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Chemical etching of Cu-ETP copper

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Abstract

Chemical etching is the controlled dissolution of workpiece material by contact with strong chemical solution. The process can be applied to any material. Copper is one of the extensively used engineering material in the fabrication of microelectronic components, microengineered structures and precision parts by using chemical etching process. In this study, copper is chemically etched with two different etchants (ferric chloride and cupric chloride) at 50 °C. The effects of selected etchants and machining conditions on the depth of etch and surface roughness were investigated. The experimental study provided that ferric chloride produced the fastest chemical etch rate, but cupric chloride produced the smoothest surface quality.

Keywords: Chemical etching; Copper; Depth of etch; Surface roughness

1. Introduction

Advancement in the manufacturing processes has been concentrated in the use of new tools and energy forms. These developments produced different new machining processes than conventional machining processes and they were named "nontraditional machining processes". They have been extensively and successfully used since 1950s.

Nontraditional machining processes are widely employed to manufacture geometrically complex and high-dimensional accurate machine parts from advanced materials in industries as diverse as aerospace, electronics and automotive. Moreover, various nontraditional machining processes have been used in micron-size parts production. The trend seems increasing in future.

Chemical etching is one of the oldest nontraditional machining processes. It uses strong chemical solution, which is called etchant, to remove unwanted workpiece material by controlled dissolution. The process is widely used in electronics, precision engineering and medical industries to produce micro-components. It is also a useful process in removing material from sheet components to reduce weight. It can be applied to any engineering material from steel to silicon. The process is sometimes called chemical machining, chemical milling, wet etching, etching, etc. [1].

Chemical etching is not a new process; it is used to shape metals in the ancient Egypt where copper was etched with citric acid to produce jewelry around 2500 B.C. The process replaced hand-tool engraving process in the 15th century, mineral acids were used for weapons, helmets and breastplates. In the 17th century, it was used for the first time as a manufacturing process of steel parts. Developments in the chemistry provided significant advancement, various acid types produced and resists were discovered during the 18th and 19th centuries [2,3].

First patent (British Patent: 565) was taken by William Fox using ferric chloride ($FeCl_3$) for etching copper. Later, John Baynes described chemical etching of materials from two sides in the US Patent 378,423 in 1988 [3]. The development of the process continued in later years.

Major developments were noticed after the Second World War and the process has been widely applied as manufacturing process since 1950s. First industrial application was conducted by the North American Aviation, Inc. (California, USA) to etch aluminium components for rockets. The company named the process "chemical milling" and patented it (US Patent No: 2,739,047) in 1956. The process was also

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used for removing excess mass from aluminium wing skins and other airframe parts. The advancement in the process resulted wider industrial applications from microelectronics components to medical parts and decorative items. The process has advantages over traditional machining processes are [1–5]:

a. Required no special tools;
b. Short necessary machining time;
c. Fairly economical machining process;
d. No plastic strain;
e. Machine complex geometrical shapes with high precision.

Copper, as one of the major commercial engineering materials, is extensively used in various industries such as electronics, automotive and chemical industries because of its excellent electrical and thermal conductivities, good strength and fatigue resistance, high corrosion resistance and ease of fabrication [6].

Copper chemically machined with different etchants for various applications. Mainly $FeCl_3$, cupric chloride ($CuCl_2$) and ammoniacal alkaline etchants have been used. The selection of optimum etchant solution depends on some etchant properties as follow [7,8]:

a. High machining rate;
b. Easy control and stable machining process;
c. Generation of no toxic fumes;
d. Regeneration of waste etchant and copper recovery;
e. Environmentally friendly.

$FeCl_3$ is an universal etchant and can be used for general engineering materials such as steels, aluminium and its alloys, copper and its alloys, nickel, etc. It is very useful etchant for small-scale copper etching process. It can dissolve copper up to approximately 120 g/l if the prolonged chemical etching time is acceptable. Major setback of this etchant is the impossibility to regenerate economically. This practically rules out its use for mass copper etching applications. Copper recovery from the used etchant is difficult and economically not possible. Various copper etching studies conducted with $FeCl_3$ [4,9–21]. The etching process was high and produced better etching properties.

$CuCl_2$ provides rapid chemical etching. It offers the advantages of easy regeneration. The cooper dissolve capacity is also higher than $FeCl_3$, i.e. around 150 g/l in practical applications. It produces no sludge formation as $FeCl_3$ does. Therefore this etchant seems more economical etchant for copper etching in comparison to $FeCl_3$. The literature survey mentioned that although the etch rate of $CuCl_2$ is lower than $FeCl_3$, it is more suitable etchant for copper and copper alloys etching [9–13,15–24].

Ammoniacal alkaline etchants have industrially introduced in the beginning of 1970s. The chemical reaction of these etchants is more complex than $FeCl_3$ and $CuCl_2$ etchants. They can dissolve up to 225 g/l copper and provides higher etching rates. Most of the etchants are proprietary formulations and details are hardly available. The stability of etchant is critical. The etching process is closed-loop system and needs high investment. These etchants can be regenerated and etched copper can be recovered. These etchants are only economical if copper etching process is as mass production [21].

The literature review produced information that $FeCl_3$ and $CuCl_2$ are suitable etchants for low and medium production levels. These are also capable to machine copper alloys. Therefore the present study concentrated on these two etchants for chemical etching of copper.

For $FeCl_3$ etchant applied for copper, the concentration of the etchant solution should be higher than 3 M, otherwise, it is reported, surface finish would be poor. However high etchant concentration decreases etch rate [4].

The use of $CuCl_2$ etchant presents different properties. The etch rate increases with increasing etchant concentration. Similar trend was also mentioned for surface roughness, high etchant concentration produced a better surface quality [25].

The selection of etching temperature influences etch rate and surface finish. In industrial application of chemical etching of copper, the highest possible etching temperature the etchant machine allowed is used. This value is around 50 °C. Low etching temperature decreases etch rate and produces poor surface quality [25].

In this study, the selected $FeCl_3$ and $CuCl_2$ chemical etchants were used to machine copper chemically. The concentrations of these etchants were 3.76 M for $FeCl_3$ and 2.33 M for $CuCl_2$. The selected chemical etching temperature was 50 °C, this value was generally applied for industrial chemical etching process. The experimental study was conducted in beaker. The study concentrated on the parameters of depth of etches, surface roughness and etched copper weights. The influence of etchant solution on the parameters were investigated and compared.

2. Experimental

The selected copper material was electrolytic tough pitch high conductivity copper (ISO code is Cu-ETP) and its chemical composition was 99.90% Cu, 0.005% Pb and 0.001% Bi. The hardness of materials was 55 HV. The thickness of specimens was 1 mm and cut at 20 mm × 100 mm dimension. The specimens were cleaned to remove chemical and particulate contaminations such as oil, wax, grease, rust, oxide and dirt in ultrasonic cleaning machine. The prepared cleaning solution was mixture of distilled water and addition of %1 HCl. The cleaning process was completed at 40 °C for 25 min. The cleaned specimens were rinsed with tap water and subsequently examined by dripping water on the cleaned surfaces. A uniform, continuous thin film of water spreading over the cleaned surfaces indicated that the surface cleaning was adequate.

$FeCl_3$ and $CuCl_2$ chemical etchants were prepared at 3.76 and 2.30 M, respectively. The amount of etchant for each experiment was 100 ml. Etchant was poured into beaker that

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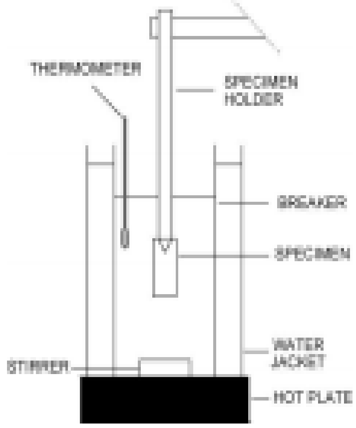

Fig. 1. Experimental set-up of chemical etching in beaker.

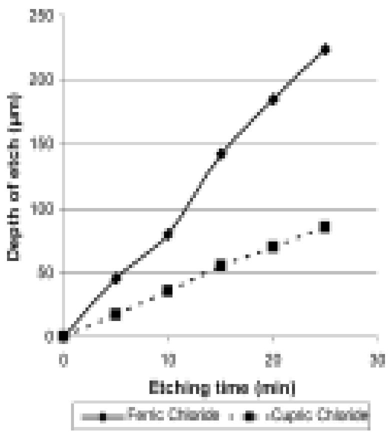

Fig. 2. Depth of etch against etching time.

was put into water jacket to control chemical etching temperature (Fig. 1). The selected machining temperature was 50 ± 2 °C. Double-sided chemical etching process was conducted. The chemical etching period was 25 min in total and the measurements were completed after 5-min intervals.

The measurements of thickness were carried out by Mitutoyo outside micrometer (deviation was ±0.001) and surface roughness was measured by Taylor-Hobson Surtronic 3+. For each etchant, three specimens were chemically machined and three different measurements were taken from each specimen.

3. Experimental results and discussion

It is important to find the chemical reaction of selected copper material with etchant. Each etchant reacts differently during chemical etching process. The chemical reaction of copper with $FeCl_3$ is as follows:

$$FeCl_3 + Cu \rightarrow FeCl_2 + CuCl \qquad (1)$$

Copper is oxidized by the ferric ions, forming cuprous chloride (CuCl) and ferrous chloride ($FeCl_2$). CuCl oxidized further in the etchant solution to produce $CuCl_2$ as follows:

$$FeCl_3 + CuCl \rightarrow FeCl_2 + CuCl_2 \qquad (2)$$

The built-up $CuCl_2$ itself reacts also with copper and forms CuCl shown below:

$$CuCl_2 + Cu \rightarrow 2CuCl \qquad (3)$$

The chemical reaction of $CuCl_2$ with copper is simpler. The copper surface gets attacked by $CuCl_2$ while CuCl is formed. The etchant solution is not effective in further chemical etching process.

$$CuCl_2 + Cu \rightarrow 2CuCl \qquad (4)$$

It can be noticed that using $FeCl_3$ etchant for chemical etching of copper produces complex chemical reaction and provides Fe^{2+}, Cu^{2+} and Cu^{+}, but using $CuCl_2$ only produces Cu^{+}. This is a major factor for the regeneration of spent etchant after chemical etching process. It is a general approach that regeneration of any spent etchant is easy and economical if the spent etchant is simple. From this point, $CuCl_2$ seems more suitable etchant for chemical etching of copper.

The depth of etch was examined and the results were shown in Fig. 2. It was observed that the use of $FeCl_3$ produced the highest value in comparison to $CuCl_2$ etchant. After 25-min etching period, depths of etch value were 224 µm for $FeCl_3$ and 85 µm for $CuCl_2$ etchants. The chemical etch rate is 9.3 µm/min for $FeCl_3$ and 3.4 µm/min for $CuCl_2$.

$FeCl_3$ etchant in copper machining behaves like two etchants in the process. The main etchant is $FeCl_3$ and the byproduct etchant is $CuCl_2$. This causes a higher etch rate in comparison to $CuCl_2$ etchant only.

The examination of surface roughness for each etchant was conducted and the results were given in Fig. 3. General expectation from chemical etching process is to obtain the best possible surface finish. This is greatly important in the weight reduction of material. It was observed that $FeCl_3$ produced a rougher surface roughness than $CuCl_2$.

The surface roughness decreased in the beginning of chemical etching process and increased during etching process in $FeCl_3$ application. After 15-min etching period, the surface roughness value became stable. The surface roughness of R_a was 1.92 µm. The surface roughness presented different trend for $CuCl_2$; surface quality increased for first 10-min etching and then the surface roughness slightly increased and became constant. The value of R_a was 0.73 µm after 25 min of etching period.

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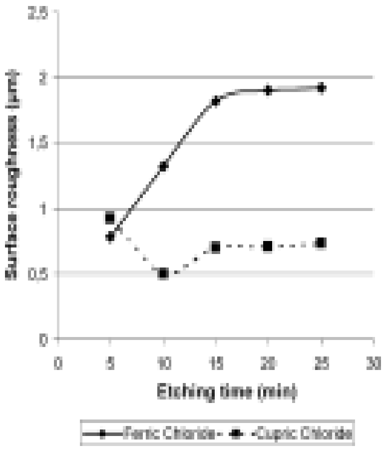

Fig. 3. Effect of etchants on surface roughness.

ness of R_a was 1.92 µm. The surface roughness presented different trend for $CuCl_2$; surface quality increased for first 10-min etching and then the surface roughness slightly increased and became constant. The value of R_a was 0.73 µm after 25 min of etching period. From surface quality point of view, $CuCl_2$ etchant produced a better surface finish than $FeCl_3$.

The other selected chemical etching parameter was the amount of etched copper weight. It was noticed that $FeCl_3$ dissolved the highest amount of copper after etching period. This weight was 1.5 g (15 g/l). The value of etched copper weight was halved when $CuCl_2$ was used for copper etching. The result of etched copper weights for both etchants was shown in Fig. 4.

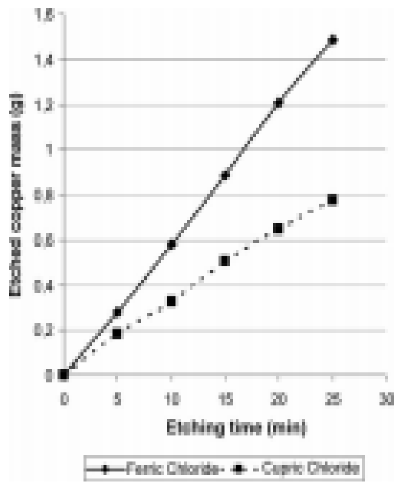

Fig. 4. The amount of etched copper mass vs. etching time.

4. Conclusion

The present study investigated two widely used etchants ($FeCl_3$ and $CuCl_2$) for chemical etching of copper. The experimental results can be concluded as follow:

a. The chemical etch rate is important factor for any material machining. The highest chemical etch rate obtained with using $FeCl_3$. This would make the machining time of process higher.
b. Surface roughness is another factor to be considered especially in case of weight reduction of material. $CuCl_2$ produced the smoothest surface quality comparing to $FeCl_3$.
c. The dissolved copper amount was compared and it was obtained that $FeCl_3$ etched more copper than $CuCl_2$ for the same etchant volume and etching period. This means that the prolonged etching time would be longer for $FeCl_3$ etchant used for copper etching.
d. Chemical reactions of copper with selected etchants were examined and $CuCl_2$ is resulted a simpler reaction than $FeCl_3$. This conclusion is effective parameter for regeneration process of used etchant. This would make regeneration process easier and more economical.

The experimental study of chemical etching of copper examined basic etching parameters. Next step of this study will be investigating other parameters such as the pH level and oxidation redox potential of used etchants, the influences of chemical addictives to the main etchant.

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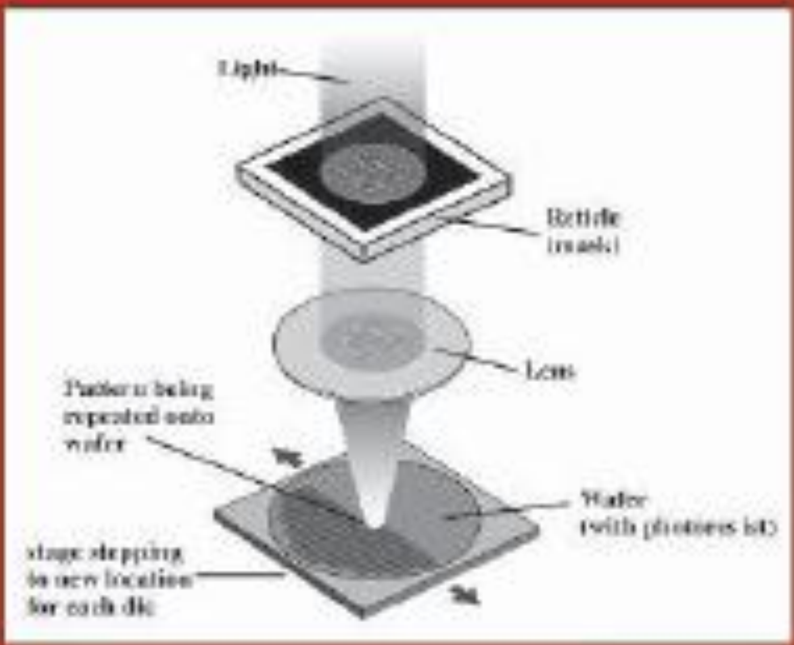

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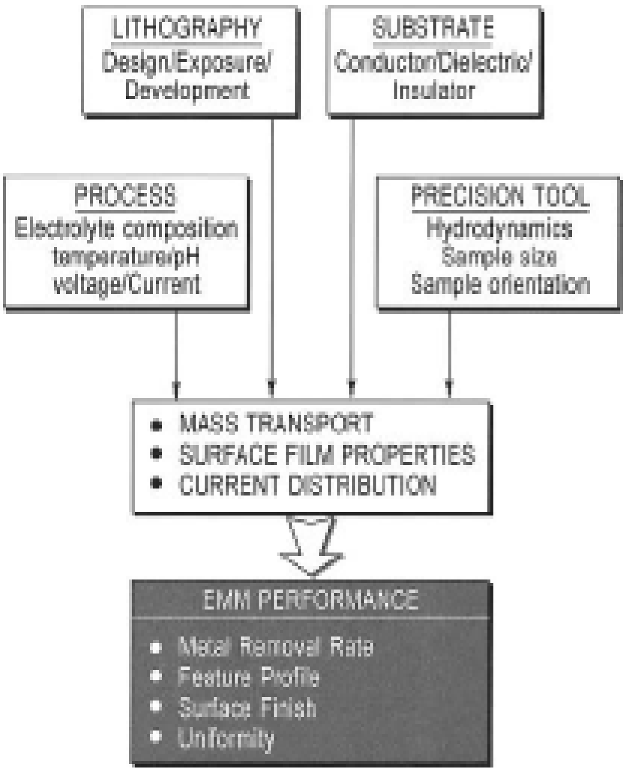

Figure 2 Dependence of EMM performance on processing and tool parameters.

raphy processing are critical to achieving desired performance. Careful design of the walls and height of photoresist masks provides opportunities to alter current distribution that reduces the photoresist undercutting. The conductivity of the substrate material is also important in influencing the current distribution of a dissolving thin film.

9.4 MATERIAL REMOVAL RATE

In an electrochemical dissolution process, the material removal rate depends on the specific electrochemical behavior of the metal/electrolyte system and is determined by the applied

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current density according to Faraday's Law [9]. The material removal rate, r in cm/s, is given by

$$r = \frac{IM}{nFA\rho} \tag{5}$$

where I is the current (A), M is the molecular weight of the dissolved material (g/mole), n is the apparent dissolution valence, F is the Faraday constant, A is the surface area (cm^2), and ρ is the density (g/cm^3). The value of n can be determined from weight loss measurements by use of Equation (6):

$$n = \frac{ItM}{\Delta WF} \tag{6}$$

where t is the dissolution time (s) and ΔW is the anodic weight loss (g).

With proper considerations of high electrolyte flow velocities and high current efficiency for metal dissolution, ex-

Table 1 Metal Dissolution Valence in Different Metal Electrolyte Systems

Metal	Electrolyte	Dissolution Valence
Ni	NaCl	2
Fe	NaCl	2 and 3
Ni	$NaNO_3$	2*
Fe	$NaNO_3$	2*
Ni	$NaClO_3$	2*
Fe	$NaClO_3$	2*
Cr	$NaCl$	6
Cr	$NaNO_3$	6
Cu	KCl	1 and 2
Cu	KNO_3	2 and 1
Cu	K_2SO_4	2 and 1
Ti	NaCl	4
Ti	NaBr	4
Mo	KOH	6
Mo	K_2CO_3	6

* Accompanied by oxygen evolution.

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tremely high metal removal rates can be obtained. A knowledge of the dependence of n on the applied voltage/current density is essential in determining the operating conditions. The literature data on experimentally determined dissolution valences for different metal–electrolyte systems are summarized in Table 1 [9].

In ECM, the distribution of the metal dissolution rate on the workpiece determines its final shape in relation to the tool [10]. The machining performance is, therefore, influenced significantly by the current density dependence of anodic reactions. Passivating metal–electrolyte systems are known to give better ECM precision because of their ability to form oxide films and evolve oxygen in the stray current region [10]. Similar results have been confirmed during electrolytic jet EMM, where passivating electrolytes have been found to yield minimized stray cutting [5].

9.5 MASS TRANSPORT EFFECTS

Mass transport processes influence the EMM performance in several ways. First, they influence the maximum rate of an electrodissolution reaction, thus giving rise to a so-called limiting current; second, mass transport-controlled anodic reactions affect the morphology of dissolved surfaces; and finally, mass transport processes influence the macroscopic and microscopic current distribution on the workpicce. An understanding of mass transport effects are, therefore, a prerequisite for the development of EMM processes. In the following, a simple description of mass transport in electrochemical systems is presented with special reference to an anodic dissolution process.

During anodic dissolution, the concentration at the anode surface can be significantly different from that of the bulk. Since these concentrations are mainly determined by the rate of mass transport, transport mechanisms and diffusion layer thickness play an important role in high-rate anodic dissolu-

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tion processes. Metal ions produced at the anode are transported into the solution by convective diffusion and migration. To maintain electroneutrality, electrolyte anions accumulate near the anode, causing the rate of convective diffusion away from the anode to be compensated by the rate of migration toward the anode. The extent of ion build-up depends on the current density, metal dissolution efficiency, and hydrodynamic conditions.

The Nernst diffusion layer concept has been used frequently to obtain a simplified description of mass transport effects in high-rate anodic dissolution of metals [9,11]. A stagnant diffusion layer of thickness δ is thus assumed to exist at the anode as shown in Figure 3. Inside the diffusion layer, a concentration gradient exists and the transport occurs exclusively by diffusion. Outside the diffusion layer, transport oc-

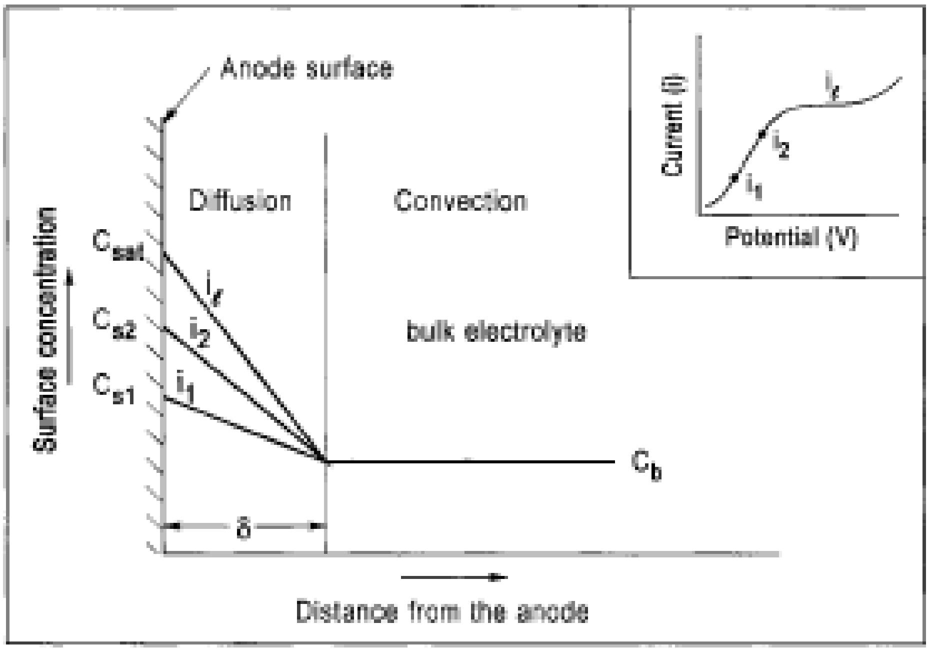

Figure 3 Nernst diffusion layer concept describing mass transport at the dissolving anode surface. A typical anodic polarization curve exhibiting a limiting current is also included (inset).

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1. Perhitungan *material removal rate* (MRR) secara teoritis

A. Variasi Arus Listrik

$\boldsymbol{MRR} = \frac{\boldsymbol{IM}}{\boldsymbol{nFA\rho}}$ mm / detik

Dimana :

I = Arus listrik yang digunakan

M = Massa rumus CuZn (64,46 gr/mol)

A = Luas kolam/bath (150 mm)

ρ = Massa jenis kuningan teori (0,00803 g/mm^3)

n = Elektron valensi (4)

F = Tetapan faraday (96485 C)

t = Waktu pencelupan (120 menit)

a. Variasi Arus 0,09 A

- Material removal rate

$$MRR = \frac{IM}{nFA\rho}$$

$$MRR = \frac{0{,}09x\ 64{,}46}{4\ x\ 96485\ x\ 150\ x\ 0{,}00803}$$

$MRR = 0{,}0000124$ mm/detik

- Laju volume = Luas x *MRR*
  = 150 x 0,0000124
  = 0,000186 mm^3/detik

- Luas massa = Laju volume x ρ
  = 0,000186 x 0,00803
  = 0,0000150 g/detik

- Massa yang hilang = Laju massa x waktu
  = 0,0000150 x 7200
  = 0,108 g

b. Variasi arus 0,12 A

- Material removal rate

$$MRR = \frac{IM}{nFA\rho}$$

$$MRR = \frac{0{,}12x\ 64{,}46}{4\ x\ 96485\ x\ 150\ x\ 0{,}00803}$$

$MRR = 0{,}0000166$ mm/detik

- Laju volume = Luas x *MRR*
  = 150 x 0,0000166
  = 0,00249 mm^3/detik

- Luas massa = Laju volume x ρ
  = 0,00249 x 0,00803
  = 0,0000200 g/detik

- Massa yang hilang = Laju massa x waktu
  = 0,0000200 x 7200
  = 0,144 g

c. Variasi arus 0,15 A

- Material removal rate

$$MRR = \frac{IM}{nFA\rho}$$

$$MRR = \frac{0{,}15x\ 64{,}46}{4\ x\ 96485\ x\ 150\ x\ 0{,}00803}$$

$MRR = 0{,}0000207$ mm/detik

- Laju volume = Luas x *MRR*
  = 150 x 0,0000207
  = 0,00311 mm^3/detik
- Luas massa = Laju volume x ρ
  = 0,00311 x 0,00803
  = 0,0000250 g/detik
- Massa yang hilang = Laju massa x waktu
  = 0,0000250 x 7200
  = 0,180 g

d. Variasi arus 0,3 A

- Material removal rate

$$MRR = \frac{IM}{nFA\rho}$$

$$MRR = \frac{0{,}3\ x\ 64{,}46}{4\ x\ 96485\ x\ 150\ x\ 0{,}00803}$$

$$MRR = 0{,}0000415 \text{ mm/detik}$$

- Laju volume = Luas x *MRR*
  = 150 x 0,0000415
  = 0,00623 mm^3/detik

- Luas massa = Laju volume x ρ
  = 0,00623 x 0,00803
  = 0,0000501 g/detik

- Massa yang hilang = Laju massa x waktu
  = 0,0000501 x 7200
  = 0,360 g

e. Variasi arus 0,35 A

- Material removal rate

$$MRR = \frac{IM}{nFA\rho}$$

$$MRR = \frac{0{,}35\ x\ 64{,}46}{4\ x\ 96485\ x\ 150\ x\ 0{,}00803}$$

$$MRR = 0{,}0000485 \text{ mm/detik}$$

- Laju volume = Luas x *MRR*
  = 150 x 0,0000485
  = 0,00727 mm^3/detik

- Luas massa = Laju volume x ρ
  = 0,00727 x 0,00803
  = 0,0000584 g/detik

- Massa yang hilang = Laju massa x waktu
  = 0,0000584 x 7200
  = 0,420 g

B. Variasi waktu pencelupan

$\boldsymbol{MRR} = \frac{\boldsymbol{IM}}{\boldsymbol{nFA\rho}}$ mm/ detik

Dimana :

I = Arus listrik yang digunakan(0,3 A)

M = Massa rumus CuZn (64,46 gr/mol)

A = Luas kolam/bath (150 mm)

ρ = Massa jenis kuningan teori (0,00803 g/mm^3)

n = Elektron valensi (4)

F = Tetapan faraday (96485 C)

t = Waktu pencelupan (menit)

a. Variasi waktu 60 menit

- Material removal rate

$$MRR = \frac{IM}{nFA\rho}$$

$$MRR = \frac{0{,}3\ x\ 64{,}46}{4\ x\ 96485\ x\ 150\ x\ 0{,}00803}$$

$MRR = 0{,}0000415$ mm/detik

- Laju volume = Luas x *MRR*
  = 150 x 0,0000415
  = 0,00623 mm^3/detik

- Luas massa = Laju volume x ρ
  = 0,00623 x 0,00803
  = 0,0000501 g/detik

- Massa yang hilang = Laju massa x waktu
  = 0,0000501 x 3600
  = 0,180 g

b. Variasi waktu 90 menit

- Material removal rate

$$MRR = \frac{IM}{nFA\rho}$$

$$MRR = \frac{0{,}3\ x\ 64{,}46}{4\ x\ 96485\ x\ 150\ x\ 0{,}00803}$$

$$MRR = 0{,}0000415 \text{ mm/detik}$$

- Laju volume = Luas x *MRR*
  = 150 x 0,0000415
  = 0,00623 mm^3/detik
- Luas massa = Laju volume x ρ
  = 0,00623 x 0,00803
  = 0,0000501 g/detik

- Massa yang hilang = Laju massa x waktu
  = 0,0000501 x 540
  = 0,270 g

c. Variasi waktu 120 menit

- Material removal rate

$$MRR = \frac{IM}{nFA\rho}$$

$$MRR = \frac{0{,}3\ x\ 64{,}46}{4\ x\ 96485\ x\ 150\ x\ 0{,}00803}$$

$$MRR = 0{,}0000415 \text{ mm/detik}$$

- Laju volume = Luas x *MRR*
  = 150 x 0,0000415
  = 0,00623 mm^3/detik
- Luas massa = Laju volume x ρ
  = 0,00623 x 0,00803
  = 0,0000501 g/detik

- Massa yang hilang = Laju massa x waktu
  = 0,0000501 x 7200
  = 0,360 g

d. Variasi waktu 150 menit

- Material removal rate

$$MRR = \frac{IM}{nFA\rho}$$

$$MRR = \frac{0{,}3 \; x \; 64{,}46}{4 \; x \; 96485 \; x \; 150 \; x \; 0{,}00803}$$

$MRR = 0{,}0000415$ mm/detik

- Laju volume = Luas x *MRR*
  = 150 x 0,0000415
  = 0,00623 mm^3/detik

- Luas massa = Laju volume x ρ
  = 0,00623 x 0,00803
  = 0,0000501 g/detik

- Massa yang hilang = Laju massa x waktu
  = 0,0000501 x 9000
  = 0,450 g

e. Variasi waktu 180 menit

- Material removal rate

$$MRR = \frac{IM}{nFA\rho}$$

$$MRR = \frac{0{,}3 \; x \; 64{,}46}{4 \; x \; 96485 \; x \; 150 \; x \; 0{,}00803}$$

$MRR = 0{,}0000415$ mm/detik

- Laju volume = Luas x *MRR*
  = 150 x 0,0000415
  = 0,00623 mm^3/detik
- Luas massa = Laju volume x ρ
  = 0,00623 x 0,00803
  = 0,0000501 g/detik

- Massa yang hilang = Laju massa x waktu
  = 0,0000501 x 10800
  = 0,541 g

C. Variasi komposisi larutan

$$Konsentrasi\ larutan\ = \frac{mol\ zat\ terlarut}{volume\ pelarut}$$

Dimana:

Mol zat terlarut = mol $FeCl_3$

Volume larutan = volume aquades

Mol Fe = 55,8
Mol Cl_3 = 3(35,45)

a. Komposisi larutan 6,67 %

Mol $FeCl_3$ = $\frac{20\ gr}{55{,}8+3(35{,}45)}$

Mol $FeCl_3$ = 0,123 mol

Konsentrasi larutan = $\frac{0{,}123}{0{,}28}$

Konsentrasi larutan = $0{,}44\ mol/lt$

b. Komposisi larutan 8,33 %

Mol $FeCl_3$ = $\frac{25\ gr}{55{,}8+3(35{,}45)}$

Mol $FeCl_3$ = 0,154 mol

Konsentrasi larutan = $\frac{0{,}154}{0{,}275}$

Konsentrasi larutan = $0{,}560\ mol/lt$

c. Komposisi larutan 10 %

Mol $FeCl_3$ = $\frac{30\ gr}{55{,}8+3(35{,}45)}$

Mol $FeCl_3$ = 0,185

Konsentrasi larutan $= \frac{0,185}{0,270}$

Konsentrasi larutan $= 0,685\ mol/lt$

d. Komposisi larutan 11,67 %

Mol $FeCl_3$ $= \frac{35\ gr}{55,8+3(35,45)}$

Mol $FeCl_3$ = 0,215

Konsentrasi larutan $= \frac{0,215}{0,265}$

Konsentrasi larutan $= 0,814\ mol/lt$

e. Komposisi larutan 13,33%

Mol $FeCl_3$ $= \frac{35\ gr}{55,8+3(35,45)}$

Mol $FeCl_3$ = 0,215

Konsentrasi larutan $= \frac{0,215}{0,265}$

Konsentrasi larutan $= 0,814\ mol/lt$

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Nama Mahasiswa	: Sigit Asmoro	Pembimbing I	: Tri Widodo B R ST, MSc, Ph.D.
Nomor Induk	: -	Pembimbing II	: Nurmuntaha A N, ST, Pg, Dip.
NIRM	: D 200 100 086	Tgl. dimulai	: 21 November 2014
Jurusan/Progdi	: Teknik / Teknik Mesin	Tgl. selesai	: 02 Juli 2015
Judul/Topik	: Pengembangan proses *deep etching* untuk aplikasi *micromachining* material kuningan		

NO.	TANGGAL	MATERI KONSULTASI	T.TANGAN *
1.	21/4 14	Artikel / Jurnal ✓	[signature]
2.	15/6 14	Material Alumunium ✓	
3.	11/8 14	Uji coba material alumunium ✓ Percobaan deep etching	
4.	26/8 14	Alat transfer desain ke plat → Box lampu	
5.	4/9 14	Alat transfer desain ke plat oke ✓	
6.	24/9 14	Studi lapangan kerumah produksi Deep etching Bp. palladi	
7.	1/10 14	Bahan etchan / pelarut dan ✓ material Al, Cu, Mg. CuZn	
8.	11/10 14	Uji coba II material Al, Cu, Mg CuZn Tanpa arus ✓	
9.	31/10 14	Pembuatan travo variasi arus.	[signature]

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NO.	TANGGAL	MATERI KONSULTASI	T.TANGAN *
10.	28/10 14	- Uji coba III material Al, Cu, CuZn, Mg dengan arus ✓	
11	2/2 15	- spesimen dan metode penelitian elektro etching ✓	
12	9/2 15	- pengujian dan pengambilan data,	
13.	23/2 15	- BAB I - BAB II - BAB III } format dan rumus diperbaiki ✓	
14	26/2 15	- BAB I, II, III oke / - foto makro di ums kurang baik	
15	16/3 15	- bab IV - tabel dan grafik diperbaiki	
16	30/3 15	- BAB IV - tabel, - grafik } oke ✓ - format, - perhitungan } diperbaiki	
17	2/4 2015	- pengujian foto makro di uns ✓	
18	10/4 15	- BAB IV - format - perhitungan - foto } ok /	

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NO.	TANGGAL	MATERI KONSULTASI	T.TANGAN *
19.	13/4 15	- BAB V - kesimpulan OK ✓ - Saran diperbaiki	Lar
20	15/4 15	- BAB V Saran ok. ✓	Lar

Catatan : - Harap dibawa setiap konsultasi
* Pembimbing Tugas Akhir

Mengetahui :
Ketua Jurusan

Tri Widodo Besar Rivadi ST. MSc. Ph.D.

Surakarta,
Mahasiswa,

Sigit Asmoro

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Nama Mahasiswa	**: Sigit Asmoro**	**Pembimbing I**	**: Tri Widodo B R ST, MSc, Ph.D.**
Nomor Induk	**: -**	**Pembimbing II**	**: Nurmuntaha A N, ST, Pg, Dip.**
NIRM	**: D 200 010 086**	**Tgl. dimulai**	: 24 November 2014
Jurusan/Progdi	**: Teknik / Teknik Mesin**	**Tgl. selesai**	: 02 Juli 2015

Judul/Topik : **Pengembangan proses *deep etching* untuk aplikasi *micromachining* material kuningan**

NO.	TANGGAL	MATERI KONSULTASI	T.TANGAN *
1	30/04 2015	Bab I & II	[signature]
2	06/05 2015	Bab III & IV. lengkapkan	[signature]
3.	19/05 2015	Bab V. tabel ok.	[signature]

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NO.	TANGGAL	MATERI KONSULTASI	T.TANGAN *

Catatan : - Harap dibawa setiap konsultasi
* Pembimbing Tugas Akhir

Mengetahui :
Ketua Jurusan ____________

Tri Widodo Besar Riyadi ST, MSc, Ph.D.

Surakarta, 02 Juli 2015
Mahasiswa,

Sigit Asmoro

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KARTU REVISI UJIAN TUGAS AKHIR

Nama : Sigit Armoro
NIM : D200 100 086
Tanggal Ujian : 22 Juni 2015

Topik TA : Material
Pembimbing I : Tri Widodo BR, ST, MSc, PhD
Pembimbing II : Nurmuntaha A. N

No	Tanggal	Materi Revisi	Penguji
	22/06 2015	Revisi sesuai naskah Acc 24/06 2015 Acc 24/6 2015 Acc	

Mengetahui
Ketua Ujian TA

(............................)

Surakarta, 02 Juli 2015
Sekretaris Ujian TA

(Nurmuntaha AN)