Journal of Scientific & Industrial Research
Vol. 70, December 2011, pp. 1026-1028

# A virtual instrument for pulsed electrodeposition: A novel technique for obtaining graded coatings

Nirmala Sanikommu*, Nitin P Wasekar, A S Joshi and G Sundararajan
International Advanced Research Centre for Powder Metallurgy & New Materials, ARCI, PO Balapur, Hyderabad 500 005, India

*Received 26 July 2011; revised 19 September 2011; accepted 10 October 2011*

This study presents a computerized virtual instrument to generate a sequence of current pulses across two electrodes immersed in an electrolyte. Pulse parameters can be entered from a keyboard. Amplitude of pulses can be fixed or programmatically varied over the process period. This system is well suited for developing coatings with graded physical properties.

**Keywords**: Electrodeposition, Graded coatings, Pulse plating, Virtual Instrument

## Introduction

Improvement in physical and electrochemical properties of coatings has been reported[1-11] by varying pulse parameters during electrodeposition. This study presents virtual instrument [VI], which permits amplitude of reverse pulses to be continuously varied at a predefined linear rate over the process period. Non linear profiles can also be added later.

## Experimental Section

### Virtual Instrument (VI)

#### *Operating Parameters and Controls*

VI is built with LabVIEW software version 8.0, a PCI 6221 Data Acquisition Card and a PC. Loaded program can be run by any unskilled operator by entering desired parameters in Front panel (Fig. 1). Operator selectable parameters are coating area, pulse on current densities, coating type & mode [fixed / graded] and data storage file name and path. In fixed mode, amplitude of pulses is kept constant corresponding to the entered values of current density and coating area. In graded mode, amplitude of successive reverse pulses can be linearly varied over the preset process period. By default, pulse amplitude is taken as the specified reverse current density times the coating area. In this case, there are 4 possibilities: i) Type 0, where amplitudes of successive pulses decrease from 0 to the peak value; ii) Type 1, where they increase from peak value to 0; iii) Type 2, where they decrease from 0 to peak and then increase back to zero; and iv) Type 3, where they start from peak, increase to zero and then go back to the peak value. There is wide flexibility in the design to add more types of operational modes later. Thus, it will be possible to vary amplitude of the forward as well as reverse pulses as a function of the process time in more ways than the linear rise or fall. Some examples of such functions are exponential, logarithmic, trigonometric, polynomial or a combination of these expressions.

#### *Measurement and Display*

Two digital indicators show the value of computed current in each direction. Waveforms of generated voltage pulses, current pulses and a plot of reverse amplitude against process time are displayed on the panel, during the process run. The program also integrates current that has flown over a specified time period, usually one second, in real time. This value is used to automatically compute and display the net charge per second (charge delivered in positive part of cycle minus that during the negative cycle, if any). RMS voltage output across the load is divided by RMS value of current to compute and display load impedance. There is also a provision to periodically store these computed values in excel compatible files, at pre-designated locations, for further analysis, whenever desired. Computed values are within ± 1% of real values.

*Author for correspondence
E-mail: nirmala@arci.res.in

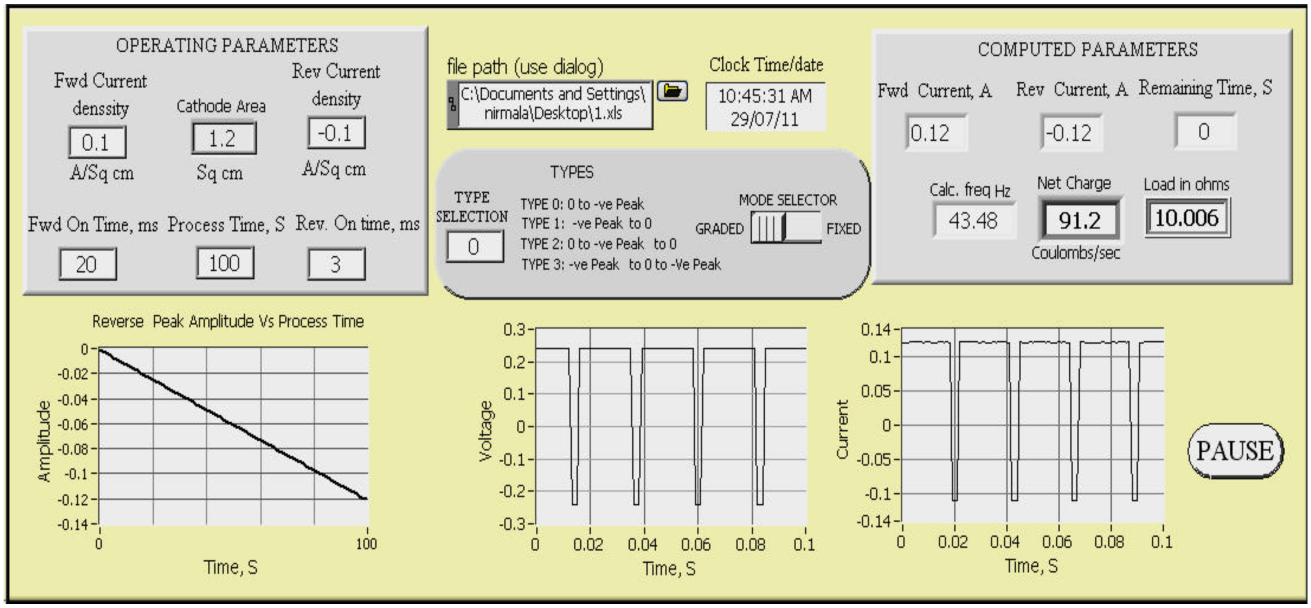


Fig. 1—Typical screenshot of front panel screen of Virtual Instrument (VI)

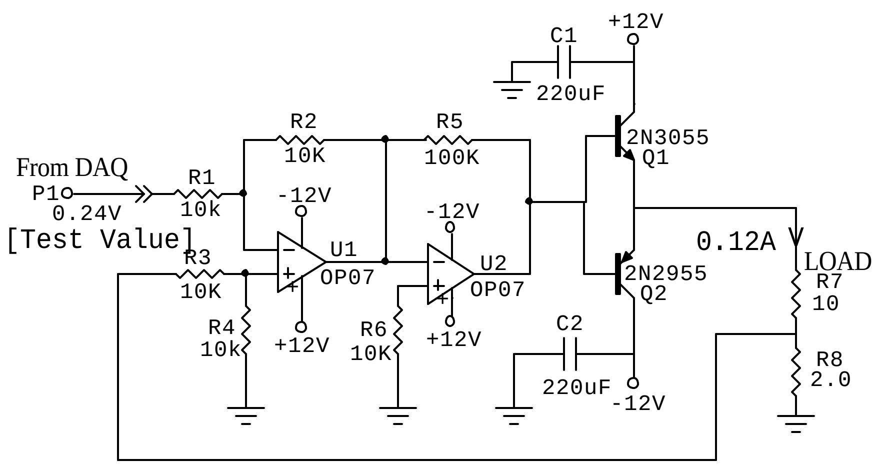


Fig. 2—External hardware, driven by Data Acquisition card (resistance R7 represents electrolyte load)

***Additional External Hardware***

LabVIEW program uses entered parameters to generate a pulse, which comprises of two independently programmed pulses, one for each direction. This pulse appears at the output of DAQ card and drives external hardware (Fig. 2). At DAQ output, 0.24 V is designed to produce 0.12 A of load current. Two complementary transistors (Q1 & Q2) generate load current through R7 and sensing resistor R8. Summing amplifier U1 compares DAQ output with feedback voltage across resistor R8. Difference between two inputs drives Q1 and Q2. Thus, even if load impedance R7 varies, the current is still maintained at desired value. Maximum value of load current delivered can be changed by varying R8 to suit application requirements.

## Results and Discussion

**Testing and Measurement**

VI was first tested on resistive loads for generating uni- and bi-directional pulses of varying pulse widths. Pulse outputs were monitored on a Digital Storage oscilloscope to confirm that generated waveforms agree with the entered parametric values. Next, computed values of load resistances were compared with their true values. The results of these tests have shown that these values are within ± 1% of each other.

**Coating Test**

An electrodeposition coating trial was carried out using a copper cathode and a nickel anode immersed in a solution of nickel sulphate. A positive pulse (amplitude, 100 mA; width, 20 ms) was immediately followed by a

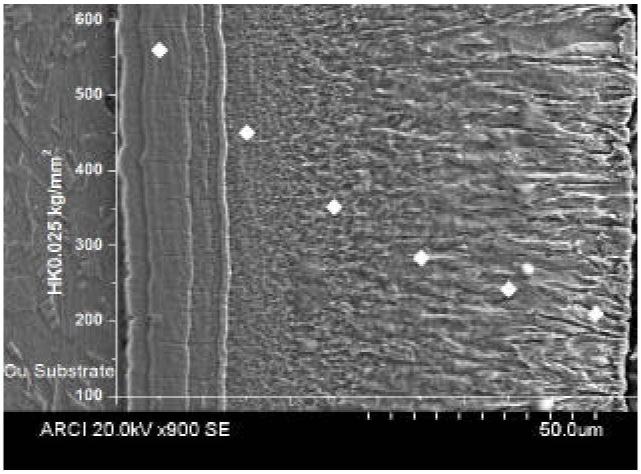


Fig.3—SEM photograph of a transverse section of coating, with superimposed hardness profile


Fig. 4—SEM photograph of coated section with microhardness indentations

negative pulse (width, 3 ms). Type 0 graded mode of operation was invoked to maintain a fixed amplitude of forward pulses while amplitude of reverse pulses was linearly increased from 0 to 100 mA over the process period of 120 min. The purpose of this test was to progressively refine grains across the thickness, as the coating develops and thus control its hardness. A transverse section of coating was studied under a scanning electron microscope (SEM). Corresponding graph of the variation of hardness across the coating thickness is also shown in the same figure (Fig. 3). Hardness was measured by a microhardness tester. Reduction in size of indentations is clearly visible in microphotograph (Fig. 4). These tests have been repeated several times to assess their reliability and consistency.

## Conclusions

A virtual instrument (VI) has been developed for pulsed electrodeposition. It is particularly useful for studying and establishing a relationship between physical properties of coatings and their pulse processing parameters. By correlating a physical property with a process parameter, it will be possible to develop functionally graded coatings with physical properties tailored to suit specific application requirements.

## Acknowledgment

Authors thank Ms N Aruna for testing and Dr S V Joshi, Associate Director, ARCI for guidance and support.

## References

1 Tao S & Li D Y, Tribological, mechanical and electrochemical properties of nanocrystalline copper deposits produced by pulse electrodeposition, *Nanotechnology*, **17** (2006) 65-78.

2 Chandrasekar M S & Pushpavanam M, Pulse and pulse reverse plating – Conceptual, advantages and applications, *Electrochim Acta*, **53** (2008) 3313-3322.

3 Mukhurov N I, Kapran Y S & Kotova I F, A source of reversible current with varying amplitude, frequency, and positive-to-negative-pulse-length ratio, *Instru Exp Tech*, **45** (2002) 285-287.

4 El-Sherik A M & Erb U, Synthesis of bulk nanocrystalline nickel by pulsed electrodeposition, *J Mater Sci*, **38** (1995) 5743-5749.

5 Lee D M, Folkerts J T, Collins F L, Dietrich A E & Keeney A, *Comparison of the electrochemical and physical properties of nanocrystalline copper deposition in the fabrication of printed wiring boards*: http://www.pcb007.cm/pages/zone.cgi?a=58490&_pf_1, May 2010.

6 Roy S & Landolt D, Determination of the practical range of parameters during reverse-pulse current plating, *J Appl Electrochem*, **27** (1997) 299-307.

7 Vidrine A B & Podlaha E J, Composite electrodeposition of ultrafine c-alumina particles I nickel matrices Part i: Citrate and chloride electrolytes, *J Appl Electrochem*, **31** (2001) 461-468.

8 Hofland R W, *The theory behind pulse plating reversal current*: http://www.circuitree.com/Articles/Web_Only_Editorial/6ef3097bf18d7010VgnVCM100000f932a8c0, 2001.

9 Chan K C, Qu N S & Zu D, Effect of reverse pulse current on the internal stress of electroformed nickel, *J Mater Process Technol*, **63** (1997) 819-822.

10 Hallez L, Petris-Wery M D, Assoul M, Feki M & Ayedi H F, Multicriteris optimization of mechanical and morphological properties of chromium electrodeposits under reverse pulse plating, *J Appl Electrochem*, **37** (2007) 843-852

11 Dobrav D, Vetter J, Angert N & Neuman R, Periodic reverse current electrodeposition of gold in an ultrasonic field using ion-track membranes as templates: growth of gold single-crystals, *Electrochimica Acta*, **45** (2000), 3117-3125.