ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Procedia Technology 17 (2014) 580 – 586
Procedia Technology

Conference on Electronics, Telecommunications and Computers – CETC 2013

Automated PECVD System for Fabrication of a-Si:H Devices

M. Fernandes[a,b] *, Y. Vygranenko[a,b], A. F. Maçarico[a], M. Vieira[a,b]

[a]Electronics Telecommunication and Computer Dept. ISEL, Lisboa, Portugal
[b]CTS-UNINOVA, Quinta da Torre, Monte da Caparica, 2829-516, Caparica, Portugal

Abstract

This paper reports a fully automated plasma-enhanced plasma chemical vapor deposition (PECVD) system for thin-film deposition. This system can be used for the deposition of hydrogenated amorphous silicon (a-Si:H) and nanocrystalline silicon for devices like solar cells or optical sensors with good film homogeneity and material properties reproducibility. The control software enables two modes of system operation: semi-manual and full-auto. In the semi-manual mode the user sets all process parameters and controls all depositions steps. In the full-auto mode, the program performs the process steps according to script commands in a recipe file. This way, complex multilayered devices can be fabricated, with a high degree of reproducibility of the device characteristics.

Peer-review under responsibility of ISEL – Instituto Superior de Engenharia de Lisboa, Lisbon, PORTUGAL.

Keywords: Amorphous hidrogenated silicon; PECVD; Computer control.

1. Introduction

The low temperature deposition of semiconductor materials was an important step in the development and cost reduction of the fabrication of large area devices like solar cells. The Plasma Enhanced Chemical Vapour Deposition (PECVD) [1] is one of the most widely used technique of thin-film growth in the Chemical Vapor Deposition family. In particular, since the discovery of the semiconducting properties of hydrogenated amorphous silicon (a-Si:H) [2], extensive progress in the material physics of this materials and alloys [3] [for example, silicon-carbide (a-SiC:H), silicon-nitride (a-SiN:H), …] has been observed.

In the PECVD processes, a thin-film is formed by surface reaction of the ionized species on a low temperature substrate from the vapor phase inside a vacuum chamber. The material composition is defined by the precursor gases introduced in the chamber during the process. The feedstock gases usually include molecules of the required element and hydrogen, namely in the form of hydrates, like silane (SiH4), germane, (GeH4), methane (CH4), phosphine (PH3), diborane (B2H6) and ammonia (NH3), usually diluted in hydrogen (H2). In order to dissociate

Peer-review under responsibility of ISEL – Instituto Superior de Engenharia de Lisboa, Lisbon, PORTUGAL.
doi:10.1016/j.protcy.2014.10.194

the atoms prior to deposition, energy has to be supplied in order to break the bonds between atoms. Several processes can be used to achieve this goal, namely by using a hot wire [4] to break the molecules or by using radio frequency (RF) energy in order to create a plasma containing the ionized atoms and electrons.

In order to attain good material properties a tight control over deposition parameters like RF Power, pressure, temperature, etc. is absolutely crucial, making the full computer control of the system a necessity. Additionally, the computer control lowers the operation costs by optimizing the use of energy and raw materials. The automation of such a system usually relies on a software/hardware combination due to the necessary integration of equipment from different providers with different communication protocols.

2. Apparatus design

The design of the developed reactor is shown in Fig. 1. It is a parallel-plate capacitive reactor with rf-electrode area of 15 cm X 15 cm. The vacuum vessel is a 300-mm diameter stainless steel cylinder. The position of substrate holder, on the top of the chamber, and RF electrode, on the bottom, was chosen in order to minimize powder formation on the substrate, as these tend to fall under gravity. The cover has a hinge, not shown on the picture for clarity of the drawing, so it can be easily opened for loading operations. The sample holder and heater block are mounted on this top plate at a distance of around 35mm, suspended by two rods and the heating resistor tubing itself. With this physical separation the heating of the top lid of the reactor is minimal, yielding an average power consumption of about 20W at a substrate temperature of 300º C. When the lid is closed, a viton o-ring with a sustaining metal ring seals the chamber.

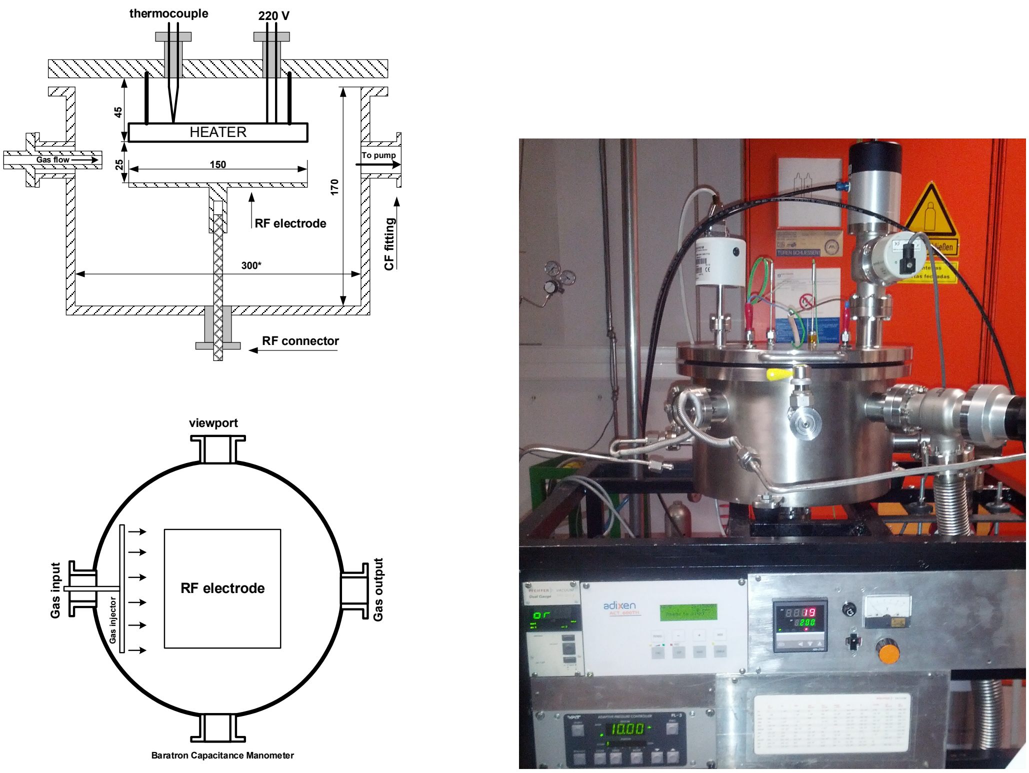

Fig. 1. (left) Design of the PECVD reactor and, (right) picture of the system.

The gas input and exhaust ports where placed close to the plasma region in order to optimize the use of the feedstock gases. To deliver the feedstock gases homogeneously to the whole lateral dimension of the plasma region, a gas diffuser was developed. During the deposition process the gas flow rate is controlled with an independent mass flow controller for each process gas and the pressure in the chamber is controlled by an electrically driven throttle valve with an associated controller type VAT PL-3 and a capacitive absolute pressure gauge EDWARDS Barocell. During pump down procedure the pressure in the chamber is measured by a full range pressure gauge type PKR251, installed on the top plate of the chamber. An electrically controlled pneumatic valve isolates this gauge from the system to avoid contamination during deposition process. Other ports exist on the chamber; some are used for, primary vacuum connection, sample observation through a dual in-line viewport, RF connection, with extra ports to enable further system upgrade.

3. Control subsystems

In the presented PECVD system all process variables can be computer controlled and the process fully automated, leaving to the operator only the tasks of substrate loading and unloading. While most of the building blocks of such a system provide some means of simple control, either by a simple digital I/O interface or communication port (typically RS-232), some other need, and provide, analog signals to control their operation.

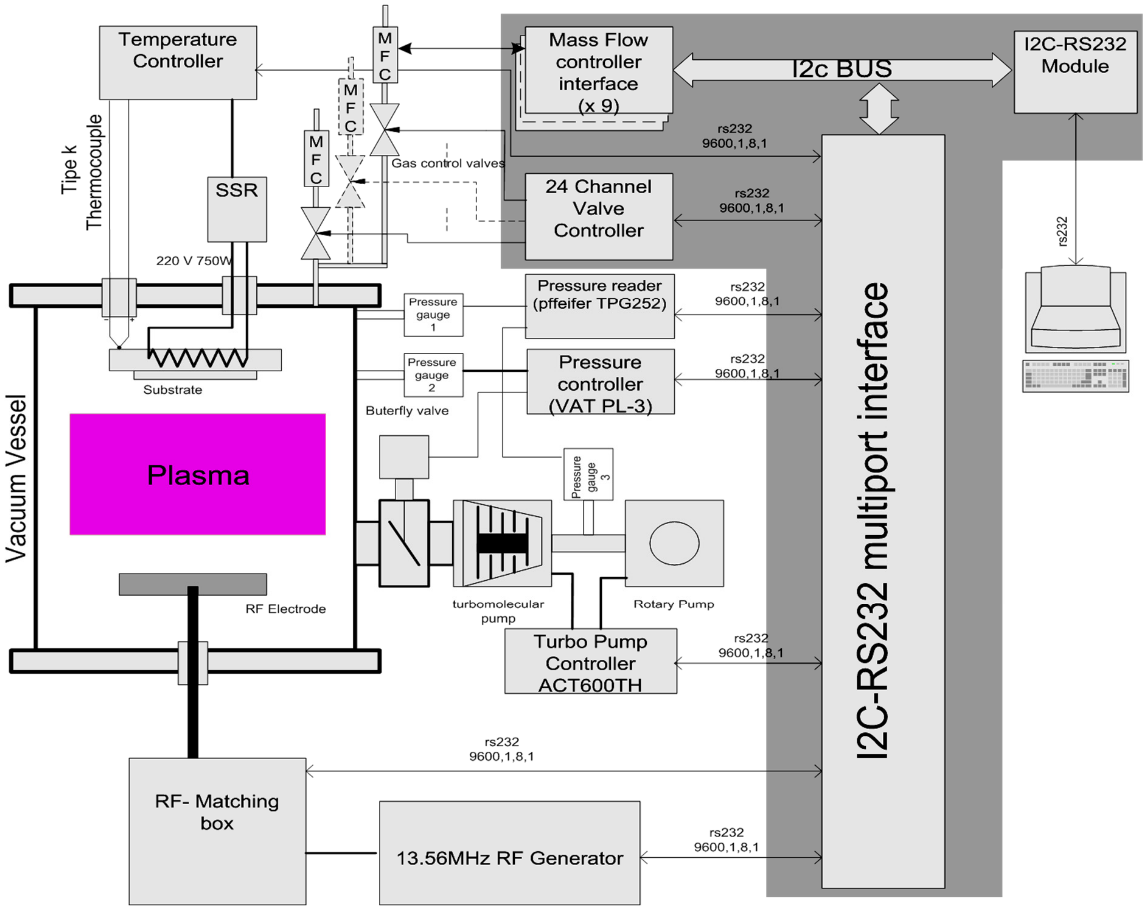

Fig. 2 Block-diagram of the PECVD control system

This way, usually a programmable controller or a personal computer with an expansion card providing analog and digital input and output signals has to be used in the automation of the system. In this system we followed a different approach in order to keep the system simple, with the only needed connection to the computer being a single RS-232 port. Fig. 2 presents an overview of the system were we can identify the different blocks for each process variable and the type of communication interface available. While most of the devices where off the shelf others had to be developed and fabricated (grayed part of the diagram).

As RS-232 is natively a point to point communication standard and several other devices needed to be connected to the communication bus (see section 3.1) we have developed the communication system based on a I^2C (Inter-Integrated Circuit) which is a multimaster serial single-ended computer bus developed by Philips. This approach lead to the development of the I^2C to RS-232 multiport interface indicated on Fig. 3 to accommodate all the equipments that natively supported the RS-232 standard. This interface works in a transparent way, routing bi-directionally the data between the computer and each equipment unit. Apart from other more complex interfaces, presented in the next sections, a simple bus transceiver was also developed to connect the I^2C bus to the PC's serial port.

3.1. Gas handling

The gas handling system consists of four lines for reactive gases: silane (SiH_4), methane (CH_4), phosphine (PH_3), diborane (B_2H_6), one line of hydrogen (H_2) for dilution and two lines for nitrogen (N_2) and argon (Ar) for purge. The gas pipe routing was performed taking in care the reduction of the contamination sources such as traps in connections and other components. The high pressure gas handling panels and the gas bottles are located in two cabinets with forced air extraction to the exterior of the building, maintaining a negative pressure inside the cabinets with respect to the reactor room. The gas valves inside the cabinets are either manual or pneumatically controlled, so no electrical connections exist inside these areas.

The low pressure gas handling and electrical control of pneumatic valves is placed on the reactor room. The metering of process gases is performed by a series of TYLAN Mass Flow Controllers (MFC) Type FC280S adapted for each type of gas and flow. Each of the MFC's where manually controlled by an analog board type RO7021, so in order to automatically control the gas flow an interface board had to be developed. Fig. 3 shows the block diagram of the proposed solution for the control of MFC´s.

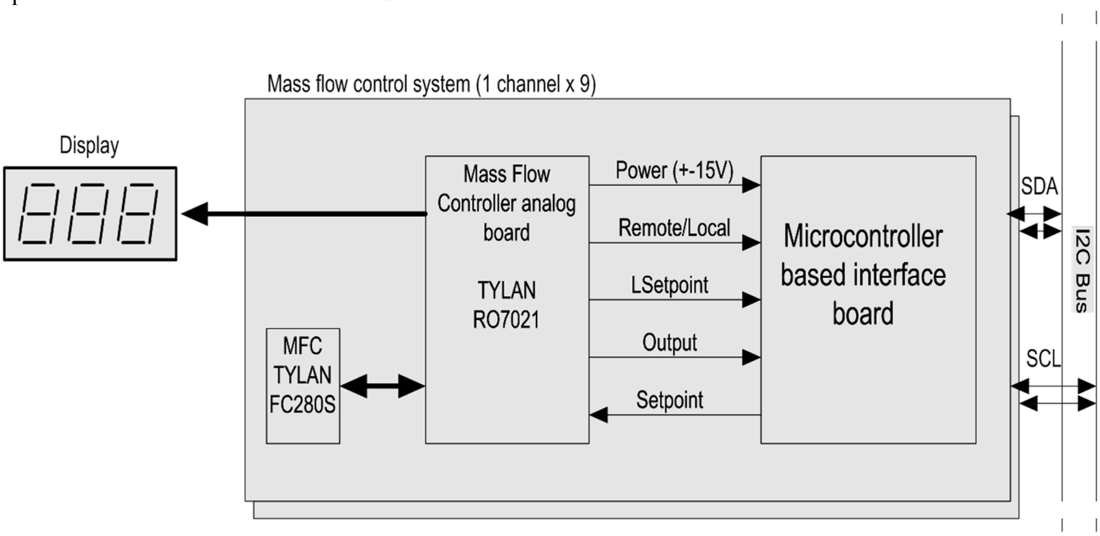

Fig. 3. Mass flow control system block diagram.

Due to the high number of channels required, a local multipoint communication bus was implemented, based on the I2C standard. The developed microcontroller based interface can mimic all the necessary activities to simulate manual control of the analog boards, like applying and reading out voltages or perform switching of internal relays, and enables real time computer control of process gases.

3.2. Control of the substrate temperature

Among the parameters controlling the quality of a-Si:H films, the substrate temperature is a critical one, as it determines the incorporation of hydrogen and the electronic properties of the deposited films, namely the density of states. A low density of states in a-Si:H is obtained at T_s >230 ºC [5,6]. By this reason it is evident that a precise control of the substrate temperature is essential to the correlation of the plasma conditions to a-Si:H quality and effectively to the comparison of the properties of films deposited in different reactors. In order to address this issue, two type K thermocouples were installed on the system; while one is connected to a PID temperature controller (REX C100) with an RS-232 interface, the other one is used for substrate temperature readout. Both thermocouples are in direct contact with the substrate holder.

3.3. Valve switching

The gas valve switching is a very important issue to be addressed on the design of a PECVD system, not only due to process related aspects but also due to security issues. For this purpose a single multichannel control unit was developed with the ability to control up to 24 valves, with independent return paths for valve status determination. With this approach a possible valve jamming can be promptly detected and the system can take corrective measures or even interrupt the process and go to a safe shutdown mode. As an extra safety feature, the controller can also be programmed to permit only allowed valve sequences.

3.4. Control software

One important piece of any automated system is the control software. The control software was developed bearing in mind different aspects of the problem: real time monitoring of all process variables; implementation of a simple script language to automate the deposition process; and process security issues. The program was written applying the object-oriented programming concept and using VB.NET for the MS Windows platform. A user interface form is shown in Fig. 4. The program enables two modes of system operation: semi-manual and full-auto. In the semi-manual mode the user sets all process parameters and controls all depositions steps. In the full-auto mode, the program performs the process steps according to script commands in the recipe file. This enables programmed tuning of the process parameters such as gas flows, rf-power, or pressure to deposit a graded layer, and/or multilayered structures can be deposited with high reproducibility.

The interface is intuitive and self explanative, with the controls and indicators for each equipment or functional block grouped by area, in a way that a rapid look is sufficient to get information about system status.

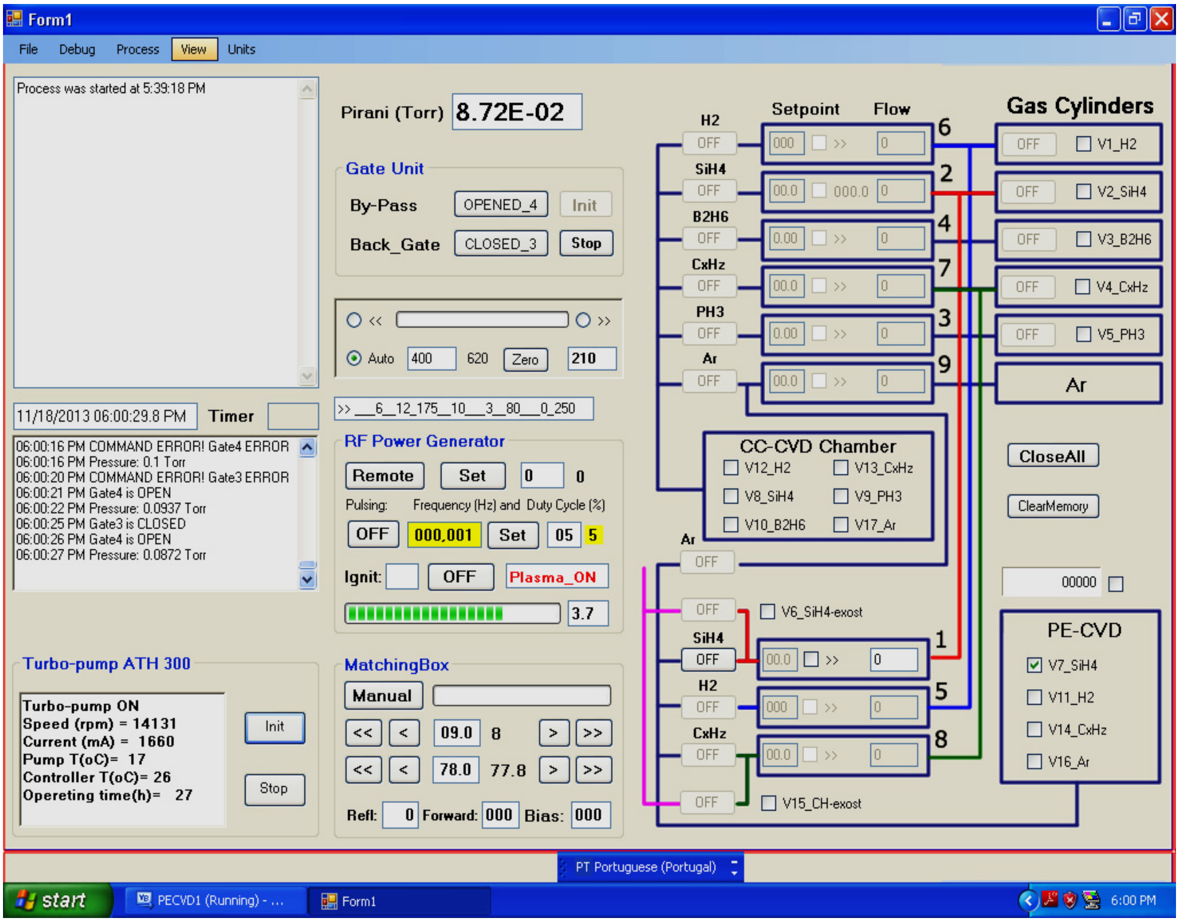

Fig. 4. User interface form of the computer program.

4. Conclusions

The automation of the existent PECVD system enabled the optimization of the operation and the development of a recipe based fabrication procedure for thin-film silicon-based devices. The tight control over deposition parameters enables the fabrication of complex device structures with less dependency on the knowledge of the system operator, as demonstrated by samples produced on the PECVD system.

As a next step to this work different samples fabricated under specific deposition conditions will be characterized in order to infer the optimal parameters of the presented system. The fabrication of complex multilayered optoelectronic devices is foreseen to support investigation of the group in the field of optoelectronic sensors.

Acknowledgements

The authors are grateful to the Portuguese Foundation of Science and Technology through the PIDDAC Program funds and research Project PTDC/EEA-ELC/115577/2009 for financial support of this research for providing necessary equipment to carry out this work.

References

[1] Plasma Synthesis and Etching of Electronic Materials, edited by R. P. H. Chang and B. Abeles, Materials Research Society, Pittsburg, PA, (1984), Vol. 38.
[2] R. C. Chittick, J. H. Alexander, and H. F. Sterling, J. Electrochem. Soc. 77, 116 (1969).
[3] Proceedings of the First International Conference on Amorphous Semiconductor Technology, edited by M. J. Thompson and D. E. Carlson, Asheville, NC, USA, August 24-25 (Elsevier, Amsterdam, 1989).
[4] A.H. Mahan, J. Carapella, B.P. Nelson, R.S. Crandall, and I. Balberg, Journ. Appl. Phys., 69, 6728 (1991)
[5] D. E. Carlson, Prog. Cryst. Growth Charact. 4,173 (1981).
[6] I. Solomon, R. Benferhat, and H. Tran-Quoc, Phys. Rev. B 30, 3422 (1984).