 2, 2011, https://www.wired.com/2011/02/turing-patterns/

[2] https://www.sciencehistory.org/distillations/magazine/patterning-the-world-the-rise-of-chemically-amplified-photoresists

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