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A microprocessor based autoscanner for electromigration studies in thin films

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Abstract. Mass transport due to electromigration can be estimated if the diffusion coefficient D and the electromigration effective charge number Z^* are known. Neutron activated tracer scanning method determine the radioactivity at different positions. An automatic scanning system for determining the radioactive concentration profiles developed using a microprocessor is described in this paper. Using the radioactive concentration profiles the electromigration shift is determined. From this shift the electromigration effective charge number Z^* is calculated. The system developed was tested for tin thin films.

Keywords. Microprocessor based instrumentation; electromigration; tin thin films.

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1. Introduction

The reliability in the performance of electrical or electronic devices in which high current densities $> 10^8$ A/m^2 are involved, was found to a large extent due to the associated mass transport. Particularly this effect is manifested in the interconnecting metal stripes in integrated circuits (Black 1969; Agarwala *et al* 1970). This variation in mass distribution in any thin film device where current densities are large, affects the device performance.

Mass transport arising due to uniform electric field is called electromigration (Chemla 1954). In bulk materials, Adda and Philbert (1961), Huntington (1975) discussed the electromigration. Simultaneous determination of both the diffusion coefficient D and electromigration effective number Z^* which are characteristic values for a given material are useful for estimating the mass transport. These values also depend on the physical form of the material i.e. D and Z^* for single crystals may be different from that of polycrystalline case of the same material which in turn differ from the values for thin films. This variation is mainly due to the fact that mass transport can take place only when defects are present.

Sun and Ohring (1976) reported a radioactive tracer scanning method for determining D and Z^*. However this method lacks precision in the estimation of electromigration shift as internal reference point is not provided. Beniere, *et al* (1976) reported a neutron activated sectioning method for determining D and Z^* of copper in aluminium thin films, with internal reference to estimate electromigration shift. This method was modified as neutron activation tracer scanning method (Reddy and Prasad 1984) for the study of self diffusion D and electromigration effective charge number Z^* in indium thin films. This method requires the accumulation of data over a long time (sometimes for 15h). In this paper we describe the automation introduced for this method to avoid the strain in monitoring data by constant vigil during the entire period of data collection.

2. Experimental methods

The experimental sample is shown in figure 1. The detailed description of the method of preparation was described elsewhere (Reddy and Prasad 1984). The test sample is mounted on a movable platform in an $X-Y$ micrometer shown in figure 2. The shaft of this micrometer has a pitch of 0·5 mm and hence one complete revolution of the shaft causes lateral translation of 500 μm. However the sample is screened by a window

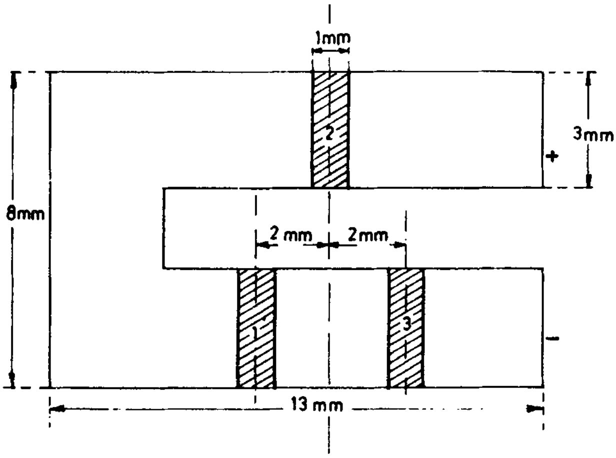

Figure 1. The experimental sample consisting of U shaped tin thin film and the three radioactive dots.

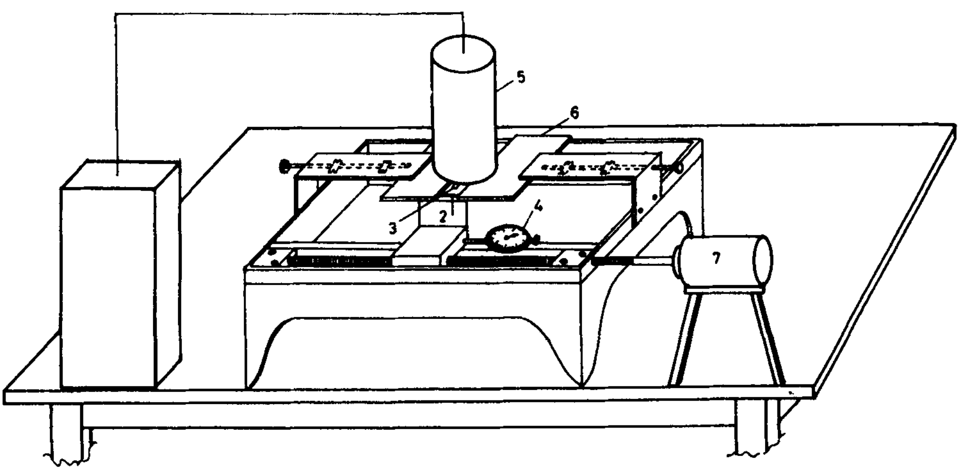

Figure 2. Experimental testing jig for mounting the sample and scanning the radioactivity. 1. Single channel analyser, 2. Sample holder, 3. Sample, 4. Dial gauge, 5. Detector, 6. Adjustable slit, 7. Stepper motor.

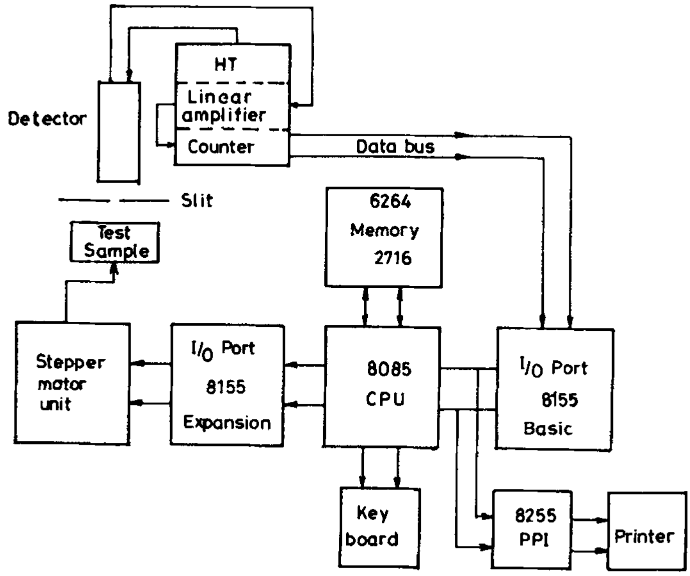

Figure 3. Block diagram explaining the signal processing from the test sample to the printer.

of 100 μm slit width. A plastic scintillation detector senses the β rays emerging out of the sample. This detector rests over the window and hence at any instant, the detector can detect radiations coming from the test device through this window.

The block diagram of the automatic scanning arrangement designed and fabricated for the study of electromigration in thin films is shown in figure 3. The output of the photomultiplier is fed to a linear amplifer from where it enters the single channel analyser which is operated in the normal mode. In this mode both the upper and lower window settings can be varied independently. The output of the single channel analyser gives TTL compatible pulses. These pulses are then counted by a cascaded decade counter, decoded and displayed using seven segment display I.Cs.

2.1 *Software*

The software for the automation is written in assembly language compatible to 8085 based microcomputer. The flowchart shown in figure 4 explains the algorithm involved in the process of automation. Ports A and B of the basic 8155 are programmed to work as input ports. The output of the cascaded decade counter is connected to these ports. The port A of the expansion 8155 I/O port is programmed as output port. Through this port, the counter is enabled or disabled. When the counter is enabled, it counts the number of β particles for a preset time duration. To obtain this definite length of time delay, the following method explained in figure 5 was adopted. At the elapse of the counting time, the counter is disabled, then the contents of the counter is latched using IC 7475 and transferred to the memory location through ports A and B of the basic 8155 ports. After incrementing the address of the memory to accept the next data the cascaded decade counter IC 7490 is reset.

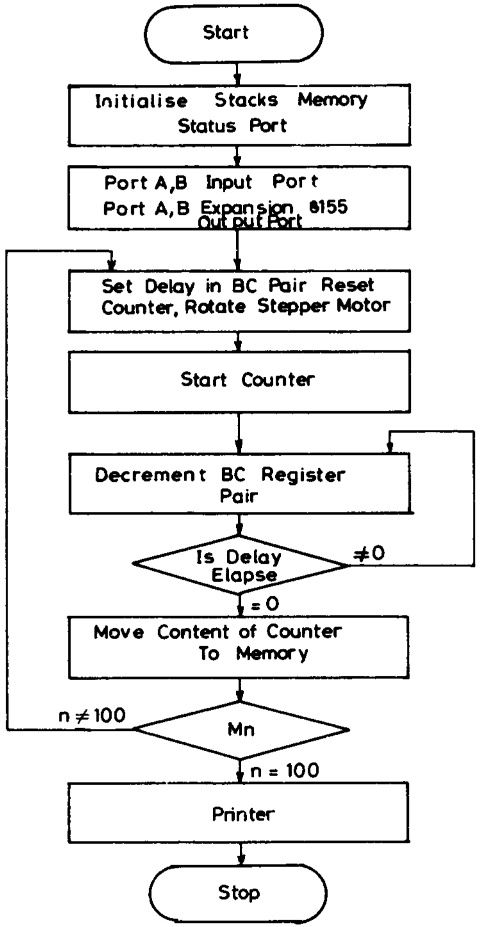

Figure 4. Flowchart explaining the operation of the processor.

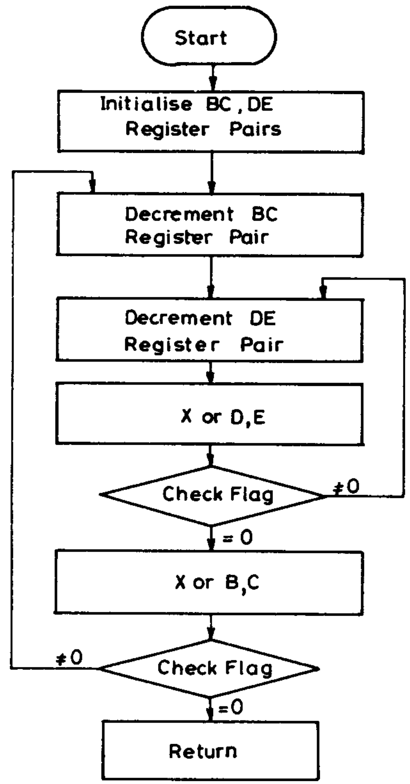

Figure 5. Flowchart of the delay subroutine for counting radioactivity.

3. Experimental details

The stepper motor is energised to rotate the shaft of the micrometer through required angle. Here the stepper motor is rotated by energising two coils at a time. Further the stepper motor needs 200 steps for one complete revolution. It is connected to the shaft of the X–Y micrometer. One complete revolution of the shaft using stepper motor, shifts the test sample by an amount of the pitch of the shaft which is equal to 500 μm. Hence one step of the motor, $1{\cdot}8^0$ corresponds to $2{\cdot}5$ μm shift of the sample laterally. Hence with this auto scanner the least displacement of the sample in the lateral direction is $2{\cdot}5$ μm.

The test sample before electromigration annealing is mounted on the platform of the micrometer. The microcomputer is initialized and then the execute command is given through the key board. It gives a signal to the stepper motor unit to rotate the shaft and the test sample is translated by a distance of 100 μm. Then the cascaded counter is enabled to count the radioactivity coming from the sample through the slit width of 100 μm. The counter counts the number of pulses for a set time. This specific preset time is also executed through the key board while initializing the computer. At the end of the preset time delay the computer disables the counter and receives the content of the counter, stores it in memory. Before resetting the content of the counter the address of the memory is incremented so as to keep it ready to receive the data corresponding to the next position of the sample. Then the impulse counter is reset and the sample is shifted to the next 100 μm distance by energising the stepper motor. This process is repeated to scan the entire length of the sample. At the end of the scan the computer prints the accumulated data and also a plot of the activity versus displacement of the sample is made. Then the test sample is mounted in the electromigration annealing set up described elsewhere (Reddy *et al* 1979) and annealed.

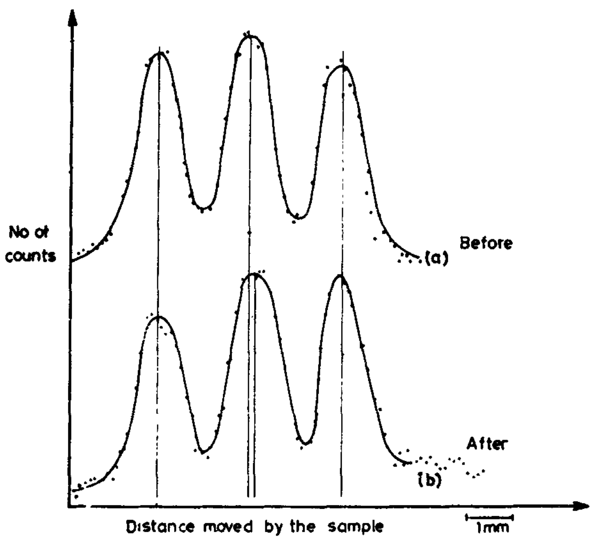

Figure 6. A plot of number of counts versus distance. Dots represent the print out of the radioactive concentration profile from the autoscanner a) Before electromigration. b) Annealed at 473 K. The current density is $2{\cdot}1 \times 10^8$ A/m^2. The continuous line is the best fit to the experimental dots.

The temperature of the furnace could be controlled within $\pm 0{\cdot}5°C$. At the same time a current density of 10^8 A/m^2 is passed through the device. After this electromigration annealing the sample is scanned again in the autoscanner and a plot of the activity versus position is made. A typical plot obtained using the autoscanner is shown in figure 6 for tin thin films annealed at 473 K with a current density of $2{\cdot}1 \times 10^8$ A/m^2.

3.1 *Evaluation of* Z^*

If l_1, l_2 and l'_1, l'_2 are the distance between the dot numbers 1, 2 and 2, 3 before and after annealing then the electromigration shift can be estimated using the following expression.

$$l = (l'_1 - l'_2)/4$$

since $l_1 = l_2$. Using this electromigration drift velocity of the migrating atom

$$v = l/t$$

where t is the time for which the current is passed through the sample. Drift mobility of the migrating atoms is

$$\mu_d = v/E$$

where E is the electric field present along the length of the sample. The electromigration effective charge number Z^* can be calculated using the Einstein relation

$$\frac{\mu_d}{D} = \frac{Z^* e}{kT}$$

where D is the diffusion coefficient, e is the unit electron charge, K is the Boltzmann's constant and T is the absolute temperature at which the sample is annealed. A systematic study of the self diffusion coefficient D and the electromigration effective charge number Z^* was studied as a function of temperature and current density for tin thin films using this automatic scanning arrangement. The results will be published elsewhere.

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