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Robotic electroplating of gold on quaternary semiconductors

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A new technique of electroplating which ensures the maintainance of highly uniform operating conditions is described. A small scale computer-controlled robot-arm is programmed to perform the complex sequence of tasks involved in electroplating gold on samples of quaternary semiconductors based on InP. The technique eliminates the irreproducibility of many aspects of the plating process, including the control of bubble formation and current pulsation.

Laser diodes and detectors operating in the 1.3–1.7 μm wavelength region are actively investigated for fiber-optic communications. For this, InP based quaternary semi-conductors are of special importance [1]. To achieve the expected performance of these materials, ohmic contacts with low resistance must be fabricated [2]. Various fabrication techniques have been reported, including evaporation and sputtering [3]. In most cases the preferred technique is electroplating from aqueous solution [4–9].

Electroplating, however, is largely still an art rather than a science. It is known, for example, that in electroplating, deposits of high quality are usually obtained only over a certain range of current densities and under specific conditions of agitation which are extremely difficult to reproduce [8]. In particular, there is a strong need to develop reproducible procedures for plating to a thickness of ~ 10 nm, which is required for fabricating low specific contact resistance ohmic contacts.

In this shortpaper a new technique of electroplating which ensures the maintainance of highly uniform operating conditions is described. A small scale, computer-controlled robot-arm has been programmed to perform the complex sequence of tasks involved in electroplating gold on samples of quaternary semi-conductors based on InP. The technique eliminates the irreproducibility of many aspects of the plating process, including the control of bubble formation and current pulsation.

The use of dedicated automation in material science is widespread [9]. Automation guarantees reproducibility of material manufacturing. However, dedicated automation is possible only after the correct procedure to manufacture the material has been discovered. To discover this procedure is often a trial-error process involving a very large number of researcher-hours. This happens essentially because it is impossible for the human experimenter to maintain uniformity of conditions from one experiment to the next. This uniformity can be maintained, or at least greatly improved, by the use of a small scale programmable manipulator.

A robot-arm Minimover-5*, which has recently become commercially available, has been used. Although primarily designed as a teaching tool for instruction in robotics and for automation of light assembly, application to physico-chemical research has recently been proposed [10]. The robot is a 5-jointed mechanical arm which provides an unusual combination of dexterity within a sphere of action of ~ 40 cm. Lift capacity is ~ 8 ounces (~ 225 g), speed of motion can reach 15 cm s^{-1} and the resolution is ~ 0.25 mm. The robot can be controlled by a variety of microprocessors. For simplicity we have interfaced it to an Apple II+† which is quite adequate for the slow-speed application described here.

The robot has been programmed to perform the following tasks.

1. Pick up the samples from its initial site.

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* Registered trademark of Microbot Inc.

† Registered trademark of Apple Computers.

2. Immerse and wash the sample in methanol for 30 s. Remove.
3. Immerse and wash the sample in distilled water for 30 s. Remove.
4. Immerse the sample in plating solution at a set position in the cell.
5. Switch on plating current pulses for 60 s.
6. Lift the sample out of the solution every 10 s to prevent bubble formation.
7. Switch off current.
8. Remove sample from solution and rinse in distilled water for 30 s.
9. Deposit sample in final position for examination.
10. Return to initial position.

Figure 1 shows part of the experimental set up. The robot-arm is in the process of moving the sample from one cleaning bath to the next. The details of the experiment are as follows. The sample holder consists of a tantalum clip on a glass slide (2 x 3 cm). The samples studied were ~ 2 x 5 mm. The samples were covered in the centre with a strip of varnish ~ 2 x 1 mm. Only the portion of the sample below the varnished strip (~ 2 mm x 2 mm) was exposed to the electrolyte. After plating, the varnish strip was removed in acetone and the thickness of gold measured on an alpha-step stylus instrument. Three sets of samples of different compositions were studied: epitaxial layers (~ 100 μm thick) of p-type $In_{0.73}Ga_{0.27}As_{0.6}P_{0.4}$; n-type $In_{0.53}Ga_{0.47}As$ (on InP semi-insulating substrates) and p-type InP. Temperature of the measurements was 55° C and the bath was illuminated with a 100 W projector lamp to aid plating on InP [8]. The gold plating solution was Autronix CI (100 cm^3 in 350 cm^3 of water at pH = 3.5). The solution was continuously stirred. The counter electrode was a platinum foil (~ 3.6 cm^2). Galvanostatically controlled square wave current pulses were applied between 32.3 mA cm^{-2} and − 5.86 mA cm^{-2} of duration 5, 50 and 500 ms. The samples were plated for 60 s.

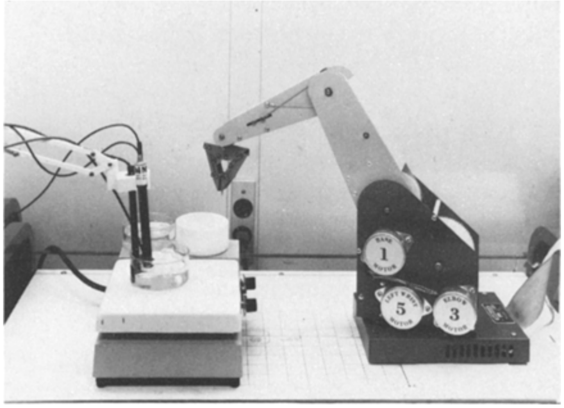

Fig. 1. Robot-arm transferring a sample from the washing solution to the plating bath.

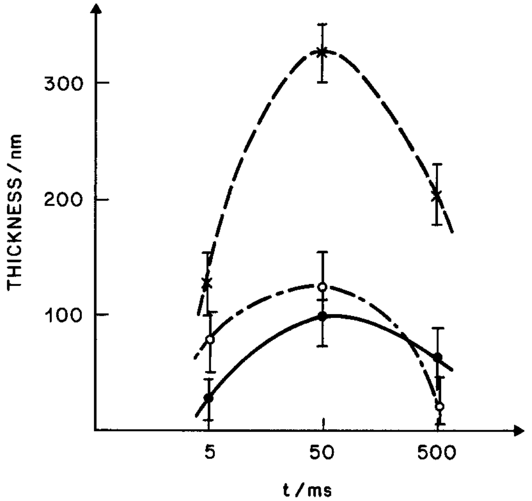

Fig. 2. Thickness of gold plated at various frequencies for; – – –, n-$In_{0.53}Ga_{0.47}As$; – · – ·, p-$In_{0.73}Ga_{0.27}As_{0.6}P_{0.4}$; ——, p-InP.

Figure 2 shows the results of the robotic plating experiment. Thickness of the plated gold varies with frequency peaking at a pulse duration of ~ 50 ms. Although the thickness differs for samples of different composition (which is expected) a clear trend emerges. More data are necessary to obtain a functional relation, but the high reproducibility of these experiments shows that this is possible, so that an optimum frequency can be selected to achieve the desired thickness.

Frequency is only one of the variables that can be changed to search for the optimum plating conditions. For example, the robot arm can be programmed to place the sample in different parts of the cell, i.e., with a different distribution of potential; or the frequency of lifting the electrode from the solution can be altered to reduce bubble formation, and so on. Furthermore, gold plating is only the first step involved in the fabrication of ohmic contacts on these materials. Thus, gold plating is usually followed by zinc plating and a second gold plating [3]. The entire process can be carried out by a robot with the same method shown here for the first plating of gold. Results will be reported elsewhere.

In this note we have emphasized the advantages of small scale robots to maintain uniformity of conditions during electroplating and to allow a systematic study of the influence of many hidden parameters (such as bubble formation).

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