

Modeling, Algorithms and Implementation of the Microcontroller Control System for the Ion Beam Forming Process for Nanostructures Etching

Aleksandr Ralo¹, Andrii Derevianko¹, Aleksandr Kropotov¹, Sergiy Styervoyedov¹
and Oleksiy Vozniy¹

¹ V.N. Karazin Kharkiv National University,

Svobody sq. 4, 61022, Kharkiv, Ukraine

ralo-a-n@mail.ru

Abstract. In this work a three-level control system for the vacuum-plasma system with the ion source based on high-frequency induction discharge architecture is described. The system is built on smart sensors and specially designed for operation in high EMI programmable logic controllers (PLCs) in the middle hierarchical level. The structure of PLC and the algorithms of the system are presented. Results of comparative simulation of classical management system and created one, as well as the results of the system applying to obtain beams of positive and negative ions and beams neutralized particles are reported.

Keywords. Programmable logic controller (PLC), control system, plasma technology, empirical model

Key terms. InformationTechnology, CommunicationTechnology, Software-System, Integration, Process

1 Introduction

Ion beams are an effective means of the surface treatment. Their application can be found in the industry of the integrated circuits manufacturing, as well as for research purposes as a powerful tool of micro-and nanoscale structures synthesis. However, during the materials treatment by ion beams due to effects of similar charges repulsion and the charge accumulation near the processed surface, defects are formed in the form of islet unetched films and vice versa – side etches. There are unwanted and unpredictable changes in the structure of the processed sample that can irreversibly change the characteristics of the ware [1]. There are several methods of excluding or compensating the charge accumulation. One of the most promising technique that can increase the rate of applicable products during plasma-beam processing is alternately etching by pulsed beams of ions of different signs and etching by high-energy beams

of neutral atoms, where the particle charge is neutralized by the ion beam away from the treated sample [2], [3], [4].

Short times and complex algorithms that should be taken into account during these experiments do not allow the operator to process without the use of modern computer automation systems that work using a process model. Therefore, the aim of this work was to create the intellectual management and control system, that will meet the requirements of operating conditions of the pulsed plasma-process plant for etching and micro- and nanostructures formation. An urgent task today is to build a system capable of independently analysis of historical data, and using them to provide the process control. Seeing the specifics of the pulsed plasma-ion process system must ensure the fastest possible response to the effects of interference that is impossible with the use of information-analytical systems (IAS) based on the classical scheme and used for the slower process.

2 The Use of Programmable Logic Controllers in Control Systems

Programmable logic controllers (PLCs) are widely used in such control systems as industrial automation and automation of scientific research. They provide significantly higher reliability than personal computers, and the same flexibility of working. Difficulties with changes in the operation make popular today microcontroller systems as not sufficient automation tool.

In order to improve the efficiency of the system it was proposed to build the hardware using three-tier architecture, as it shown in Fig. 1. The lower level consists of intelligent sensors and control elements, which control the PLC work.

PLCs have a much greater speed and are responsible for getting data from sensors, filtering, formation of data packets and for communicating with the control centre, created on the basis of a personal computer.

Algorithmic work of such system can be represented as follows:

1. Information about physical parameters, obtained by sensors, after conversion into digital codes enters with the corresponding interface to the programmable logic controller.
2. PLC forms an information packet, transmits the received information to the managing node (in our case, the system arbiter).
3. The central node addresses for the data needed to the historical data storage, analyzes them and, if necessary, generate management command. Information received from the PLC is also stored in the repository for further analysis.
4. This control command is received with the PLC, which transmits it to the appropriate control element.

This design exceeds the performance of classical one, because: first, damaged or incorrect data can be filtered by a PLC, and second, the PLC data is transferred using an optimum package format.

Modern PLC consists of three main parts:

- PLC processor module

- I/O modules
- Programming mechanism

Typically, these parts are combined with the use of crates on a physical level and a number of tiers on the logical one.

Despite the structural similarity of the PLC with the PC, the PLC must have some specific characteristics. For the experiments, and automation systems building using PLC, they should be able to work under different, sometimes very hard conditions, ensuring high availability.

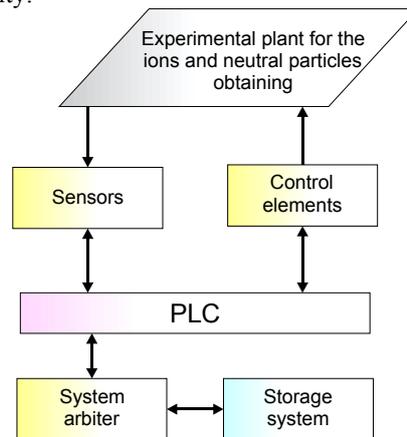


Fig. 1. The structure of the nodes communication using PLC

In the development of the PLC as a system bus selection was made from a list of the most popular, fully standardized well studied buses. The choice was made in favour of bus VMEbus [5].

By using this bus is possible to build scalable systems, where it can be increased both the number of modules that are responsible for input/output, and the number of processor modules, that makes it possible to distribute the control program in the case of its complexity.

Block diagram of the created PLC is shown in Fig. 2. As a PLC's control processor it has been selected 32-bit microcontroller AT91SAM7S from Atmel.

3 The Model Used

To provide a control on a given algorithm of complex technological processes, that includes the induction plasma source management, it is necessary to develop a model of the process. The best way to obtain it is to process the results of passive experiment that are stored in specially designed storage that provides quick access to historical data. After receiving the necessary amount of experimental data and the model creation, the control system can proceed in an active phase, i.e. manage the process.

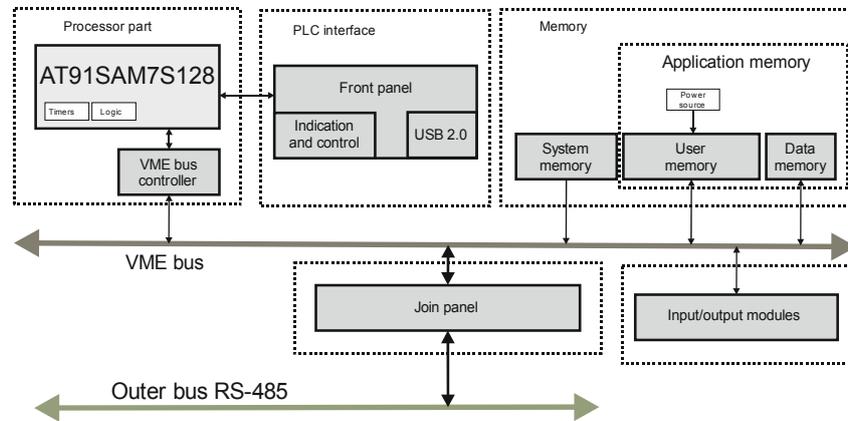


Fig. 2. PLC Block diagram

To construct the control system it was decided to use the model of the 5th class by Shantikumar [6]. In the proposed model, various simulation results for different initial conditions are used. In addition, on the basis of these results analytical model is generated. It is possible to identify the following properties of the model:

- Simulation model is used to determine the relationship between variable parameters and target factor
- An analytical model is a generalization of the results of various simulations; such systems are more accurate, than the solutions obtained only by using theoretical calculations, since they are based on multiple real data
- After receiving the analytical solution, which is not changing under the new simulations, this model can be used in the process control system to predict its results for the given parameters and, hence, it provides accurate information for quick decision-making [7]

The proposed class of models of simulation plays an important role in the investigation of the system behaviour. The results are used to derive analytical models to predict system performance. There may be a situation when the analytical model without simplifications can not be created, and the approximate model is not sufficiently accurate. Thus, models of this class are applicable in the cases:

- When the correlation between the target factor and the system parameters is not known that makes the analytical model is very difficult to develop, in this case, when analytical models are very expensive, unreliable or impractical, simulation can help in understanding the relationships between all factors that makes it possible to develop an analytical model
- In many practical problems the useful signal is often superimposed with lot of noise, which is almost impossible to take into account, simulation allows to investigate the behaviour of dynamic systems and to identify key parameters for evaluation, so that these parameters are then included in the analytical model

The process of a given class model constructing was described in [8]. As a result of simulation data processing system receives a functional relationship between the experiment factors and coefficients of these relationships. To find a list of dependencies

there has been used a list of 34 functions [9], that is sufficient to describe the most of physical processes.

4 Simulation of the Control System

During the system development phase to select the most efficient architecture of its work simulation was carried out. At the same time a number of software products used to data networks simulating was observed.

- OPNET and NetSim++ – graphical network modelling environment;
- SMURPH (University of Alberta) and Ptolemy (Berkeley) use an eclectic language for describing data lines;
- OMNet++ that uses its own language to describe the architecture that is then translated by the pre-processor to standard C++.

The choice was made in favour of the last instrument, as being open, easy embeddable in third-party software products and having multiple trusted code in its composition.

OMNet++ is not a programming language – it’s just a class library for the simulation. These classes are: modules, gateways, connections, settings, reports, histograms, assemblers, precision registers, etc.

First of all, it was composed a system model, built using “common bus” architecture with a central arbitration. The algorithm works as follows: arbiter sends a request to the sensors. The intensity of the queries depends on the particular sensor. The request is broadcast, thus it contains the sensor’s address. Sensor, recognizing the address, sends the data back. The size of datagram is also dependent on the sensor’s type.

The appearance of the simulation software modelling the system is shown Figure 3 (a).

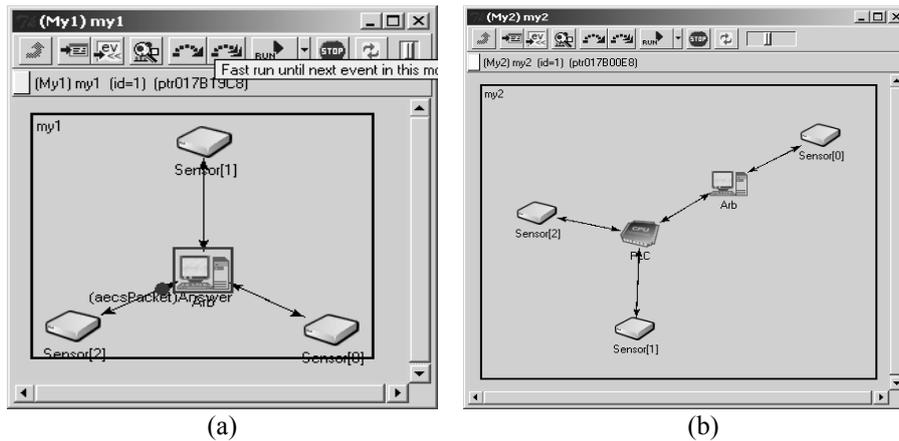


Fig. 3. OMNet++ work for simplified systems

To simulate the operation using the PLC part of the terminal devices was connected to an intermediate device, which operates as a PLC. The appearance of the resulting system in the program OMNet presented in Figure 3 (b).

Time and composition of each message sent and received is saved in a special vector file, that is then processed to obtain statistical information. As a result, basing on multiple system runs and changing the parameters such as: number of devices, data rate, processing time, etc. it was found that the use of PLC increases the productivity of an average of 1.5 times. Figure 4 shows the number of posts at different loads on the media for the cases of classical architecture and the use of the PLC. The fact that the use of OMNet++ allows programming in C++, made it possible to produce a bust of the parameters automatically.

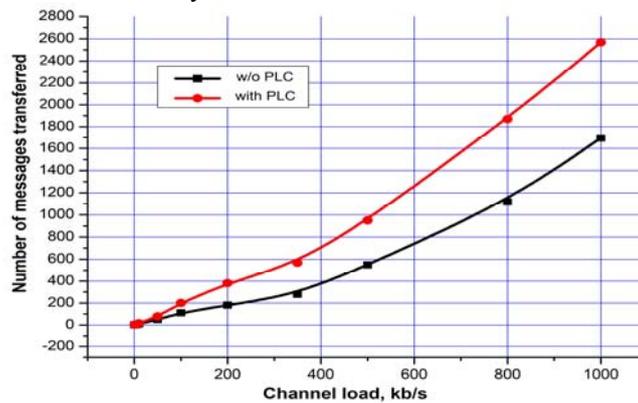


Fig. 4. Dependence of the sent messages number from the bus bandwidth

5 The Results of the Developed System Application

Concrete implementation of information management system was worked out for the experimental setup of vacuum-plasma nanostructures etching, schematically depicted in Figure 5 [10].

The vacuum chamber is a cylindrical volume of diameter 600 mm and length 800 mm. On the side flange of the chamber it was mounted an RF ion source based on the inductive discharge. With the ions extracted passage through the electrode system the beam of desired particle charge or neutral particles is formed. In front of the source a quadrupole mass spectrometer with an integrated energy analyzer with a resolution of 0.1 eV mounted. Plasma excitation is done with an inductor connected to the RF generator operating at a frequency of 13.56 MHz.

The management system's task was a search for optimal etching parameters and the stabilization of these parameters to ensure the repeatability of the experiment, as well as to change the programmable modes of control elements.

Modes of RF discharge source and power blocs forming voltages on the beam extraction system are controlled by PLC, that uses the internal bus commands to control elements, responsible for setting the pulse's amplitude, polarity, duration and duty

cycle. PLC via USB 2.0 was connected to the computer where the accumulation of experimental data and the search for functional relationships between them was done. The system supports the operator control mode and independent search of optimal parameters for this type of beams and maintains these parameters constant. The user interface and the corresponding signals taken from the outputs of power blocks are shown in Figure 6.

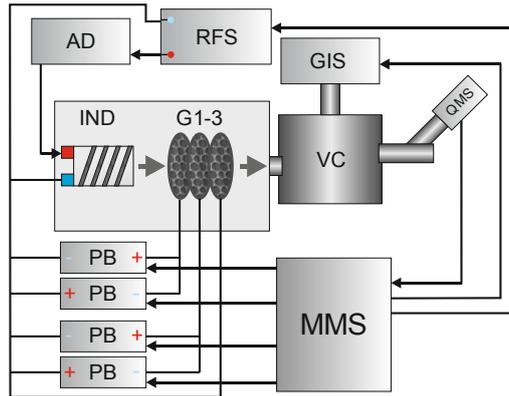


Fig. 5. Structural diagram of the setup for nanostructures etching. VC – vacuum chamber for ion-plasma treatment, QMS – quadrupole mass spectrometer with energy analyzer, RFS – RF source, AD – agreement device, PB – power blocks IND – inductor, G1-3 tree-grade electrode system, GIS – gas inlet system, MMS – microcontroller management system.

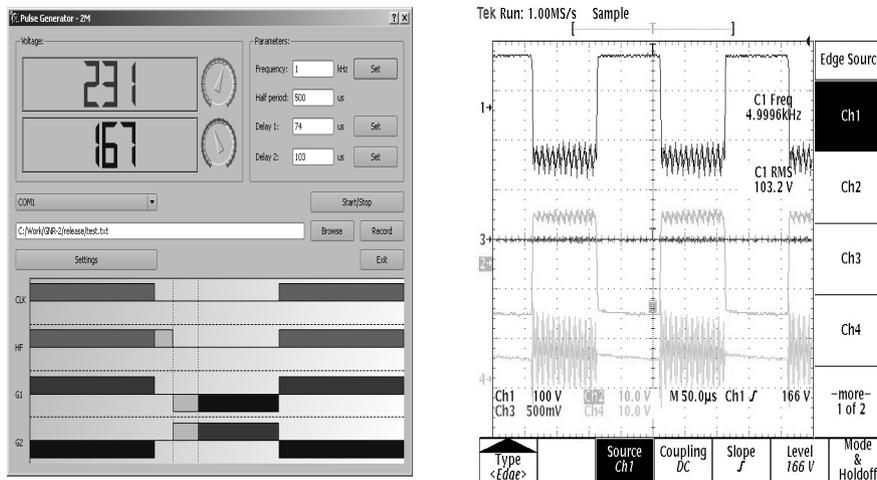


Fig. 6. The user interface and the corresponding control signals

6 Conclusion

Three-level information management system of vacuum-plasma system with the ion source based on high-frequency induction discharge is designed to produce beams of positive and negative ions and neutralized beam of particles used in the nanostructures etching. On the middle hierarchical level of the system there are specially designed programmable logic controllers based on a 32-bit microcontroller from Atmel AT91SAM7S, that have increased noise immunity characterized, advanced computing power and optimal capacity for a given task. PLCs make the primary information processing and greatly accelerate the process of information exchange, particularly at high pulse loads.

Despite the overall effectiveness of the method of constructing process models to manage them based on statistical data accumulated, in practice, large amounts of data to process and requirements for high-speed make this method not always usable. Therefore, the task of modelling and process control between the main control mechanism and the PLC allocation is important.

Testing of the system to manage the real process has shown its efficiency and allowed to obtain an adequate empirical model of the controlled ion source based on high-frequency discharge from tree-grades control.

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