Photochemical machining

I.1 Introduction - Definition

Photochemical **machining** (**PCM**), also known as photochemical cutting, chemical milling or photochemical etching, is a cost-effective manufacturing process used to produce metal parts with complex geometries with high precision (see Figure 1). Photochemical machining was born in the 1950s with **photolithography** for printed circuits, combining the application of a photosensitive resin and chemical etching to create metal parts.

Photolithography is a process used to transfer a geometric pattern onto a substrate by projecting light through a mask using a photosensitive resin (see Figure 1).

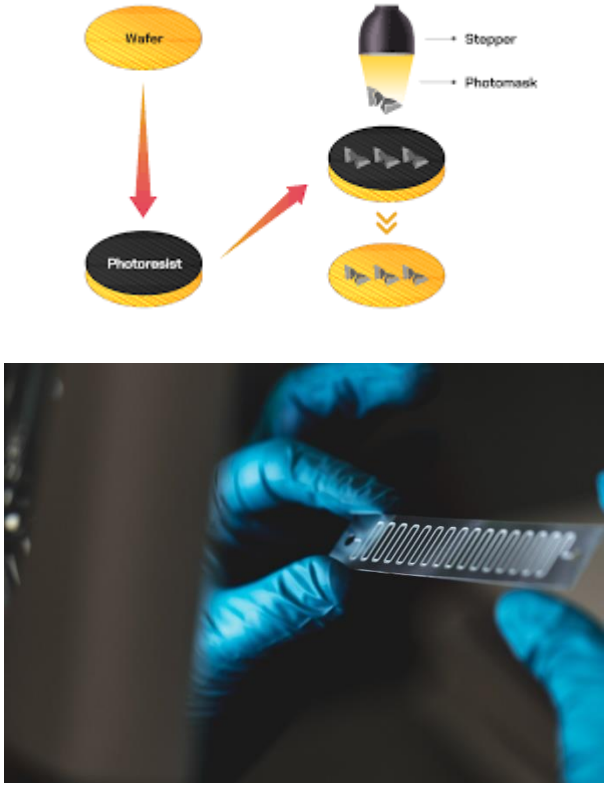


FIG. 1 Photochemical machining

Photochemical machining combines chemical cutting and photographic techniques to produce precise parts that would be difficult, impossible, to manufacture using traditional mechanical methods. In this work, we will also explore the advantages and limitations of photochemical machining, as well as its applications in various industries.

I.2 Steps in the process

The first and certainly one of the most important steps is the **preparation of the material**. The plates pass successively through several **surface preparation** baths (degreasing, deoxidation of the base substrate) in order to optimize the adhesion and to prepare the material correctly for the chemical etching step.

The next **step is the application of the photosensitive coating**. For this there are two main techniques which are:

- Deep-coating which allows the installation of liquid resin for applications which generally require greater precision.

- Hot lamination of solid resin.

Once the material has been coated, the plate is **exposed to UV light** through a photo tool comprising the negative of the part to be cut.

UV radiation will have the effect of polymerizing the photosensitive resin. One therefore finds oneself with a hard part, called to resist the etching agent which will be used subsequently to cut the parts, and a non-polymerized part of the resin which will have to be removed.

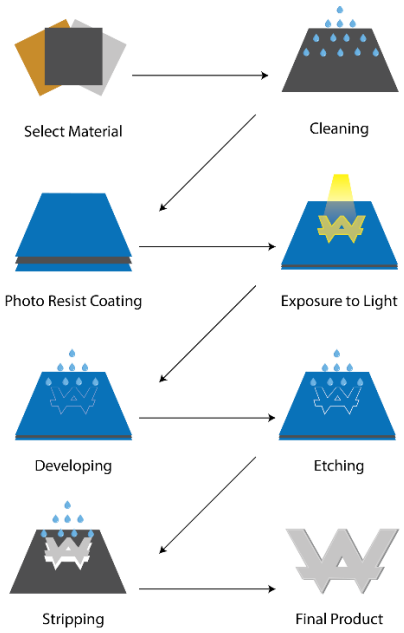
Then, the plates are **immersed in a development solution**, which eliminates the non-hardened parts of the photosensitive coating, thus revealing the metal zones that will be etched.

These three rolling, exposure and development operations are carried out in the clean room to protect the production of particles and dust that could leave artifacts on the plates during exposure to UV light. It is also a matter of protecting the plates from natural UV light emanating from the sun.

I.3 Photochemical machining process

The photochemical machining process begins with the application of a photosensitive resin to a sheet of metal. The photosensitive resin is then exposed to ultraviolet light via a mask with motifs called a photographic mask. The unexposed zones of the photosensitive resin are then developed and removed before the sheet is vaporized with an etching agent - generally ferric chloride - which chemically dissolves the exposed metallic zones.

I.3.1 What is photochemical machining?



This process consists in using a photosensitive resin and etching agents to selectively remove the material from a metal sheet:

- Preparation of the sheet of metal: a thin sheet of metal (usually stainless steel, brass or copper) is carefully cleaned and covered with a photosensitive material.

Photochemical machining

Prepared by Dr. ROUABHI Youcef

- Exposure to light: The coated sheet is then exposed to light through a photographic tool or mask. The zones not exposed to light remain covered with photosensitive resin.
- Development: After exposure, the metal sheet is developed, which makes it possible to eliminate the unexposed photosensitive resin. The metal surface is thus exposed according to the desired pattern.
- Etching: the sheet is then sprayed with an etching agent which reacts chemically with the exposed metal zones, dissolving them or etching them selectively. The remaining photosensitive resin protects the areas that must remain intact.
- Pickling: After etching, the remaining photosensitive resin is removed, leaving the final metal part, etched accurately.

Photochemical machining makes it possible to manufacture parts in almost all metals, but also in certain materials, such as, for example, glass or polyimide. But stainless steels, ferrous metals and copper metals account for the majority of production in photochemical machining. Panels with a thickness of a few microns to 2 mm are used, mainly in industry. Applied to materials of small thickness (less than 0.1mm) and combined with the precision of photolithography, this method ensures the production of parts with very complex geometric shapes and tight tolerances. Generally, the tolerances given for parts in photochemical machining are +/- 10% of the thickness of the machined material. Technical details: Material thickness (t): 0.005 mm - 2 mm Tolerance: depending on the thickness of the material, in general: +/- 10 to 20% of the thickness of the material Smaller aperture: $t \geq 0.1$ mm $\Rightarrow \emptyset$ minimum = 0.8 to 1 x $t \leq 0.1$ mm $\Rightarrow \emptyset$ minimum = 1 to 1.2 x t Minimum internal radius = 0.5 x t

I.4 Advantages of photochemical machining

Unlike traditional mechanical methods, which can create burrs or deformations on the edges of parts, photochemical cutting uses a chemical process to accurately remove the metal from the surface of the material. This results in sharp edges, without burrs or mechanical stresses capable of weakening the part.

The photochemical cutting process also makes it possible to create very fine characteristics and patterns from a wide range of metals and alloys. Indeed, the process is entirely chemical and the photosensitive resin acts as a mask, which allows a very precise control of the size, shape and tolerances of the final part.

I.5 Drawbacks of photochemical machining

Although photochemical cutting offers many advantages, such as any metal machining process, it also has certain limitations. PCM is more suitable for relatively thin materials, which are generally less than 2.5 mm thick. This process is therefore not necessarily suitable for the production of thicker parts.

The size of parts that can be produced using the ECHP is also limited. Indeed, the size of the sheet is limited by the width of the chemical cutting machine used.

Photochemical machining

Prepared by Dr. ROUABHI Youcef

Although photochemical machining (PCM) is a cost-effective and efficient process for the rapid and cost-effective production of high-precision parts with complex geometry, it is not necessarily suitable for the production of three-dimensional or simpler parts on a very large scale. In fact, traditional processes for machining sheet metal generally offer more favourable production times and unit costs.

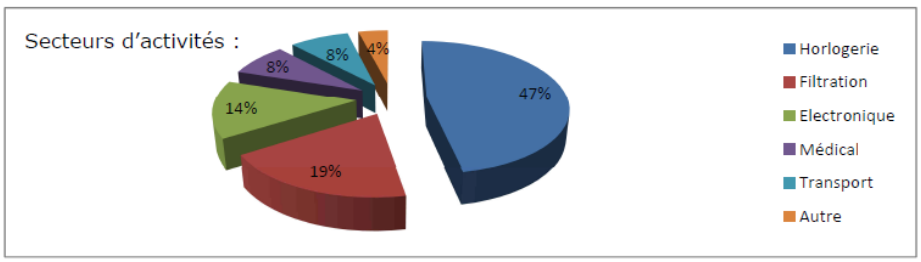
I.6 Types of metals commonly used

Although a variety of metals can be processed photochemically, some common metals include:

- Stainless Steel: Photochemical machining is often used for precision machining of stainless steel components, such as medical device components.
- Copper: Copper is another metal commonly machined according to this process. It is widely used in electronic and electrical applications.
- Brass, an alloy of copper and zinc, is also suitable for photochemical machining.

These metals are chosen according to their compatibility with the photosensitive resin and the etching chemicals used in the process. Specific requirements may vary depending on the application and desired characteristics of the engraved components.

I.7 Application of photochemical machining



Photochemical machining offers a wide range of high-precision applications for metal components:

- Precision metal shims
- Flat springs
- Connection grids
- Electrical connectors
- EMI armour
- Filters, fluid flow plates
- Implantable devices

These components can be produced with exceptional precision and consistency, without requiring expensive tooling. Photochemical machining is advantageous for producing complex and detailed parts with high precision, which makes it suitable for applications such as,**medical devices**, electronic **components**and precision parts for **aerospace andautomotive** industries. It is a cost-effective and flexible method for creating complex metal components in large or small production series.

Photochemical machining

Prepared by Dr. ROUABHI Youcef

I.8 Conclusion

Photochemical machining is an efficient and economical process that allows the rapid and cost-effective production of high-precision parts with complex geometries. It has several advantages, such as precision, versatility of materials and applications, low costs, short delays and cleanliness of the machining results. However, the process has certain limitations, particularly in terms of material thickness, size and scalability for simpler designs. Nevertheless, it remains an excellent option for many industries that wish to manufacture precise metal components of great geometric complexity.