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Continuity Microplating using Image Processing

Ting-Chao Chen, Yean-Ren Hwang, and Jing-Chie Lin

***Abstract*—**A real time image-guided electroplating system is proposed in this paper. Unlike previous electroplating systems, instead of using the intermittent mode to electroplate 500um long copper specimen, a CCD camera and a motion controller are used to adjust anode-cathode distance to obtain better results. Since the image of the gap distance is highly deteriorated due to complex chemical-electrical operation inside the electrolyte, to determine the gap distance, an image processing algorithm is developed and mainly based on the entropy and energy values. In addition, the color and incidence direction of light source are also discussed to help the image process in this paper. From the experiment results, the specimens created by the proposed system show better structure, better uniformity and better finishing surface compared to those by previous intermittent electroplating setup.

***Keywords*—**Electroplating, image guided, image process, light source.

I. Introduction

IN the past few years, the micro-anode-guided electroplating (MAGE) process [1-3] had been developed to control a micro-anode and guide a copper electroplating process in fabrication the copper columns. However, during the operation in these works, the anodes were moved intermittently only when the copper columns touched the anodes. Not only the adherence problem of the anode and specimen often happened and failed the fabrication process, but also the shape of the columns was not smooth with large variation diameters. To improve the process, a CCD camera to capture the image of anode and copper column is used. Based on which the distance between the column tip and the anode is determined through a proposed image process. The distance information is fed into motion controller to adjust the cathode position. The experiment result shows better quality copper column is fabricated using the proposed algorithm.

The micro-manufacture techniques, including the electroplating process, have been attracting more and more attentions in the past decades. Madden, et. al. [4, 5] proposed the "localized micro-electroplating" by using electroplating to deposit the micrometer-scaled Ni-column and spring. Despite the micro-Ni-column have rough surface, defective in structure and nodular contour, the localized micro-electroplating had advantages as quick process, low cost, various products fabrication and open-air process, and hence was considered as a workable process. Later, the scanning electrochemical microscope method proposed by El-Giar, et. al. in [6, 7] to localize electrochemical deposition the leading wire inside the electric part, let copper microstructures be a interconnects between the two part in the chip for the microelectronics. The MAGE process [1, 2] used a motion controller to adjust the anode position by monitoring the operation voltage. The anodes were moved intermittently when the voltage suddenly decreased to zero and the current rapidly increased. Often happened was the copper column touched and stuck to the anode. This phenomenon affected the quality of the copper column and sometimes induced broken column when trying to separate the adherence.

It was found that the distance between the anode and cathode playing a critical role in local electrochemical plating [8, 9]. To observe the anode-cathode distance and the influence of deposition surface, the coherent microradiology using X-ray was proposed by Seol et. al. [8, 9]. Although better solution was obtained, the equipment was expensive and had to be handled by specialist with special license. In order to maintain the anode-structure distance to obtain good quality of the copper column and to avoid using radiological equipment, a CCD camera with a magnifier lens to capture the image of electroplating process is proposed in this work. Since the image was highly deteriorated due to the complicate chemical-electrical operation inside the electrolyte, a developed image processing algorithm based on the entropy and energy values is used to determine the anode-column distance. Although theorems and techniques for image processing have been developed for many years [10-12], only few are applied to micro-electroplating systems.

The remainder of this paper is organized as follows. The setup of the electroplating system and software functions are introduced in Section 2, the operation flowchart is described in Section 3, the experiment result is shown in Section 4 and the conclusion is stated in Section 5.

II. Hardware Setup and Software Functions

As shown in Fig. 1, the proposed system contains a computer and two major hardware subsystems, i.e. the image capturing subsystem and the micro-electroplating subsystem. The image capturing subsystem includes a CCD camera, a video capture Matrox CronosPlus card and a magnifier lens. The electroplating subsystem contains the electrical power supplier and the motion control system. The computer integrates both subsystems by processing the image from the image capturing subsystem and determining the gap distance and sending motion control commands to the electroplating subsystem. In

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Fig. 1, V, C, D, M, H, S, F, L and G represent the power supplier, the computer, the motion driver, the micro-stepping motor, the micro- anode (diameter of 125um), the cathode(10 mm×10 mm× 1mm pure copper), the electrolytic cell, the high-power LED module and the magnifier lens, respectively.

The camera is fixed to the position such that its view covering the anode and copper specimen. Once the specimen column grows longer, the holder of the copper specimen will be moved by the motion controller through a stepping motor while the anode is remained at the same position. Hence the field of view always covers the region around the gap.

The anode of the electroplating system is made of platinum wire in diameter 125 um and put it to a bakelite tube with cold-mounted resin. The diameter is 0.5 mm and length 60 mm. One end of platinum wire is welded with a copper conducting wire to connecting to a DC-power supply. The cathode is made of a piece of square (10 mm×10 mm× 1mm) pure copper, whose one side is adhered to a copper wire with conducting glue to the connection to DC-power supply, the copper was mounted with resin to expose the other side. The depositing cell is constructed with PMMA in a dimension of 50 mm × 50 mm × 60 mm, uses a typical sulfate bath with the composition of 0.8M $CuSO_4 \cdot 5H_2O$ and 0.65M H_2SO_4. Furthermore install a high-power LED to increase illumination behind the cell, and use pump to made the electrolyte convection and carry the bubble made from electroplating off.

The software is mainly divided into two parts: user interface and image processing. As shown in Fig. 1, the user interface includes four major areas. The upper left block is for the image display from CCD camera. The parameters for the CCD camera and motor driver are listed in the upper right and lower right blocks, respectively. The lower left block contains intermediate images.

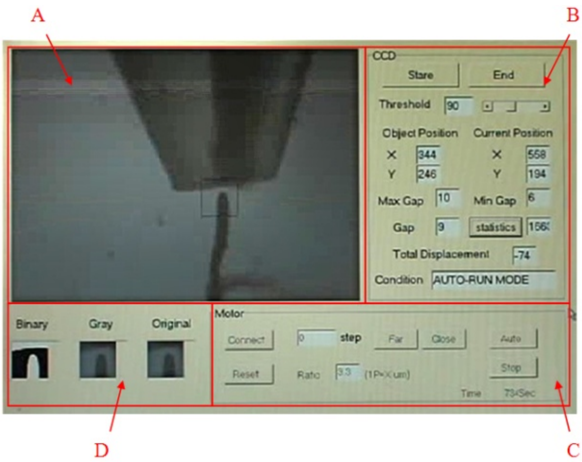

Fig. 1 The user interface of the electroplating system

All the positions are showing at the follow picture:

A：CCD display

B：Interface of image control

C：Interface of motor control

D：State display

The image process portion includes the operations of the noise filtering, region segmenting, and anode-cathode distance determination. During the electroplating process, bubbles frequently appear due to the chemical reaction of the electrolyte. The anode and copper column are not distinguishable because of bubbles since the image becomes too chaotic. To evaluate the clearance of the image, the entropy and energy values [8], whose definition given in following equations, are calculated and compared.

$$Entropy = -\sum_i p(i)\log p(i) \quad (1)$$

$$Energy = -\sum_i \sum_j f^2[i,j] \quad (2)$$

where p[i,j] represents the grayness value of the i-th row and j-th column pixel of the image. Fig. 2、3 and 4 show the entropy and energy values for different images. It is found that when there exists more bubbles, the entropy values will become higher while the energy values become lower.

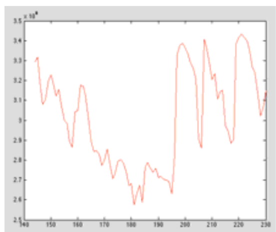

Fig. 2 Energy

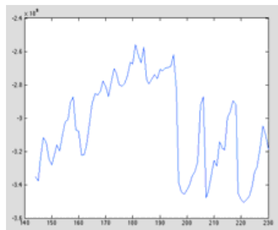

Fig. 3 Entropy

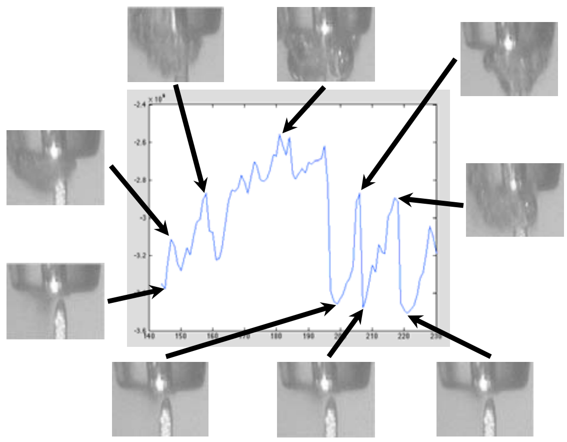

Fig. 4 The relationship chart with entropy number and the quantity of bubbles

Once, the image is clear enough, the anode and column tip will be found. The distance of the gap will be fed into the motion controller to adjust the cathode holder position.

III. Experimental Technique

Before starting electroplating, set the image system and the ratio of amplify. Then adjust the relation coefficient base on the ration of amplify. Because of the process of electroplating produces bubbles and affects the image process. To make the image process become easier, set up a pump on the electroplate bath to take away the bubbles. It is also important to considerate the effect of the light source. There are two main issues of the effect of the light source. One is the color of the light source and the other is the incidence direction.

A. Light Source

1. Color of the Light Source

Table I shows the datasheet of LED.

TABLE I
DATASHEET OF LED

Color	Input voltage	Output power	Current	Radiate angle	Lumen
White	6.5V | 7.2V	5W	1.0a | 1.5a	180°	260 | 270
Warm White	6.5V | 7.2V	5W	1.0a | 1.5a	180°	240 | 250
Green	5.0V | 6.0V	5W	1.0a | 1.5a	180°	240 | 250
Red	2.5V | 3.5V	5W	1.0a | 1.5a	180°	180
Yellow	2.5V | 3.5V	5W	1.0a | 1.5a	180°	180
Blue	4.5V | 5.0V	5W	1.0a | 1.5a	180°	200 | 220

In order to achieve the best efficiency, use the spectrometer to test the absorption spectrum of $CuSO_4 \cdot 5H_2O$ solution. Fig. 5 presents the spectrometer below.

Fig. 5 Spectrometer

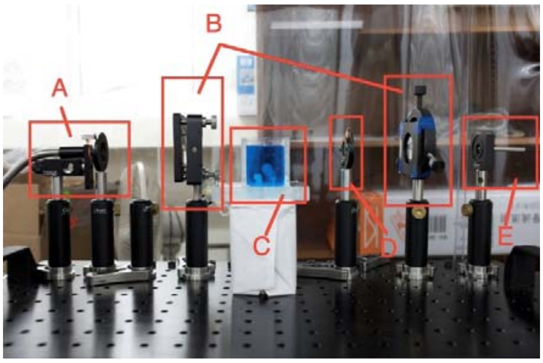

Fig. 6 Equipment of measuring absorption spectrum of $CuSO_4 \cdot 5H_2O$ solution

Fig. 6 shows the equipment of measuring absorption spectrum of $CuSO_4 \cdot 5H_2O$ solution.

A：Continuous spectrum

B：Lens

C：$CuSO_4 \cdot 5H_2O$ solution

D：Aperture

E：Receiving end of spectrometer

The experiment used a spectrometer to measure the original spectrum luminous of the wavelength from 300nm to 1200nm, and the absorbed spectrum luminous which are absorbed by passing the $CuSO_4 \cdot 5H_2O$ solution. As shown in Fig. 7, the light is been absorbing when wavelength except 500nm, and completely absorbed when wavelength over 600nm. Therefore, this experiment finds that the green light and blue light can get much higher luminous intensity. Choosing these two type lights to be the light source of this system can capture much clearer images which are helpful to do the image processing.

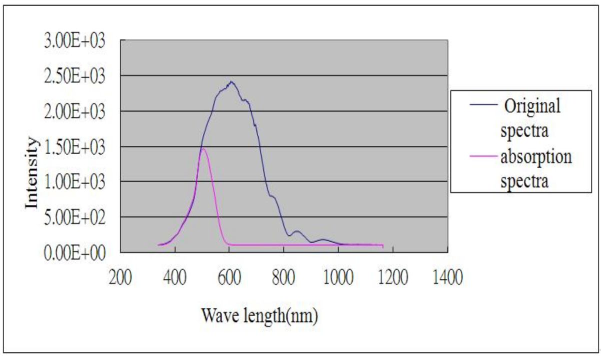

Fig. 7 Absorption spectrum of $CuSO_4 \cdot 5H_2O$ solution

2. Incidence Direction of Light Source

There are several issues may affect the quality of the image process, such as different incidence direction of the light source, the average light intensity, the distribution light

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intensity, and the outline of the main body. However, how to choose an ideal incidence direction was the most important thing of all. For example, by using the light source at a 45 degree of front incidence, the deposition process of the copper micro-column can be observed, but the uniform brightness on the images caused the difficulty of the image processing. Therefore, four different incidence, front at a 45 degree, back at a 45 degree, rear area and after expands collapses the diffused light were set respectively to form better images.

Fig. 8 is the diagram of different incidence of the light source. Because of the blue light and the green light have higher effectiveness of intensity. Therefore, blue light and green light were used in the following experiment as the light source. Fig. 9 shows the blue light source and Fig. 10 shows the green light source of different four incidence.

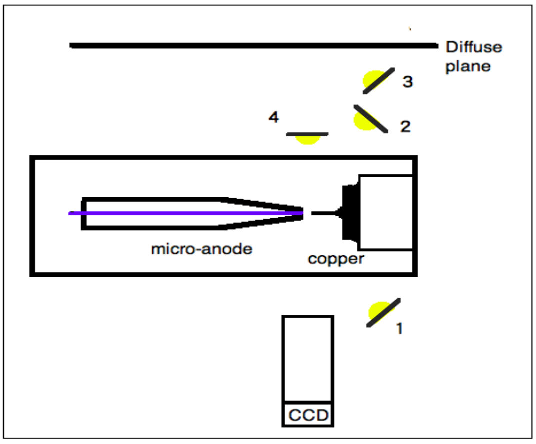
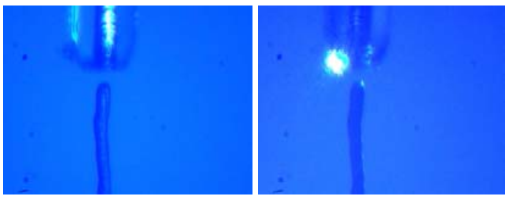
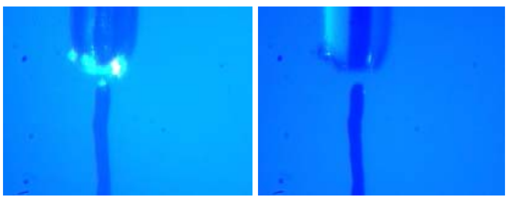


Fig. 8 The light source of different incidence

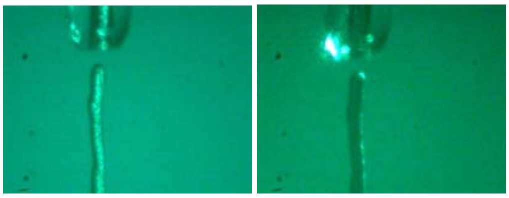


(a) front at a 45 degree (b) back at a 45 degree



(c) rear area (d) diffused light

Fig. 9 The blue light source of different incidence



(a) front at a 45 degree (b) back at a 45 degree

(c) rear area (d) diffused light

Fig. 10 The green light source of different incidence

When the incidence of the light source was at the front of 45 degree, the brightness of the images was more average. Also, the surface of micro-anode can be seen clearly. However, the outline was not obvious and the gap distance between two poles was hard to be estimated as well.

When the incidence of the light source was at the back of 45 degree, the outlines of the images were more obvious and clear. However, the uniform brightness on the images would cause the erroneous judgment of image processing.

When the incidence of the light source was at the rear area, the effectiveness of the light was the highest. However, the light intensity was distributed so concentrated that not only the outline of the copper but also the gap distance cannot be clearly observed and estimated.

When the light source was diffused light, the average brightness was lower compared to the mentioned incidence. Although the brightness on the images was uniform and the light intensity was lower, the outline was obvious. Thus the incidence of the light source was determined in this experiment.

IV. Operation Flowchart

As shown in Fig. 11, the flowchart of the electroplating operation requires users to assign the parameters of the operation, such as the maximum and minimum range of the gap and the enlargement ratio of the magnifier lens. The electroplate power supplier will then be turned on through the following procedures.

The gray images are consistently captured from the CCD camera during the electroplating process and processed to determine the existence of bubbles. If the image is clear enough, then the distance of the gap will be determined by measuring the pixels between the anode and the specimen. Otherwise, the system will discharge the current image and process the next one.

Once the distance is different from the setup value, the movement commands will be sent to the motion controller to adjust the cathode holder position. Before the copper specimen length reaches the required value, the above procedures will be repeated.

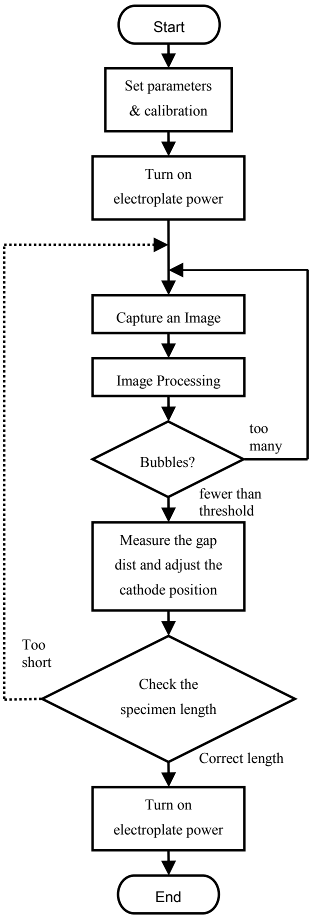


Fig. 11Operation Flowchart

V. Experiment and Discussion

An experiment was designed to show the difference of the intermittent and the proposed continuous electroplating. At first, the micro-anode and cathode are placed inside the electrolytic cell. The CCD camera is fixed to capture the image of the tips of anode and cathode. The parameters are assigned to the image processor and motion controller according to the magnification ratio of the lens.

Fig. 12 show the equipment of real time image-guided electroplating system, pass through the CCD to catch the image of the micro-anode and cathode in electroplate bath, then increase image intensity and contrast by using light source system, crease bubble by circulate pump to identify the gap between two pole, finally using the data to move the micro stepping motor.

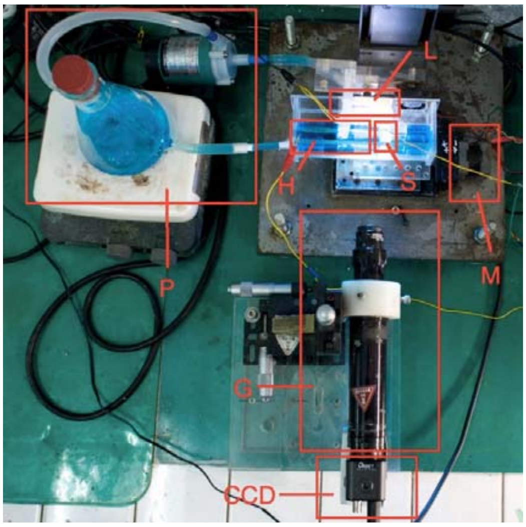


Fig. 12 Equipment of real time image-guided electroplating system

All the positions are showing at the follow picture:

M：Micro stepping motor

H：Micro-anode (diameter 125μm)

S：Cathode (10mm*10mm*1mm)

L：High power LED

P：Circulate pump

G：Amplify lens

CCD：CCD

Firstly, the intermittent mode of electroplating is adopted to electroplate 500um copper specimen. Secondly, within the same environment and using the same parameters, the image guided continuous mode electroplating is used for another 500um copper specimen. Fig. 13 shows 70 times SEM image of the copper specimen. The first part of the specimen, which using the intermittent mode method, does not have smooth surface, and the diameters of the column change dramatically. On the other hand, the second part of the specimen has smooth surface and uniform structure, and the diameter remains almost the same along the specimen.

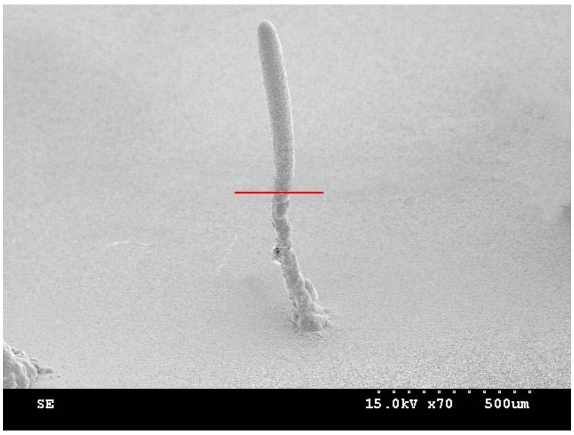


Fig. 13 The image of copper specimen electroplated by intermittent mode and continuity mode

VI. Conclusion

This paper presents a real time image-guided electroplating system using a CCD camera and a motion controller to adjust the anode-cathode distance. An image processing algorithm based on the entropy and energy values is developed to determine the clearance of the image. The measured distance is fed into the motion controller to adjust the cathode position. Compared to the previous intermittent method, the experiment results showed that better quality of specimen is obtained by using the proposed algorithm.

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