Computer Control of Pressure in Plasma Processing

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Abstract: - A system for computer control of working pressure in a plasma nitriding unit by using a DCM (Distributed Controlled Modules) system is described. Plasma nitriding as a thermochemical process of materials surface treatment is widely used in many areas of industrial applications such as microelectronics, automotive industry, air space industry etc. This process is in development, especially concerning plasma generators and related electronics. The processes at the surface of workpieces require a very precise control of many process parameters, the most important being the working gas composition, substrate temperature, pressure and discharge voltage. Generally electrical discharge is used for both the plasma processing and heating of the substrate by the surface bombarding particles. The first process step is the so called cleaning and heating stage, which is characterized by large number of glow-to-arc discharge instabilities. Besides an independent and precise control of the process parameters cited above, a computer control is needed to minimized the arcing processes and the other plasma instabilities.

The total pressure inside the processing chamber is important for homogeneity control of the surface treatment of complex shaped substrates. The local overheating due to so called hallow cathode effect may be controlled by appropriate working pressure adjustment. This paper deals with computer control of working pressure in the plasma nitriding unit JONEL1254, which consists of gas supply station, vacuum chamber with corresponding vacuum components, plasma generator, measuring unit and control unit for computer acquisition and control of plasma processing parameters.

The control unit is a DCM slave node, connected to the PC through the serial BitBus interconnect. Each DCM node contains a microcontroller Intel 8051, which provides data processing inside the node itself. A DCM communication software, actually an operating system for BitBus compatible modules, is developed and used for the communication between PC and control unit, i.e. between DCM master and slave node.

*Key-Words:*pressure control, plasma nitriding, Distributed Controlled Modules

1 Introduction

Plasma nitriding is intended for thermochemical treatment of substrate material surface, in order to modify a surface zone by thermal diffusion of nitrogen particles from surrounding medium. The nitrogen diffusion process and nucleation of new material phases depends on the substrate temperature and chemical reactions at the substrate surface. The thermochemical processes and “activation” of the substrate surface may be controlled by glow discharge voltage, substrate current density, total pressure and gas composition [1]. For the workpieces heating, by the substrate bombarding particles, a certain level of substrate current density is needed, so that the system operates in the abnormal glow discharge regime. This type of discharge is unstable, i.e. a glow-to-arc transition may frequently appears [2]. In order to reach the process stationary state the stage of cleaning and substrate heating has to be performed successfully. Due to a very large number of arcing at the cathode surface this process step is governed by stochastic instabilities in the system.

Besides the main process parameters, such as the treatment time, gas mixture composition and pressure, a glow discharge plasma processing requires the lowering of the arcing frequencies and the adjustment of the plasma generator voltage pulses width and height in the case of the DC pulse power supply. For the best process results the independent control of all process parameters is required, which means that the best performances can be achieved by using a computer control of all process steps.

In this investigation the plasma nitriding unit JONEL1254 was used, which consists of the working gas supply station, vacuum chamber with the various vacuum components, plasma generator, measuring and control unit. The system is intended primarily for plasma nitriding of various functional components made of steel or other ferrous materials, in order to enhance the surface properties like microhardness, wear resistance, corrosion resistance, fatigue resistance and tribological properties.

The existing plasma processing systems use an on-board microprocessor or a personal computer for the data acquisition and process control. A flexible hardware solution is applied in the JONEL1254 unit, which provides computer process control by means of a microcontroller and/or PC. The control unit of the plasma nitriding unit is a DCM slave node, connected to the PC through the serial BitBus interconnect. This solution provides the data processing inside each node, containing the microcontroller Intel 8051. The process parameters control can be located at the desired position in the system due to DCM systems multitasking concepts.

The aim of the total pressure control in the dynamic vacuum, during plasma nitriding, is to provide a precise gas mixture pressure adjustment in the range from 0.5 to 10 mbar, at any binary gas mixture of hydrogen and nitrogen. An inappropriate total gas pressure may initiate the arcing processes or the formation of so called hallow cathode effect, which usually leads to the local overheating of complex shaped workpieces. The arc formation can seriously damage the substrate surface and a large arcing frequencies causes a large treatment time.

In a dynamic vacuum system, the stationary pressure is determined by the pumping speed of the vacuum pump, the overall system conductivity and the gas flow at the vacuum vessel inlet. The pressure control is usually realized by the gas flow variation at the processing chamber inlet and by changing the system pumping speed by the throttling valves at the outlet. In reference [3] the RVG 040 control unit and the RME 010 valve for the total gas flow control were used, without a separate control of the gas pumping speed. The desired pressure is achieved by comparing the pressure sensor signal and the set-point of the PID regulator. The drawback of this solution is the lack of the pumping speed control, which means that the pressure range is limited, the gas consumption is large as well as the system reaction time, but the cost of the hardware is lowered since a special throttle valve at the chamber outlet doesn't exist. In addition, an absolute pressure meter is necessary, which output signal doesn't depend on the gas composition.

In this paper a pressure control method, based on actuators mounted at both input and output of the working chamber, is described. The total input flow of the gas mixture is controlled by two thermal mass flow controllers [4], designed for the flow range from 0 to 500 ml_n/min. The pumping speed at the chamber outlet is controlled by three on-off valves, in which way three ranges of the pumping speed are obtained. By using the algorithm described in this paper, a fast and precise pressure control was performed at any desired working gas mixture composition.

2 Plasma nitriding unit JONEL1254

An industrial 50 kVA plasma nitriding unit JONEL1254, developed at the School of Electrical Engineering, University of Belgrade, contains (Fig.1):

- Electric power supply unit, which consists of 50kVA dc plasma generator and 5kVA supply unit for infrared heating of workpieces.
- Vacuum process chamber ϕ 900x1200mm.
- Vacuum system includes a rotary vacuum pump and three electrically operated on-off valves.
- Gas supply station.
- System for preparing the processing gas mixture by using two thermal mass flow controllers (Hi-Tec) for hydrogen and nitrogen dosing.
- Water cooling system.
- Process monitoring system (measuring unit) with various sensors.
- Control unit, which forms a DCM slave node and allows computer control of plasma processing.
- Personal computer, which is a DCM master node.

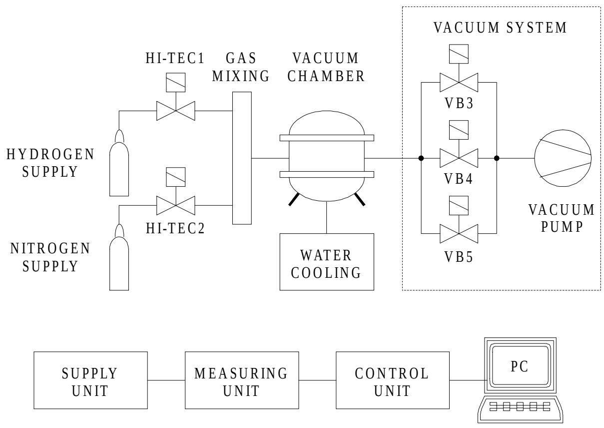

Fig. 1. The plasma nitriding unit JONEL1254

3 DCM systems

A DCM system consists of one master and up to 250 slave nodes, that communicate via the BitBus network. A DCM system is realized with BitBus compatible boards and modules [5], [6]:

- DTX344 BitBus Master Controller Board, which generates BitBus from the iSBX connector. DTX344 contains microcontroller 8051, external memory, serial and iSBX (parallel) interface.
- DT901 Remote Controller Board, which forms a slave node in the DCM system. DT901 contains microcontroller 8051, external memory, serial interface and 4 iSBX connector for I/O expansion.
- DTX311 iSBX-compatible A/D converter module with 12-bit resolution. The DTX311 provides 16 single-ended or 8 differential analog input channels and converts the analog signal to digital data at rate of up to 20kHz.
- DTX328 iSBX-compatible D/A converter module with 12-bit resolution. The DTX328 provides 8 analog output channels, which provide a voltage or current output.
- DTX350 iSBX-compatible digital I/O module, which uses an Intel 8255A Programmable Peripheral Interface. The DTX350 provides 24 parallel I/O lines software-configurable as 3 ports.

DCMCF (DCM Controller Firmware), which resides in each DCM node, monitors and controls all operations in the DCM system. DCMCF is composed of the four parts:

- Power-up and diagnostic tests.
- iRMX 51 Executive monitors the DCM system and allows communication between nodes on the BitBus interconnect.
- Communications services automatically handle all communications in the DCM system.
- RAC (Remote Access and Control) interface provides a means to manipulate memory and I/O areas in the DCM systems. It allows the user to manage remote functions without creating a task.

Creation of the BitBus is a two-step process: first, an iSBX bus must be derived from the host computer system bus and second, a BitBus must be generated from the iSBX bus. On the IBM personal computer the iSBX bus is provided by using the DT2806 Multi-Function I/O Expansion Board [7]. The BitBus is generated by the DTX344 plugged into the iSBX connector. The DTX344 converts the iSBX bus into the BitBus and becomes the master node of the BitBus network it supports.

The BitBus is a high speed, differentially driven, serial bus that supports IBM's SDLC (Synchronous Data Link Control) and uses RS485 standard. BitBus supports both synchronous and self-clocked mode of operation. The synchronous mode provides the highest performance at a relatively short distance (30 meters or less), while self-clocked mode permits long distance communications (up to 13.2km) with reduced transmission rate (62.5Kbaud or 375Kbaud). BitBus is intended for the industrial control applications, because it provides noise protection and allows communication over long distances.

Communications on the BitBus are controlled by the iRMX 51 Executive, which resides in both the DTX344 (master node) and the DT901 (slave node). It is a multitasking package which provides the protocol, message structure and individual task control programs. Message exchanges between nodes are based on a hierarchical architecture in which the master initiates communication with a slave, which simply replies to the master node. However, intertask communication is possible in the DCM system, through RAC interface, which permits a user task to control and monitor an I/O device on the same node as the task or on a remote node. The RAC commands also allow the user to invoke iRMX 51 system calls.

Main quality of the DCM system is providing processing power on each node on the BitBus. Each slave node contains intelligence (firmware) which enables it to make event control decisions at the local level without accessing the master node. Moreover, the slave nodes can exchange information with the master node while executing concurrent tasks. The node intelligence consists of the preconfigured DCM controller firmware. However, the user can store additional control tasks in the node external memory device and tailor node function to his own application.

4 DCM system of the JONEL1254 unit

The DCM system of the plasma nitriding unit JONEL1254 contains one master and one slave node, which are connected through the BitBus interconnect (Fig. 2). The self-clocked mode with 375kBaud transmission rate is used. The master node is derived from the personal computer, by using DT2806 and DTX344 boards. The control unit is a slave node, which allows computer control of the plasma nitriding process parameters and switching of some plasma nitriding unit subsystems.

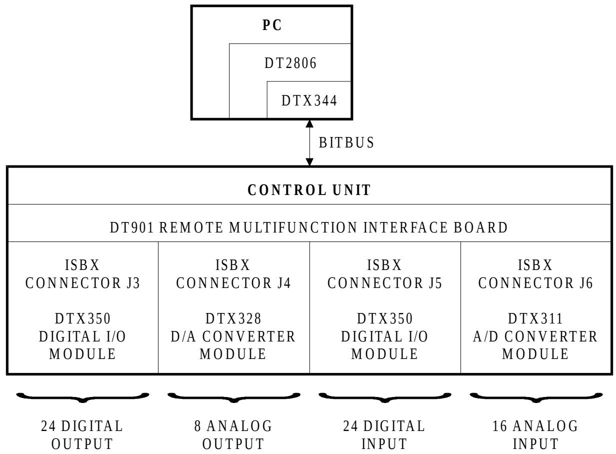

Fig. 2. The DCM system of the JONEL1254 unit

Control unit contains:

- DT901 controller board with microcontroller Intel 8051 and 4 iSBX connectors for I/O expansion. DT901 board provides communication to the PC (DT901 contains the DCMCF) and allows data processing through the microcontroller programming (by storing user tasks into the microcontroller external program memory).
- DTX350 digital I/O module, with 24 outputs, for a on-off control of various valves, switches, relays and LED indicators, is used for some subsystems switching, control of some process parameters and light indication of the switching elements state.
- DTX350 digital I/O module, with 24 inputs, allows monitoring of the switching elements state, controlled by the DTX350 output module.
- DTX328 D/A converter module, with 8 analog outputs, allows setting of some process parameters (gas flow, electric discharge voltage).
- DTX311 A/D converter module, with 16 analog inputs, allows data acquisition from various sensors (flow, pressure and temperature meters).

5 DCM communication software

The DCM communication software [8] is used for the communication in the DCM system of the plasma nitriding unit and it is originally developed for the service mode of the JONEL1254 unit operation [9]. The DCM communication software provides program support for communication between personal computer and control unit and basically represents the operative system for the BitBus compatible modules. The DCM communication software consists of the routines for BitBus messages exchange and the routines for operation with control unit.

The routines for BitBus messages exchange provides basic software support for communication between personal computer and control unit. The movement of information between personal computer and DTX344 board through the iSBX interface is in the form of a BitBus message, while DTX344 serializes and deserializes data and communicates with the control unit through the BitBus interconnect. The BitBus messages consist of a series of data bytes delimited by a command byte. The first data byte in a message is a value that indicates the number of bytes in the message. A message is sent by writing data bytes to the iSBX interface, starting with a length field, followed by writing a command byte. A message is received by reading a series of data bytes until a command byte is available and read.

The routines for operation with control unit provides tasks control, data read/write from/into the control unit data memory and operation with the I/O modules of the control unit. The basic of this program part consists of the routines for exchange BitBus messages with the RAC parameters, which invoke RAC services. The RAC interface provides two type of services: data access and task control. The data access services allow data read/write from/into the internal and external data memory of the DCM nodes, while the task control services allow the user to invoke iRMX 51 system calls on a remote node.

The I/O modules of the control unit are seen as a register assembly in I/O memory space of the control unit, so the routines for manipulation with the I/O areas allow I/O modules control without creating a task inside the control unit. In that way data acquisition from the DTX311 A/D converter module and DTX350 digital input module and setting parameters to the DTX328 D/A converter module and DTX350 digital output module are provided.

6 Algorithm for pressure control

In the dynamic vacuum system the stationary pressure is achieved when the total gas flow at the chamber input is equal to the pumping flow of the output pumping system. In the JONEL1254 system the dynamic pressure control is performed by controlling both the input gas mixture flow and the throughput of the pumping system. Since the hydrogen and nitrogen mixture is used, the flow of each gas is controlled by a thermal mass flow controller, working in the range from 0 to 500 ml_n/min.

The aim of the pressure control algorithm is to achieved the desired stationary pressure starting from the actual pressure level and to provide the achieved pressure during certain time period. The component gas flow sum makes the total mixture flow into the system and hazed to be equalized to the output flow at desired pressure, at any gas composition value. The pumping speed of the vacuum pump is non-linear function of pressure, so that the desired pressure range has to be selected by using the on-off valves with different conductance, which corresponds to the flow range of the thermal mass flow controllers.

At the higher pressure values the vacuum pump throughput exceeds the maximum flow of the thermal mass flow controllers, so the throttling of the output flow is needed. The three different conductance of the on-off valves were found to be necessary in order to provide the pressure range from 0.5 to 10 mbar:

- Valve Vb3 with the inner diameter 2mm for the pressure higher than 4.5 mbar.
- Valve Vb4 with the inner diameter 3mm for the pressure range from 2 to 4.5 mbar.
- Valve Vb5 with the inner diameter 10mm for the pressure lower than 2 mbar.

The relation between pressure and the system stationary gas flow is given in Fig. 3. The given values were obtained at the stationary state when the total input gas flow is equaled to the pumping flow. It can be seen that for the different pressure ranges different valves are used and that the subsequent pressure ranges overlap. The process itself requires certain minimum gas flow since a part of nitrogen is taken by the samples surface due to the diffusion process. It follows that a specified valve must be used for the specified range of pressure control.

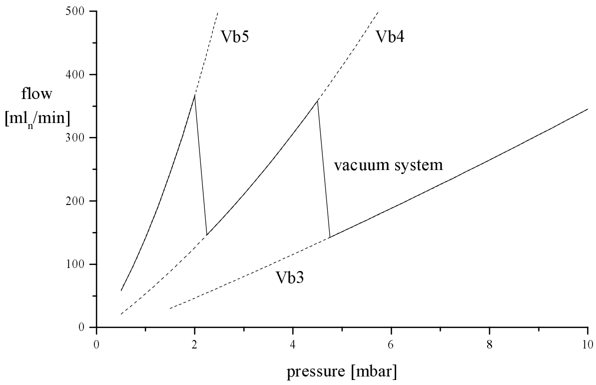

Fig. 3. The total gas flow as a function of the system stationary pressure for a given on-off valve used for output flow range control

The pressure increase in the system is obtained by closing all outlet on-off valves and increasing the input gas flow, with the constant relative flow of component gases. For the pressure decrease the maximum pumping speed is used by opening all output valves, without any input gas flow. In that way a relatively fast pressure change is obtained. After the desired pressure is reached an algorithm is necessary to maintain this pressure value during the plasma processing. This means that the corresponding stationary gas flow in the system must be obtained. The additional problem is related with the pressure meter output signal. The used Pirani gauges have a very non-linear characteristics in the desired pressure range, which is also strongly dependant on the gas mixture composition used [10]. It follows that the pressure measurement resolution varies with the pressure and gas composition.

The pressure maintenance algorithm is composed of three phases: rough, intermediate and fine pressure maintenance. The global algorithm is given at Fig. 4. The desired pressure is denoted by p, the actual pressure is p[t], Δt is pressure sampling time (1 minute), Q is actual total gas flow, p2Q is pressure-to-flow conversion factor and CPT is constant pressure time.

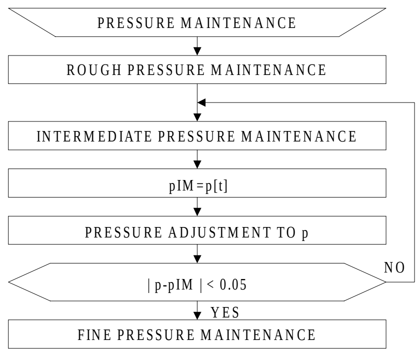

Fig. 4. The pressure maintenance algorithm

The algorithm for rough pressure maintenance estimates the stationary gas flow for the desired pressure, based on the data given in Fig. 3. In this phase the input flow adjustment is based on the difference between the subsequent pressure values using a pressure-to-flow conversion factor, which is constant for given working chamber. This algorithm is terminated when the total input flow is inside the 10 ml_n/min range around the stationary flow value. The algorithm for rough pressure maintenance would be the only one in the case of an arbitrarily precise pressure measurement.

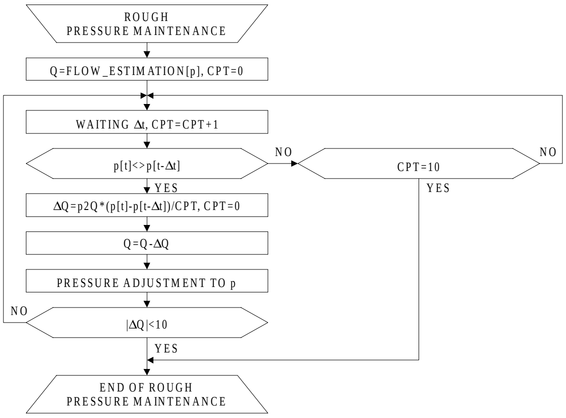

Fig. 5. The rough pressure maintenance algorithm

In the fine pressure adjustment phase (Fig. 6) the minimum step of the input flow change is applied, which is 0.15 ml_n/min, so that the flow oscillation is avoided. This flow step may appear inappropriate in the case of large deviation of the actual input flow from the stationary flow. In this case the intermediate pressure maintenance algorithm is used (Fig. 7), with the flow step of 1.2 ml_n/min.

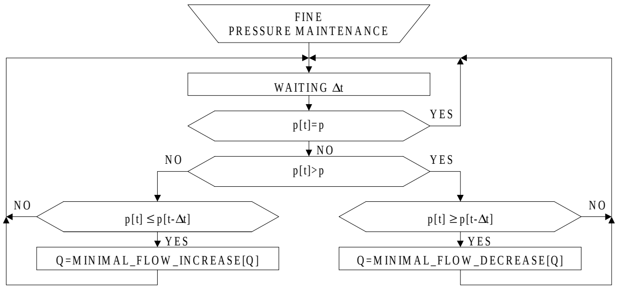

Fig. 6. The fine pressure maintenance algorithm

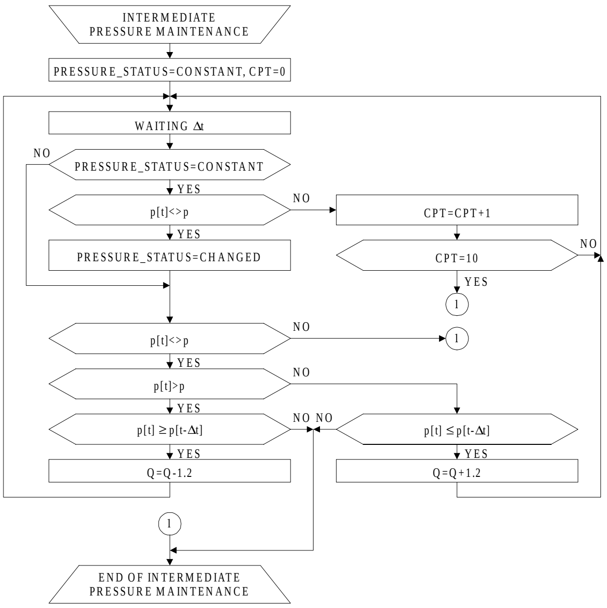

Fig. 7. The intermediate pressure maintenance algorithm

7 Conclusion

A simple system for computer control of the total pressure in a plasma nitriding unit and a control algorithm is presented. The system consists of two thermal mass flow controllers at the vacuum chamber inlet and a rotary vacuum pump and three on-off valves at the vacuum vessel outlet. The desired pressure is attained in the stationary state, when the input gas flow is equal to the pumping flow at the chamber outlet. The total input gas flow is the sum of the component gas flows (hydrogen and nitrogen). In order to maintenance constant gas mixture composition the relative flow of the component gases must be capped constant. The described algorithm contains three phases for rough, intermediate and fine pressure adjustment around the desired value, in which the different flow change steps are used. This algorithm has been successfully tested during the operation of a 50 kVA plasma nitriding unit.

References:

[1] T.Gredic, M.Zlatanovic, “Surface Coating Technology”, 48, 1991, pp. 25

[2] M.Zlatanovic, B.Tesic, D.Nojkovic, “Glow-to-Arc Transition Instability Sensor in Processing Plasma”, Proc. MIEL ‘95, Vol.2, 1995, pp. 597

[3] Balzers, “HV Gas Dosing Valves”, Vacuum Components Edition 86|88, 1988, pp. H35

[4] Bronkhorst High Tech B.V., “Mass Flow Meters and Controllers Instruction Manual”, 1989

[5] “ISBX 344 Intelligent BitBus Interface Board User’s Guide”, Intel Corporation, 1985

[6] Complete Set of User Manuals for DT901, DTX311/DTX311EX, DTX328, DTX350, Data Translation, 1985, 1987

[7] “DT2806 User Manual”, Data Translation, 1987

[8] M.Zlatanovic, Z.Zirojevic, I.Popovic, D.Obradovic, “Communication Software for DCM System of Plasma Nitriding Unit JONEL1254”, Proc. IT ’99, 1999 (in serbian)

[9] Z.Zirojevic, M.Zlatanovic, I.Popovic, D.Dujkovic, “Service Mode For Remote Control Of Plasma Nitriding Unit”, Proc. ETRAN ’98, Vol. 4, 1998 (in serbian)

[10] M.Zlatanovic, “Sensors in Diffusion Plasma Processing”, Proc. MIEL’95, Vol.2, 1995, pp. 565