

CONSIDERATIONS ABOUT COOPER ETCHING BY PHOTOCHEMICAL MACHINING

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ABSTRACT. In this paper is studied the copper etching by Photochemical Machining (PCM). The work –piece material is shaped by using a strong chemical solution to dissolve the metallic material that was selectively exposed to machine areas using photographic techniques. Copper etching is the main process in the printed circuit board manufacturing. Ferric chloride (FeCl_3) and copper chloride (CuCl_2) are the best etch agents for copper and copper alloys. The etching efficiency was analyzed by comparing the etch rate for different concentrations of the two etch agents.

KEYWORDS: photochemical machining, photo-resist, etchant, etch rate

1. INTRODUCTION

Photochemical machining (PCM) is a non conventional machining process that uses photographic and chemical etching techniques. The action of the chemical etching agent is represented by the dissolution of the surface from the processed object.

The photoetching process consist from protecting the metal surface with a mask called photoresist that will allow the chemical erosion of the unprotected metal. The photoresist coated work-piece is exposed to ultraviolet light and the selected areas are dissolved with a chemical agent by chemical etching technique

The process has some advantages such as low tool cost, independent on the physical and mechanical properties of materials and high precision. The disadvantages of the process are the workpiece material thickness limitation (up to 2 mm for most of the materials, 6 mm for copper).

Copper etching is applied in the printed circuit board manufacturing for electronics application. The most used etchant is ferric chloride (FeCl_3) and it is still used as an etchant in some production lines.

In this paper was achieved a comparative study between etching agents FeCl_3 and CuCl_2 for copper and copper alloys. The efficiency of the etching process was established depending on the effect of etchant concentration on the etch rate of cooper. Etching is the main machining step in chemical and photochemical machining process [5].

Photochemical etching (PCM) is applied for the manufacturing of thin, flat and complex parts (lead frames, sensors, heat plates, printed circuit boards, etc.) in electronics and in the decorative industries in the past thirty years (fig.1)



Fig.1 Work pieces obtained by photochemical machining

2 PHOTOCHEMICAL MACHINING PROCESS

The photochemical machining process has the following stages: cleaning of the metal (copper) coating the work-piece surface with photoresist, photoresist processing, exposing to ultraviolet light (UV), etching with the chemical agent of the unprotected areas, photoresist removing. These stages are represented in figure 2.

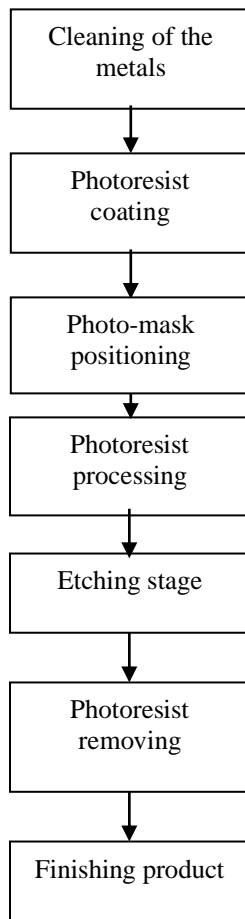


Fig. 2. Scheme of the etching process

The work piece is cleaned for removing the dust, grease and impurities that hinder a good adherence of the photoresist on the metal surface. After that is applied the photoresist which is dried and exposed to a light source (UV) on both sides.

After that the work-piece is developed and the photosensible substance that has not polymerized is washed. On the metallic surface remains the protection offered by the polymerized photoresist and the etchant solution can attack the unprotected metal and dissolve it.

The photochemical machining assures the obtaining with a high precision of the printed boards but has the disadvantage of a high price and the necessity that the entire copper surface is covered with photosensible substance. In the same time the process requires special photographic techniques.

The selected etchant for workpiece material is heated up to 50-55°C depending on the spray machine allowance and etchant is sprayed from nozzles onto the workpiece surface.

The etching process of a copper work-piece from both sides is presented in figure 3.

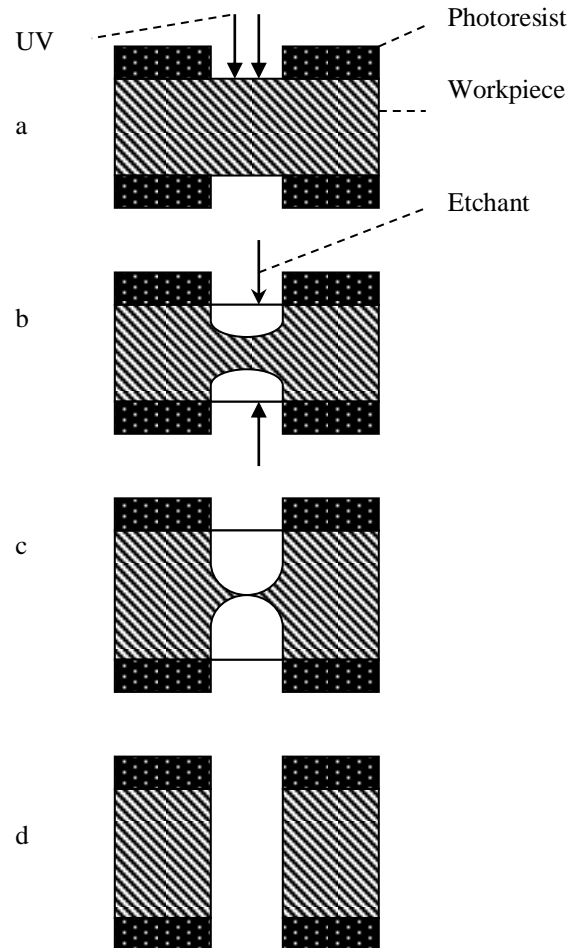


Fig. 3: Metal etching on both sides by photochemical machining

- a- exposure of metal coated with photoresist at UV light
- b- chemical etching
- c- partially etched metal on both sides
- d- finally etched metal

The etching solutions are chosen depending on the material type and the configuration of the processed object. Chemical etchants are corrosive solutions with different concentrations that can be applied for most metals or alloys so photochemical machining is suitable for stainless steel, copper, brass, nickel and aluminum.

Because of the elements from aluminum alloys the results obtained at the machining by chemical erosion are not always satisfactory. Copper, iron and zinc the main components from aluminum alloys make galvanic elements with aluminum during chemical erosion and results surfaces with great roughness.

Metal thickness is very important but for thick part the etch time is greater. This involves a lower production rate and the process becomes expensive.

Because the metal at the surface of a sheet is exposed to the etchant longer than the metal at the center of the sheet, the surface of a part etches laterally more than metal at the center.

3. COOPER AND COPPER ALLOYS ETCHING BY PHOTOCHEMICAL MACHINING

One of the most common method for printed boards obtaining is by photochemical machining. The technological process of chemical etchings has the following stages: cleaning and degreasing of the cooper plate, covering the surface with photo-resist (FR), applying the photo-mask (PM) with the printed pattern, exposure to UV light, photo-resist developing, chemical etching of the copper from the unprotected areas, removing of the photo-resist (fig.4):

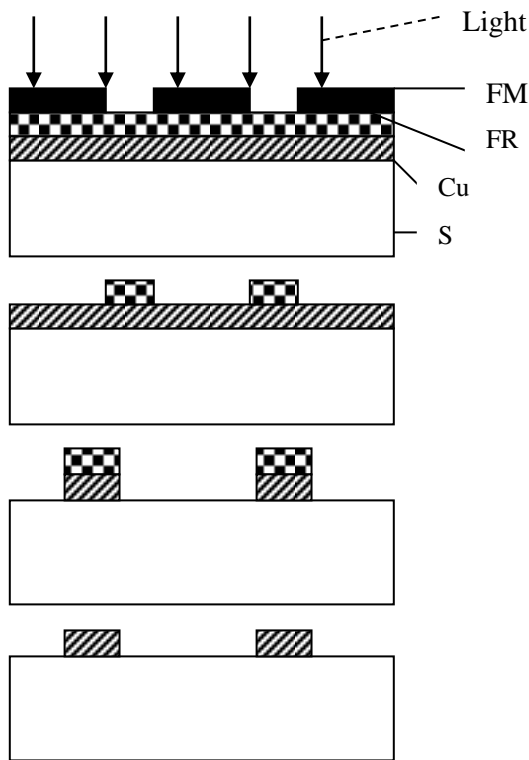


Fig. 4: Photochemical etching of copper

FM- photo-mask;
FR- photo-resist;
Cu –copper
S- isolated support

4. EXPERIMENTAL METHOD

Brass is the commonly etched copper alloy. It is used to produce precision parts as well as decorative items.

Various etchants are used for copper based alloy etching. Ferric chloride FeCl_3 has been widely used for this purpose. Using ferric chloride for brass etching will produce ferric and copper ions and the used solution becomes chemically complex.

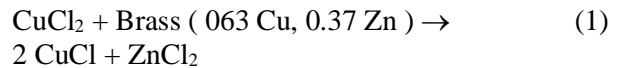
At the brass etching with FeCl_3 , the etch rate of zinc was much higher than copper and so etched surfaces became zinc free. It was noticed that copper etch rate was higher than the brass.

Copper chloride, CuCl_2 , is a suitable etchant in etching copper and copper alloys at a larger scale [1], [3].

Brass etching with cupric chloride, CuCl_2

Cupric chloride is a yellow-brown, hygroscopic solid. If cupric chloride is not dissolved by the HCl it adheres on the copper surface.

The chemical reaction of brass etching is:

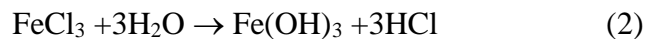


The copper surface gets attacked by CuCl_2 while cuprous chloride (CuCl) is formed.

Brass etching with ferric chloride

Ferric chloride is the most used chemical agent for copper etching. It has an acidic reaction in the absence of HCl that hinders to establish the amount of HCl.

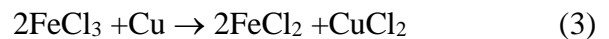
In solution FeCl_3 is hydrolyzed resulting iron hydroxide and HCl:



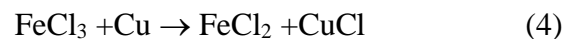
By heating and dilution the solution is darkened because of the iron hydroxide.

A sequence of chemical reactions explains the process occurring between etchant (ferric chloride) and the etched cooper.

Ferric chloride makes with copper, cupric chloride (CuCl_2) and ferrous chloride (FeCl_2):



When ferric chloride is in small amount (the etching solutions are consumed) results cuprous chloride with white color.



The ferric chloride solutions have at the beginning a specific amount of hydrochloric acid that requires to be neutralized. For this purpose is dissolved ferric hydroxide, achieved from the reaction between ammoniac and a small quantity of ferric chloride.

The etch factor depends both on the undercut and depth of etch. The undercut is half of the increase of width produced by etching whereas the depth is the thickness loss. The deviation from a straight edge profile (undercut) is dependent on the thickness of the etched metal.

The etch rate is calculated with the relation:

$$v_e = \frac{G_1 - G_2}{t \cdot A} \quad (6)$$

Where:

v_e – etch rate; G_1 - original weight; G_2 - final weight; t - etch time; A - area etched

If the metal is etched on its two sides, this etch rate has to be divided by 2 and would be equal to:

$$v_e = \frac{G_1 - G_2}{2 \cdot t \cdot A} \quad (7)$$

The etch rate can be also calculated from the material thickness loss. The samples thickness has been measured with a micrometer. The etch rate is therefore the difference in thickness by the etch time, as shown in the following expression:

$$v_e = \frac{h_1 - h_2}{t} \quad (8)$$

If the metal is etched on its two sides, this etch rate would be equal to:

$$v_e = \frac{h_1 - h_2}{2 \cdot t} \quad (9)$$

The etch rate has been calculated by taking an average of 5 etch rate measurements.

5. RESULTS AND DISCUSSIONS

The purpose of this study was to compare two etchants used for copper etching: ferric chloride (FeCl_3) and copper chloride (CuCl_2). The etching efficiency was estimated by comparing the etch rates for different concentrations of the etching agent.

For obtaining the best results at copper etching, the etchant must have a high etch rate, a capacity to remove a great quantity of metal as well as an easy control of the process.

The etching process is positively influenced by temperature, with temperature increasing, increases the etch rate for copper and copper alloys.

For the best results at the copper etching with FeCl_3 and CuCl_2 , temperature was maintained around 50°C .

Table 1 presents some characteristics of FeCl_3 and CuCl_2 used for copper etching [3].

Table 1 Characteristics of FeCl_3 and CuCl_2

Etchant	Corrosiveness	Toxicity	Operational cost
Cupric Chloride	High	Medium	Low
Ferric Chloride	High	Low	Medium

If the concentration of ferric chloride is high, the etch rate decreases because the solution is more viscous and does not corrode the copper support.

In table 2 are presented the etch rates dependence on the etch concentration for CuCl_2 and FeCl_3 :

Table 2 Etch rate dependence on the etch concentration [M]

Etchant	Concentration [M]	v_e [microm/min]
FeCl_3	2,1	25
	2,3	28
	2,45	30
	2,68	29
	2,75	28,5
CuCl_2	3,2	20
	2	30
	2,3	32
	2,45	34,5
	2,68	37
	2,75	35
	3	37,5
	3,2	38

The etch rate was calculated with the relations (8) and (9).

In figure 5 is presented the graphical dependence between the rate of etch and etch concentration [M]:

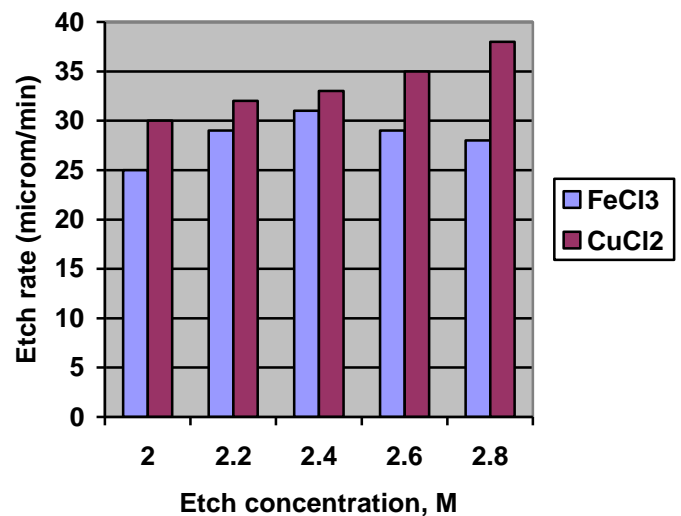


Fig.5 Influence of the etchant concentration on rate of etch

In figure 6 is represented the dependence between etch rate and etch time:

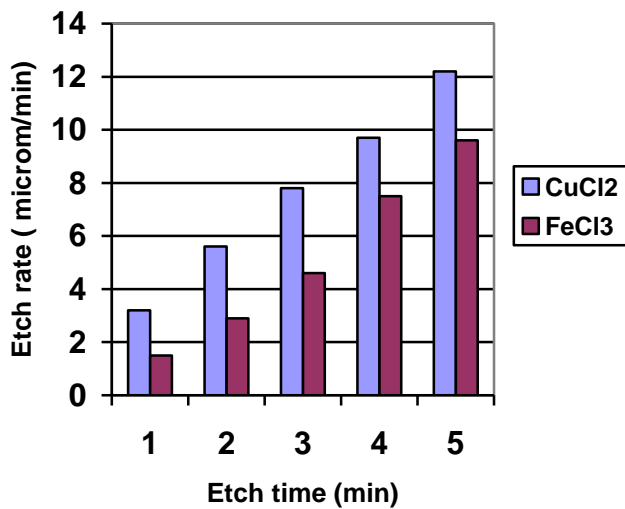


Fig.6 Effect of the etch time on the etch rate

The etchant concentration influences the surface roughness. The higher the etchant concentration the lower the removal material rate and the better the surface finish. At higher etchant temperature the etching will be distributed over grains areas with the obtaining of a smoother surface.

If the concentration is high, ferric chloride becomes more viscous and has a reduced erosive action on the metal. The temperature increasing has a positive effect on the etching rate because is accelerated the diffusion process of the erosive agent to the copper support. In figure 7 is presented the effect of ferric chloride concentration on the average rate of etch at different temperature:

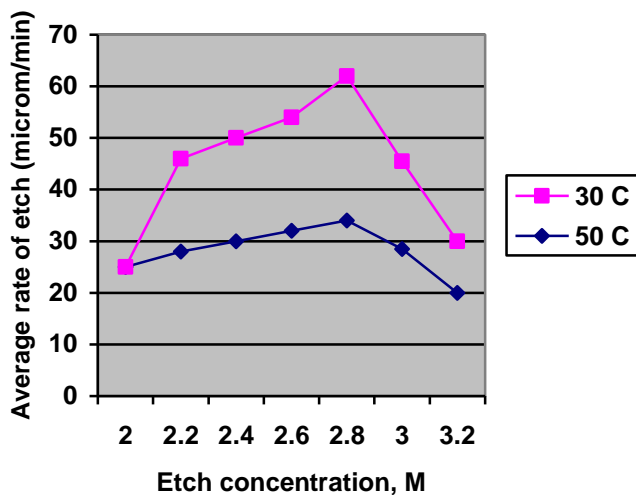


Fig.7 Influence of the etchant concentration on average rate of etch for FeCl₃

It is observed that with the increasing of the concentration at values above 2.8 M, decreases the etch rate because increases the ferric chloride viscosity and the penetration of the ferric ions

towards the copper support reducing the etching rate.

4. CONCLUSIONS

In this paper was studied the copper etching by Photochemical Machining, PCM., with two types of etching agent ferric chloride (FeCl₃) and copper chloride (CuCl₂).

The best etchant have to assure a high etch rate, a high dissolution of the metal and a minimum undercut.

In Photochemical Machining, PCM, there are two main parameters: etchant type and etching temperature [4]. These parameters influenced the etch rate and surface roughness.

For Photochemical Machining (PCM), CuCl₂ is most suitable than FeCl₃. Cupric chloride provides high etch rate when compared with FeCl₃ and produces low undercut. Cupric chloride is also used for copper alloys as brass, bronze, etc.

CuCl₂ has a better capacity to dissolve the copper than FeCl₃.

The etch rate for CuCl₂ is higher than for FeCl₃ and produce a low undercut in copper etching.

The etching temperature should be kept as high as possible the etchant machine allowed that would be up 45-55⁰C.

The selection of the etchant should be carried out with the selection of suitable waste etchant regeneration process.

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