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NEW
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ACCESS TO
MIKRONIEK

- THEME: MICROMANUFACTURING
- BRINGING PARTICLE CONTAMINATION TO LIGHT
- MATERIAL CHALLENGES IN MANUFACTURING AND CLEANLINESS
- ORDER OF FRICTIONS AND STIFFNESSES MATTERS FOR VIRTUAL PLAY

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The cover image (3D cut of the Large Hadron Collider dipole at CERN) is courtesy of Daniel Dominguez (CERN). Read the article on page 15 ff.

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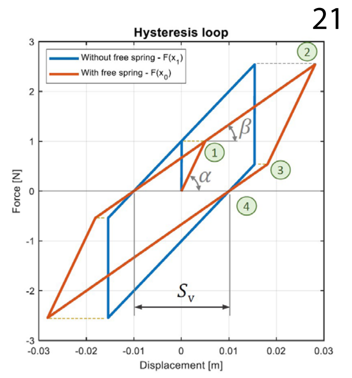

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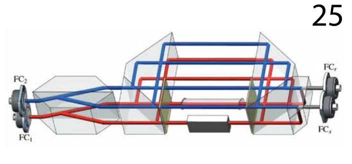

FEATURES

UNLOCKING HIGH PRECISION

In precision manufacturing, photochemical etching stands out as a versatile and efficient technique that offers unparalleled precision and flexibility. Photochemical etching, also known as photochemical machining, is a subtractive manufacturing process that utilises chemical etchants to remove metal, creating high-precision metal parts. This process allows the achievement of tight tolerances and fine detail that are often unachievable with traditional machining methods. A variety of materials can be handled, including stainless steel, copper, titanium, brass, gold, molybdenum and nickel alloys. This versatility ensures that the specific requirements are met of various industries, from aerospace and semiconductor to the medical device industry.

One of the key advantages of the photochemical etching process is its ability to produce complex geometries without the need for expensive tooling. This not only reduces production costs but also shortens lead times, allowing for rapid prototyping and quick turnaround on production runs. Typically, metal can be etched from 0.003 up to 1.5 mm thick, providing flexibility in design and application. Additionally, parts can be produced with intricate patterns, fine meshes, making it ideal for components that require high precision and detail.

The benefits of photochemical etching are manifold, making it a preferred choice for manufacturers seeking efficiency, precision and cost-effectiveness. Unlike traditional machining, which can be labour-intensive and expensive, photochemical etching is a highly efficient process that can produce high volumes of parts with consistent quality. This makes it ideal for both small and large production runs, offering significant cost savings without compromising on quality.

One of the most significant advantages of the etching process may be its ability to produce burr-free and stress-free parts. Traditional machining methods often leave burrs and induce stress in the material, which can compromise the integrity and performance of the final product. Furthermore, photochemical etching offers unparalleled design flexibility. Complex designs and intricate details that would be impossible or prohibitively expensive to achieve with other manufacturing methods are easily attainable. This opens up a world of possibilities for designers and engineers, allowing them to innovate and push the boundaries of what is possible.

Photochemical etching solutions may be pivotal in a wide range of industries, each with its unique set of requirements and challenges. In the aerospace industry, where precision and reliability are paramount, etched components play a crucial role in ensuring the safety and performance of aircraft. Examples include parts such as fuel system components, heat exchangers, and EMI/RFI shielding that meet the stringent standards of the industry.

In the medical field, the etching process is used to manufacture components that require exacting standards, ensuring the safety and performance of medical devices. Parts for surgical instruments, implants and diagnostic equipment, are all designed and etched to meet the rigorous demands of the healthcare industry.

The electronics industry also benefits greatly from photochemical etching, with the production of complex connectors, lead frames, and RF shielding components that are essential for the performance and reliability of electronic devices. The creation of fine features and complex patterns makes the process ideal for the miniaturisation and high-density requirements of modern electronics.

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BRINGING PARTICLES TO LIGHT

Particle contamination monitoring and cleanliness control are fundamental to micromanufacturing processes across diverse industries to achieve cost-effective production of high-quality and reliable microscale devices and components. However, practice learns that producing in an ISO class cleanroom does not automatically guarantee a clean manufacturing process or product. By implementing cleanroom environments in combination with continuous particle deposition monitoring, manufacturers can design closed-loop clean process validation and process improvement procedures to prevent particle defects that lead to yield losses. This article introduces technology for cleanroom validation and qualification on the workspace where it really matters, using a Particle Fallout Scanner (PFS) that continuously measures particles falling onto critical target surfaces.

YOLANDA VILLANUEVA-PALERO AND NIELS LEIBBRANDT

Introduction

Microtechnology drives many technological advancements and is enabled by the production of highly precise and miniaturised components and devices on (sub)micrometer and smaller scales. Its applications span across many high-tech industries, pushing the boundaries of what is possible with modern manufacturing techniques.

Particle deposition in cleanrooms is a critical concern in microtechnology manufacturing, as even minute contaminants can significantly affect the performance of microscale devices and cause considerable yield losses. The mechanisms by which particles (visible and invisble, see Figure 1) are generated, transported and deposited in cleanrooms involve various physical and environmental factors. Understanding and continuous quantitative monitoring of these mechanisms are required to develop effective particle contamination control strategies, provide direct feedback to cleanroom operators and maintain cleanliness of the manufactured products [1, 2].

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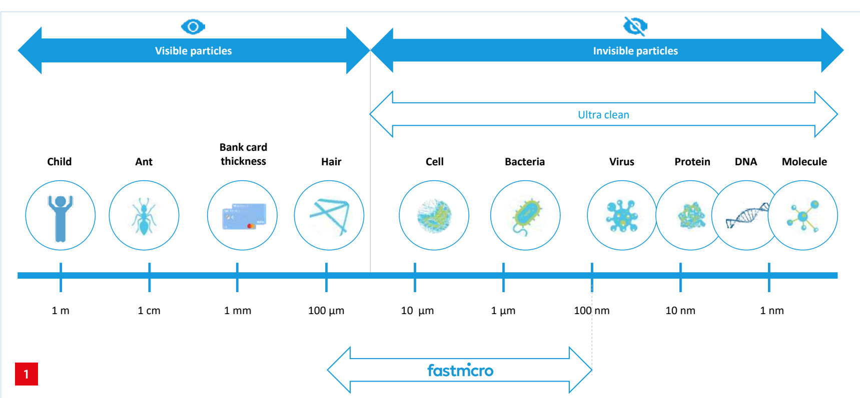

Visible and invisible particles on the dimensional scale. (Source: H.D. Felton, "Long-term measurement of ultrafine particles in the Urban and Rural Environment", 2017)

This article introduces the case for cleanroom qualification and process monitoring on the workplace itself, according to the standard ISO 14644-17: Particle deposition rate applications. This is achieved by using a Particle Fallout Scanner that continuously measures the particles falling onto critical target surfaces at the same particle-size levels down to 0.5 µm as those that apply for the Airborne Particles Counter (APC) measurements according to the ISO 14644-1 cleanroom standard.

Cleanroom standards in monitoring particle cleanliness

In micromanufacturing, cleanrooms are indispensable as they provide the contamination-controlled environment necessary to produce microscale devices and components. They enhance production yield, reliability and performance, while supporting advanced manufacturing techniques and compliance with stringent industry standards.

Effective management of particle deposition in cleanrooms involves understanding and controlling the various mechanisms that cause particles to settle on surfaces. By implementing comprehensive contamination control strategies, such as maintaining cleanroom airflow patterns, using appropriate filtration systems, minimising electrostatic charges, and following strict cleanroom operator procedures, manufacturers can significantly reduce the risk of particle contamination.

Unfortunately, particle contamination cannot be completely prevented. The air may be clean, but the contamination sources can come from the people, workspace and workflow in the cleanroom. A step closer to prevention is real-time monitoring and detection on critical surfaces. Parameters such as surface cleanliness of product, tools and equipment, media and environment as well as air cleanliness and particle deposition rate should be monitored.

The International Organization for Standardization (ISO) provides an essential tool for defining and controlling the cleanliness levels inside a cleanroom.
ISO 14644 is a globally recognised standard that provides guidelines for the classification of cleanliness in cleanrooms and controlled environments. This standard establishes uniform criteria for allowable maximum particle concentrations based on particle size. It outlines methods for monitoring, testing and maintaining cleanroom environments to ensure compliance with specified cleanliness levels [3, 4].
While ISO 14644-1 serves as the foundational standard for cleanroom and controlled environment classifications, defining particle cleanliness levels based on airborne particulate contamination, ISO 14644-9 establishes the classification of surface cleanliness by particle concentration (SCP) for a size between 0.05 µm and 500 µm.
The fairly recent ISO 14644-17 introduces an important parameter, the particle deposition rate (PDR) level, that can be used to determine particle contamination risk on critical surfaces and predict the product cleanliness grade.

By adhering to these standards, manufacturers can set the quality norms to optimise their production environment, equipment and processes, to enhance product quality and mitigate particle contamination risks, ultimately achieving higher production yield and improving their environmental impact.

Importance of particle deposition control and monitoring

Particle contamination control and monitoring play crucial roles in micromanufacturing across various industries where precision, reliability and cleanliness are paramount. Applications include:

1. Semiconductor manufacturing
   In wafer fabrication, even tiny particles can lead to defects in integrated circuits. Particle deposition control is essential during lithography, etching and deposition processes to ensure the integrity of patterns and features on wafers.
   In cleanroom operation, particle monitoring is critical for maintaining cleanroom environments in semiconductor fabs. Continuous monitoring enables identifying particle bursts and trigger contamination alarms, and ensuring production process compliance according to cleanliness standards.
2. Biomedical devices and implants production
   Particle control is critical in the production of biomedical implants, such as pacemakers and orthopaedic implants, to prevent contamination that could lead to device failure or adverse biological reactions in patients. Moreover, in micromanufacturing techniques used to produce precise drug-delivery systems, such as microneedles and microcapsules, particle monitoring ensures the cleanliness and integrity of these systems for safe and effective drug delivery.
3. Optoelectronics and photonics
   Particle control is essential in the production of optical components, such as lenses, mirrors and fibre optics, to maintain optical clarity and performance. In microscale optical devices, particle deposition monitoring ensures the cleanliness of components used in telecommunications, sensing and imaging applications, which prevents performance degradation due to contamination.
4. Aerospace and mobility
   Micromanufacturing is used to produce miniature components for aerospace and mobility applications, including sensors, actuators, fuel injectors and microelectronics. Particle control ensures reliability and functionality of these components in application areas where possible malfunctions cannot be tolerated.

Particle deposition rate monitoring for cleanliness control

Particle deposition rate monitoring is used to detect, measure and analyse particulate contamination on surfaces within cleanroom environments. It plays a crucial role in maintaining and verifying the cleanliness standards required in micromanufacturing and other high-precision industries by monitoring deposition of particles over time.

Key attributes

1. Detection and measurement
   - Surface monitoring: assessing particle contamination on various surfaces, including workbenches, equipment and critical production areas.
   - Particle counting: counting the number of particles deposited on a defined surface area, providing data on contamination levels.
   - Size distribution: measuring and classifying particles based on size, typically ranging from a few nanometers to several micrometers.
2. Data collection and analysis
   - Quantitative data: providing quantitative data on the number and size of particles, which is essential for maintaining cleanroom standards.
   - Trend analysis: continuously or periodically monitoring surfaces, which helps to identify trends in particle deposition, enabling proactive contamination control.
3. Automation and integration
   - Automated scanning: allowing for consistent and repeatable measurements without manual intervention.
   - Data logging and reporting: using software for data logging, analysis and reporting, which helps in maintaining records for compliance and quality control.

PCE FROM PCB TO PCR

The photochemical etching (PCE) process, distinguished for its unparalleled precision and versatility, is revolutionising traditional metalworking methods, which often compromise the intricate detailing and material integrity essential in modern applications. This article looks at developments to enhance the PCE process made by micrometal. These enlarge the potential of this manufacturing technology in various high-tech industries.

JOCHEN KERN

Introducing PCE

The PCE process starts with the application of a light-sensitive resist to a metal surface. This metal sheet is then exposed to ultraviolet light, imprinting a precise design based on a photomask. The exposed areas, now vulnerable to the etching chemicals, undergo a controlled removal process, meticulously stripping away unwanted material. This method starkly contrasts with traditional fabrication techniques like stamping, laser cutting, or machining, which can compromise the metal's integrity through mechanical stress or heat distortion.

The precision of PCE lies in its ability to produce extremely fine features, often down to micrometer dimensions. This is particularly advantageous for complex designs where traditional methods falter due to their mechanical or thermal limitations. The process is able to maintain consistency across large production runs, which further elevates its appeal in industries where uniformity is paramount. Figure 1 shows examples of PCE-produced products.

The (digital or glass) tooling is inexpensive to produce, and therefore inexpensive to change even up to a few minutes before manufacturing commences. Unlike the case of stamping, the cost of digital tooling does not increase with part complexity, which stimulates innovation, as designers focus on optimised part functionality rather than cost. As PCE does not use hard tools, distortion and stress are eliminated. The flexibility of the PCE tooling and production process supports rapid prototyping and customisation, enabling manufacturers to experiment with new designs and concepts more freely.

PCE offers several advantages over conventional machining techniques, including the ability to produce components without inducing stress or altering material properties. This aspect is particularly important for semiconductor, medical and other applications where the integrity of the material can significantly impact device performance. In addition, components produced are absolutely flat, with a clean surface and no burrs, as the metal is dissolved away uniformly and evenly until the desired geometries are achieved; burr-free components are a critical requirement in many high-precision applications.

Precision and tolerances

In metal fabrication, achieving high precision and tight tolerances is often synonymous with complexity and increased costs. However, PCE defies this norm by offering

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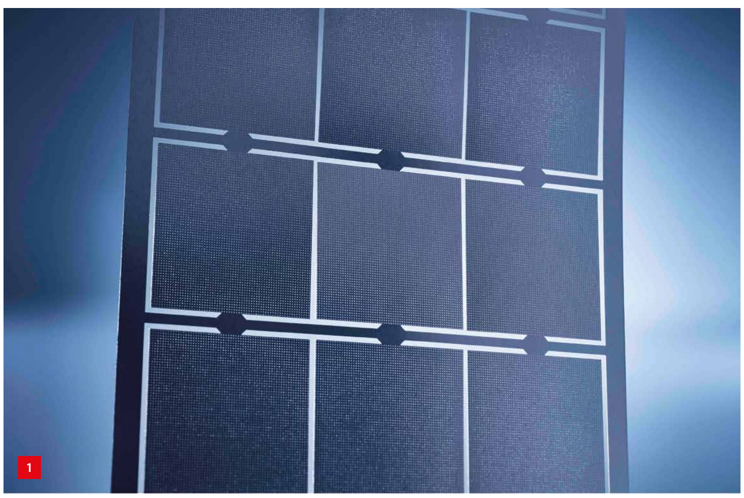

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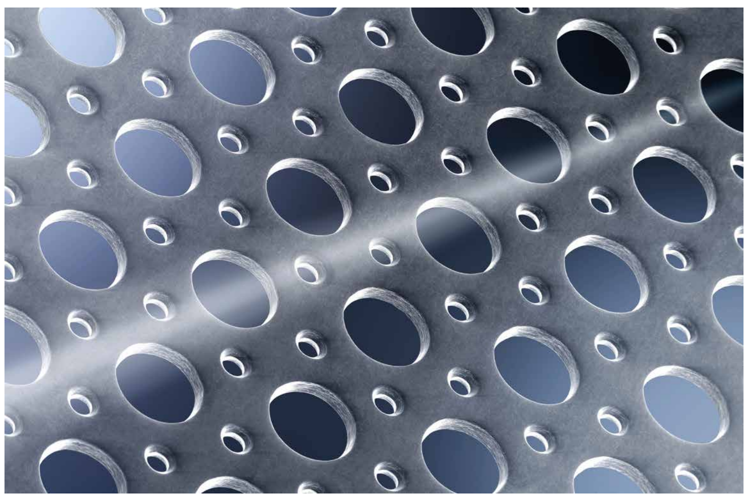

Examples of photochemically etched filters. Typical holes are 40 µm diameter in 50 µm thick material.

exceptional precision at a fraction of the cost and time involved in conventional methods. The accuracy of PCE is not just in the dimensions it can achieve but also in its ability to maintain these tolerances consistently across production batches.

One of the most significant advantages of PCE is its material-agnostic nature. The process can be applied to a wide range of metals and alloys, including those that are traditionally challenging to machine, such as titanium, nickel alloys, and stainless steel. Moreover, PCE is known for its ability to maintain the intrinsic properties of the metal, such as hardness and grain structure, which can be altered or degraded in other fabrication processes. The non-contact nature of PCE ensures that the structural integrity and surface finish of the metal are preserved.

Tolerances as low as ±7 μm can be achieved, depending upon the material and its thickness. Micrometal can process stainless steel, nickel, and copper alloys up to 400 μm thick with feature sizes down to 80% of material thickness and tolerances of ± 10% of thickness. Stainless steel, nickel, and copper above 400 μm thickness, and other materials such as tin, aluminium, silver, gold, molybdenum and titanium can have feature sizes down to 120% of material thickness with tolerances of ± 10% of thickness. Traditional PCE is only able to achieve 100 μm feature sizes and a minimum hole diameter of 100-200% material thickness. The maximum material thickness that can be etched at micrometal is 1.5 mm.

Design innovation

Design engineers are increasingly turning to PCE as they are under pressure to create smaller and increasingly complex precision metal components. For example, many flexure spring designers and designers of intricate metal components specify PCE due to its burr- and stress-free nature, zero tool wear and speed of supply.

2

A surgical instrument produced by PCE with control of the etch cusp to create the characteristically profiled sharp cutting edge.

One example of PCE's design freedom is the inherent edge 'cusp' that can be introduced during the manufacturing process, i.e. the curved 'phase' between the two surfaces of the material when different photomask tools are used top and bottom. By controlling etch cusp a range of profiles can be introduced allowing the manufacture of sharp cutting edges, such as those used in medical blades (Figure 2), or conical openings, such as those used to direct fluid flow in filtration meshes.

Advanced technologies

Micrometal has redefined the boundaries of PCE by integrating advanced technologies such as glass tooling, liquid resist, and a continuous process flow. These advancements have not only enhanced the precision and efficiency of metal etching but also opened new possibilities in various high-tech industries.

Glass tooling

Micrometal's glass photo tooling technology can deliver tolerances in the range of 1-2 μm as it is printed at 100k dpi, nearly ten times the resolution of conventional film-based photomasks. Glass tools, compared to conventional film tools, last a lifetime and are impervious to fading, temperature, humidity and other environmental factors. This means that every part is identical, every time, for the life of the project.

The use of glass as a tooling material ensures a higher degree of transparency and superior alignment capabilities, which is essential for intricate designs. The large size of glass photo templates (up to 760 mm long and 280 mm wide) allows for a broad design area. This also contributes to maintaining high accuracy over extensive etching areas. For instance, over a 700 mm etch span, a 5-10 μm tolerance can be achieved.

Liquid resist

Another cornerstone of micrometal's approach is its use of liquid resist in the PCE process. Unlike traditional hard masks and dry film resists, liquid resist can be applied precisely and smoothly in varying thicknesses, allowing for greater flexibility and control over the etching process. This adaptability is crucial when working with complex or uneven surfaces, ensuring uniform coverage and consistent etching across the entire component.

The liquid resist used by micrometal is formulated to offer finer resolution, while it also contributes to the overall efficiency of the process, reducing waste and improving the turnaround time for high-volume production runs.