PECVD/ECR/HWCVD Multichamber System with Robotic Substrate Handling System for deposition of Thin Film Electronic Devices

P. Rava

Elettrorava s.p.a. Via Don Sapino 176, 10078 Venaria, Torino Italy
tel +39-011-4240237, fax +39-011-4240364.

E-mail: paolo.rava@elettrorava.com

Abstract. The present work reports on progress in the design of modular UHV cluster tool multichamber systems. A wide range of processes has been implemented in the Deposition Process Chambers (DPC’s), including rf-PECVD, vhf-PECVD, ECR-PECVD and HWCVD. A wide range of intrinsic and doped amorphous and microcrystalline silicon and silicon alloy materials have been produced and have been used in the fabrication of several types of electronic devices such as solar cells, Light Emitting Devices (LED’s), Thin Film Transistors (TFT’s), etc. using multichamber systems at several laboratories worldwide.

1. Introduction

Thin film electronic devices are formed by several layers of materials with different characteristics. The main layers in several types of devices are based on hydrogenated amorphous or microcrystalline silicon and its alloys such as silicon carbide and silicon nitride: these materials form the active layers in photovoltaic solar cells, sensors, detectors, LED’s, thin film transistors, etc. These devices, in addition to p-doped, intrinsic and n-doped semiconductor layers, typically consist of several other layers, such as insulator layer, Transparent Conductive Oxide (TCO) layer, and metal layer.

The technique of radio frequency plasma enhanced chemical vapour deposition (rf-PECVD) is commonly used for the deposition of hydrogenated amorphous or microcrystalline silicon and its alloys such as silicon carbide and silicon nitride; more recently other techniques such as vhf-PECVD, ECR-PECVD and HWCVD are being increasingly used for the deposition of these materials. The extensive work carried out both in research laboratories and in industry has resulted in the development of a wide range of deposition systems with widely varying features and many different reactor structures have been proposed to improve the quality of plasma deposited thin film materials and devices.

The main part of a deposition system consists in a vacuum chamber evacuated by a pumping unit to some appropriate vacuum level. After achieving the desired ultimate vacuum, the process gas mixture is introduced via Mass Flow Controllers and the pressure is kept constant by a variable conductance valve. Plasma is then ignited by an RF generator (or other source capable of generating high energy electrons); process gas is decomposed in ions and radical which are then deposited as thin films. The important figure of merit for any vacuum system, and in particular for a deposition
chamber, is the total leak and degassing rate when the reactor is at deposition temperature: the ratio of this parameter to the process gas flow rate will largely determine the achievable purity of films deposited in that reactor.

In order to optimize the properties of each layer and therefore the characteristics of the electronic devices, it is desirable to deposit each layer, and in particular the active semiconductor layer, in high purity conditions; it is therefore necessary to minimize all external sources of contamination as well as cross contaminations among the different layers of the device.

Use of a UHV system which can achieve a good ultimate vacuum and therefore a low outgassing rate minimizes external sources of contamination, and therefore the incorporation in the deposited films of residual impurities such as oxygen, nitrogen and carbon, which can have a detrimental effect on the properties of silicon thin films. Deposition Process Chambers (DPC’s) are constructed according to ultra high vacuum (UHV) standards (stainless steel construction and all metal seals) which allow ultimate pressures in the $10^{-9}$ mbar range at room temperature and in the $10^{-7}$ mbar range at process temperature to be readily reached with turbomolecular pumping.

For a UHV system to maintain a good base vacuum with as little contaminants as possible it is desirable to keep the process chamber always under ultra high vacuum (UHV) conditions, using a Load Lock chamber (LLC) isolated from the process chamber by a gate valve: only the Load Lock chamber is vented to atmosphere for substrate loading, and the substrate is introduced into the process chamber by means of a substrate handling system under vacuum.

Cross contamination is a very important factor for the deposition of devices, since these consist of several layers deposited from different gas mixtures: its effects may be detrimental especially in the case of boron and phosphorous doping, since a concentration of these dopants at the ppm level seriously degrades the optoelectronic properties of the intrinsic semiconductor layers. Cross contamination is a severe problem in the case of a system consisting of a single chamber in which several layers are deposited from different gas mixtures, due to outgassing from previous deposits on fixturing and chamber walls.

Cross contamination among different layers is avoided using a system configuration with multiple separate deposition process chambers (DPC’s) for the deposition of each layer with a specific gas mixture. Several configurations of multichamber systems have been used. The in-line system consists of multiple reaction chambers configured in line, including entrance and exit load lock chambers. The cluster multichamber configuration consists of multiple reaction chambers configured in a circular geometry; the contamination at the interface between layers is avoided using a central vacuum chamber connected to all process chambers to transfer the substrate from one process chamber to another without venting it, named transfer chamber (TC). As a result of the avoidance of cross contamination, the reproducibility of each layer can be better guaranteed and therefore the device properties can be better controlled even if a variety of devices are deposited using a different sequence of layers.

Multichamber cluster systems with a vacuum transfer chamber are commonly used for research and production of thin film devices. The vacuum transfer chamber is kept under vacuum during normal operation and a Load Lock chamber is used for substrate loading. The handling system to transfer substrates under vacuum to the process chambers is the key technological component of multichamber systems and different technical solutions have been used in the multichamber systems installed (Fig.1).

The deposition of good quality materials requires also a good control of the plasma parameters during the deposition process in each DPC. The independently variable parameters of the plasma deposition process include the flow rate of the gases, the total pressure of the gas, the interelectrode distance, the substrate temperature and the electrical excitation parameters such as power and frequency. A combination of appropriate values for these parameters has to be chosen in such a way as to obtain the desired film properties, such as film thickness uniformity, high deposition rate, good adhesion, good electrical and mechanical properties. Reactors capable of depositing good quality
materials should feature a good control by means of instruments with feedback loops of all the deposition parameters described above; automatic control and supervision of the whole system by means of a personal computer allows an improved control and repeatability of all deposition parameters, particularly in the case of devices with a large number of layers.

2. Deposition of the cluster tool multichamber systems

Several UHV cluster multichamber systems in different configurations have been installed at several locations worldwide. These include the IMM-CNR laboratory in Bologna and Politecnico di Torino in Italy, the University of Utrecht, the Technical University of Delft and Energy Centre Nederland (ECN) in The Netherlands, University of Barcelona and ITMA in Spain, Philips Research Laboratories in the UK and LNT at Vietnam National University. The deposition process technologies used in the DPC’s of these systems are rf PECVD, vhf PECVD, HWCVD, ECR PECVD.

A five chamber cluster system for 156mm x 156mm substrates using rf PECVD in four process chambers (DPC1 for intrinsic silicon, DPC2 for p-doped silicon, DPC3 for n-doped silicon, DPC4 for silicon alloys), and plasma etching in DPC5 has been manufactured and installed at the ECN laboratories in The Netherlands (Fig.2). The system features complete control by PC with capability of simultaneous independent operation of each DPC and will be used for R&D on various types of thin film electronic devices.
The main features of the UHV cluster multichamber system for deposition of high quality thin semiconducting films designed by Elettrorava are described in the following.

The system consists of five Deposition Process Chambers (DPC’s) positioned around a central Transfer Chamber (TC) which contains the robotic transport arm.

The substrate handler used in the transfer chamber in the multichamber system is based on a reliable and field proven compact robotic manipulator which transfers under vacuum the necessary movements of the substrate carrier. The following movements are performed by the arm during the substrate transfer operations: rotary to allow positioning of the arm in front of each DPC; linear horizontal using a highly stable and reliable two or four sector arm to allow extension into the DPC’s; linear vertical to allow engage and release of the substrate carrier by means of a pan shaped end effector.

An additional Load Lock Chamber (LLC) with easy access is connected to the front of the TC for front loading of substrates. Several substrates (156mm x 156mm) are first placed in the LLC for introduction into the TC; the substrates are then introduced into one of the DPC’s to perform the relative process; after the process the substrate is extracted from the DPC and can be introduced into any other DPC for another process or taken into the LLC for unloading. The DPC’s and the LLC are separated from the TC by means of gate valves which are open only to allow substrate insertion and extraction from the DPC’s and LLC. This configuration allows the deposition of layers in any sequence to produce any type of multilayer device, avoiding cross contamination between different layers.

The DPC’s are cylindrical chambers constructed according to ultra high vacuum (UHV) standards (stainless steel construction and all metal seals) which allow ultimate pressures in the $10^{-9}$ mbar range at room temperature and in the $10^{-7}$ mbar range at process temperature to be readily reached; dedicated turbomolecular pumping for each chamber is used both during pump down and during process, in order to avoid all possible contaminations from the pumping system; all pumps are purged by nitrogen to protect some of their most sensitive parts and to avoid possible accumulation of toxic or explosive components when reactive gases are used. The substrate is positioned by the robotic arm in each DPC on a holder facing downwards to avoid accumulation of dust particles on its surface; a heater placed outside vacuum (to avoid contamination by this source) heats the substrate by irradiation up to a maximum temperature of about 500°C; each DPC has a dedicated gas manifold for delivery of process gases; high vacuum is measured prior to process by an ionization gauge and process pressure is controlled by a throttle valve connected to a capacitance manometer; a dedicated rf generator with relative automatic matching network is connected to the electrode in each DPC for plasma excitation; the distance between the substrate and the electrode can be adjusted externally from 1 cm to 5 cm; the flange where the electrode is installed is removable and can be readily replaced with components for
different deposition technologies, such as ECR and HWCVD. Optionally high temperature capability (1000°C) is available.

The multichamber system is controlled entirely by PC, which allows stable and repeatable control of all deposition parameters and make the system particularly suitable for the deposition of multilayer devices.

3. Experimental results
State of the art amorphous and microcrystalline semiconducting materials have been deposited using the multichamber systems installed by Elettrorava, research programs have been carried out on several types of devices.

The extensive solar cell research program carried out at Utrecht University and Technical University Delft has allowed to deposit devices with efficiencies in excess of 10% (1). More recently the addition of HWCVD chambers on the multichamber system has allowed to optimize deposition of amorphous and polycrystalline silicon thin films by HWCVD and to produce highly stable pin devices.

Extensive research programs have been carried out on the system installed at the IMM-CNR laboratory in Bologna and have led to scientific results reported in many papers. The main topics investigated and the main results obtained are summarized here.

Deposition of silicon carbide alloys using rf PECVD: the optoelectrical properties of amorphous silicon carbide have been optimized for films deposited in gas mixtures of silane and methane/acetylene both undiluted and with the addition of hydrogen (hydrogen diluted gas mixtures). It has been shown that the energy gap can be varied in a wide range and that hydrogen dilution improves the optoelectrical properties for films with high values of the energy gap (2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 17, 19, 20, 21, 22, 25, 26, 27, 29, 33).

Deposition of silicon nitride alloys using rf PECVD: the optoelectrical properties of amorphous silicon nitride have been optimized for films deposited in gas mixtures of silane and ammonia both undiluted and with the addition of hydrogen (hydrogen diluted gas mixtures). It has been shown that the energy gap can be varied in a very wide range and that hydrogen dilution improves the optoelectrical properties for films with high values of the energy gap (15, 16, 24, 28, 30, 34).

Deposition of silicon and its alloys using vhf PECVD: amorphous silicon, silicon carbide and silicon nitride alloy films have been deposited at 100 MHz. These films are deposited at a high deposition rate and at the same time show good optoelectrical properties.

Deposition of multilayer structures: multilayer structures consisting of alternate high energy gap and low energy gap layers have been deposited; these structures show good photoluminescence properties (30, 32).

Deposition of heterojunction solar cells: intrinsic and doped amorphous silicon layers have been deposited on crystalline silicon wafers in order to produce photoelectrically active pin devices with good optoelectrical quality (13, 23, 31).

Deposition of LED’s: LED’s using as active layer amorphous silicon carbide and silicon nitride layers as well as multilayers have been deposited; these devices show good emission in the visible spectrum (18,32).

Extensive research programs are being carried out on the PECVD multichamber system installed at ECN: optimization of deposition processes for amorphous and microcrystalline silicon, silicon oxide and silicon carbide is in progress

4. Conclusions
Cluster tool multichamber systems have been used for the deposition of a wide range of semiconducting materials and devices with state of the art properties. The design of the systems has
been improved with a highly reliable substrate transport arm and with complete computer control of the whole system.

References

[1] A. Madan, P. Rava, R. E. I. Schropp, B. Von Roedern. "A new modular multichamber Plasma Enhanced Chemical Vapor Deposition system". Applied Surface Science 70/71, 716-721, North-Holland (1993).

[2] J. Daey Owens, R. E. I. Schropp, C. H. M. van der Werf, M. B. von der Linden, C. H. M. Maree, W. F. van der Weg, P. Rava, F. Demichelis, C. F. Pirri, E. Tresso. "Effects of electrode spacing and hydrogen dilution on a-SiC:H and a-Si:H layers". Amorphous Silicon Technology-1993; E. A. Schiff, M. J. Thompson, A. Madan, K. Tanaka, P. G. LeComber Editors, Materials Research Society Symposium Proceedings, vol.297, p.61, Pittsburgh (PA) (1993)

[3] T. Pisarkiewicz, T. Stapinski, F. Demichelis, C. F. Pirri, E. Tresso, P. Rava. "Undoped and phosphorus doped μ-SiC:H films: investigation of electrical properties and Hall effect". Amorphous Silicon Technology-1993; E. A. Schiff, M. J. Thompson, A. Madan, K. Tanaka, P. G. LeComber Editors, Materials Research Society Symposium Proceedings, vol.297, p.431, Pittsburgh (PA) (1993)

[4] F. Demichelis, G. Crovini, C. F. Pirri, E. Tresso, L. Battezzati, P. Rava. "Structure and morphology of μ-SiC:H films produced by PECVD". Microcrystalline Semiconductors: Materials Science and Devices; F. M. Fauchet, C. C. Tsai, L. T. Canham, I. Shimizu and Y. Aoyagi Editors, Materials Research Society Symposium Proceedings, vol.283, p.543, Pittsburgh (PA) (1993)

[5] F. Demichelis, G. Crovini, C. F. Pirri, E. Tresso, R. Galloni, R. Rizzoli, C. Summonte, F. Zignani, G. Amato, P. Rava, A. Madan. "Optimization of optoelectronic properties of a-SiC:H films". Amorphous Silicon Technology-1993; E. A. Schiff, M. J. Thompson, A. Madan, K. Tanaka, P. G. LeComber Editors, Materials Research Society Symposium Proceedings, vol.297, p.681, Pittsburgh (PA) (1993)

[6] F. Demichelis, G. Crovini, F. Giorgis, C. F. Pirri, E. Tresso, G. Amato, H. Herremans, W. Grevenendonk, P. Rava. "Electronic density of states in a-SiC:H films" Journal of Non-Crystalline Solids 164/166, 1015, (1993).

[7] F. Demichelis, G. Crovini, C. F. Pirri, E. Tresso, G. Amato, U. Coscia, G. Ambrosone, P. Rava. "Optimization of a-Si1-xCx:H films prepared by ultra high vacuum plasma enhanced chemical vapour deposition for electroluminescent devices ". Thin Solid Films 241, 274, Elsevier Sequoia (1994).

[8] F. Demichelis, G. Crovini, C. F. Pirri, E. Tresso, R. Galloni, R. Rizzoli, C. Summonte, F. Zignani, P. Rava, A. Madan. "The influence of hydrogen dilution on the optoelectronic and structural properties of hydrogenated amorphous silicon carbide films" (Invited paper) Philosophical Magazine B69, 377, (1994).

[9] R. Galloni, R. Rizzoli, C. Summonte, F. Demichelis, F. Giorgis, C. F. Pirri, E. Tresso, G. Ambrosone, C. Catalanotti, U. Coscia, P. Rava, G. Della Mea, V. Rigato, A. Madan. "Defect distribution and bonding structure in high band gap a-Si1-xCx:H films deposited in H2 dilution". Amorphous Silicon Technology-1994; E. A. Schiff, M. Hack, A. Madan, M. Powell, A. Matsuda Editors, Materials Research Society Symposium Proceedings, vol 336, p.517, Pittsburgh (PA), (1994)

[10] R. Rizzoli, R. Galloni, C. Summonte, F. Demichelis, C. F. Pirri, E. Tresso, G. Crovini, P. Rava, F. Zignani. "Boron and phosphorous ion implantation in a-Si,C1-x:H thin films". Amorphous Silicon Technology-1994; E. A. Schiff, M. Hack, A. Madan, M. Powell, A. Matsuda Editors, Materials Research Society Symposium Proceedings, vol 336, Pittsburgh (PA) (1994)
[11] R. Rizzoli, R. Galloni, C. Summonte, F. Demichelis, C.F. Pirri, E. Tresso, G. Crovini, P. Rava, A. Madan "Recent improvements on a-Si:C:H films deposited by UHV-PECVD". Proceedings of the 12th E.C. Photovoltaic Solar Energy Conference, Amsterdam, April 1994, p.366; H.S. Stephens and Associates, Bedford, UK, (1994).

[12] F. Demichelis, G. Crovini, C.F. Pirri, E. Tresso, R. Galloni, R. Rizzoli, C. Summonte, P. Rava. "Optimization of relevant deposition parameters for high quality a-Si:C:H films". Solar Energy Materials and Solar Cells 37, 315, Elsevier Science (1995)

[13] F. Zignani, R. Galloni, R. Rizzoli, C. Summonte, A. Parisini, A. Armigliato, P. Rava. "Studio della eterogiunzione silicio amorfo/silicio cristallino e sua applicazione alla realizzazzione di celle solari" Atti II Convegno Scientifico Consorzio Interuniversitario Nazionale per la Chimica dei Materiali, Firenze, Febbraio 1995

[14] F. Demichelis, G. Crovini, F. Giorgis, C.F. Pirri, E. Tresso, R. Galloni, R. Rizzoli, C. Summonte, F. Zignani, P. Rava. "High quality a-Si:C:H films and their application in p-i-n structures for optoelectronic devices". Vuoto Scienza e Tecnologia XXIV, 61, Pàtron (Bologna), (1995).

[15] C. Summonte, R. Rizzoli, R. Galloni, R. Pinghini, E. Centurioni, C.F. Pirri, E. Tresso, F. Demichelis, G. Crovini, F. Giorgis, P. Rava. "Study of amorphous hydrogenated silicon nitrogen alloys for photovoltaic applications". Proceedings of the 13th E.C. Photovoltaic Solar Energy Conference, pg. 199, Nice, October 1995, H.S. Stephens and Associates, Bedford, UK, (1995).

[16] F. Giorgis, P. Rava, R. Galloni, R. Rizzoli, C. Summonte, G. Crovini, F. Demichelis, C.F. Pirri, E. Tresso, V. Rigato. "Compositional, optoelectronic and structural properties of amorphous silicon nitrogen alloys deposited by plasma enhanced chemical vapour deposition". Journal of Non-Crystalline Solids 198-200, 596-600, Elsevier (1996)

[17] M. Fathallah, R. Gharbi, G. Crovini, F. Demichelis, F. Giorgis, C.F. Pirri, E. Tresso, P. Rava. "Light soaking in a-Si:C:H films grown by PECVD in undiluted and hydrogen diluted SiH₄+CH₄ gas mixtures". Journal of Non-Crystalline Solids 198-200, 490-494, Elsevier (1996)

[18] R. Rizzoli, C. Summonte, R. Galloni, M. Ruth, A. Desalvo, F. Zignani, P. Rava, F. Demichelis, C.F. Pirri, E. Tresso, G. Crovini, F. Giorgis, A. Madan. "Brightness degradation controlled by current induced metastable defect creation in a-Si:C:H based light emitting diodes" Amorphous Silicon Technology-1995, M. Hack, E.A. Schiff, A. Madan, M. Powell, A. Matsuda Editors, Materials Research Society Symposium Proceedings, vol 377, p.809, Pittsburgh (PA) (1995)

[19] P. Rava, G. Crovini, F. Demichelis, F. Giorgis, R. Galloni, R. Rizzoli, C. Summonte. "Power dissipation in PECVD for SiH₄-CH₄-H₂ gas mixtures". Journal de Physique IV, Colloque C5, suppl. Journal de Physique II, ed. by G.A.Battiston, R. Gerbasi, M. Porchia, vol.5, p. C5-1125, Les Editions de Physique, Les Ulis Cedex (1995)

[20] F. Demichelis, G. Crovini, F. Giorgis, C.F. Pirri, E. Tresso, V. Rigato, U. Coscia, G. Ambrosone, S. Catalanotti, P. Rava. "Effects of power density and molecule dwell time on compositional and optoelectronic properties of a-Si:C:H alloys". Solid State Communications, vol.98, no.7, p.617, Pergamon Press, Elsevier Science (1996).

[21] P. Rava, G. Crovini, F. Demichelis, F. Giorgis, C.F. Pirri. "Characterization of the effect of growth conditions on a-SiC:H films". Journal of Applied Physics 80, no.7, 4116, (October 1996)

[22] A. Desalvo, R.Galloni, F. Giorgis, C.F. Pirri, P. Rava, R. Rizzoli, C. Summonte, E.Tresso. "Optoelectronic properties, defect structure and composition of a-SiC:H films grown in undiluted and H₂ diluted silane-methane plasma". Journal of Applied Physics (1996).
[23] F. Zignani, R. Galloni, R. Rizzoli, M. Ruth, C. Summonte, R. Pinghini, Q.Zini, P. Rava, A. Madan, Y.S. Tsuo. "Study of a-Si:H/c-Si Heterojunctions for PV applications". Amorphous Silicon Technology-1996, M. Hack, E.A. Schiff, S. Wagner, A. Matsuda, R. Schropp Editors, Materials Research Society Symposium Proceedings, vol. 420, pg. 45, Pittsburgh (PA) (1996)

[24] F. Giorgis, C.F. Pirri, E. Tresso, V. Rigato, S. Zandolin, P. Rava “Wide band gap amorphous silicon based alloys” Physica B, 229, 233-239, (1996)

[25] U. Coscia, C Catalanotti, G. Ambrosone, F. Demichelis, F. Giorgis, C.F. Pirri, E. Tresso, P. Rava. "Study of gap states and photoelectrical properties of a-SiC:H films deposited by PECVD in SiH₄+CH₄ gas mixtures". Vuoto Scienza e Tecnologia XXV, 38, Pàtron (Bologna), (1996).

[26] F. Demichelis, G. Crovini, F. De Zan, F. Giorgis, C.F. Pirri, E. Tresso, G. Della Mea, V. Rigato, S. Zandolin, P. Rava. "Optimization of a-SiC:H films for optoelectronic applications". Vuoto Scienza e Tecnologia XXV, 44, Pàtron (Bologna), (1996).

[27] F. Giorgis, C.F. Pirri, E. Tresso. P. Rava “a-SiC:H films deposited by PECVD from silane + acetylene and silane + acetylene + hydrogen gas mixtures”. Diamond and Related Materials

[28] F. Giorgis, F. Giuliani, C.F. Pirri, E. Tresso, C. Summonte, R. Rizzoli, R. Galloni, A. DeSalvo, P. Rava “Optical, structural and electrical properties of device quality hydrogenated amorphous silicon-nitrogen films deposited by plasma-enhanced chemical vapour deposition”. Phil. Mag. B, 77, no.4, 925-944, (1998)

[29] F. Giorgis, C.F. Pirri, P. Rava, E. Tresso “Correlation between optoelectronic properties and structure of a-SiC:H films grown from C₂H₂ source” Phil. Mag. B, 75, no.4, 471-483, (July 1997)

[30] F.Giorgis, F. Giuliani, C.F. Pirri, P. Rava, R. Galloni, R. Rizzoli, C. Summonte, A. Desalvo, F. Zignani, P. Rava, F. Caccavale. "Photoluminescence and optical characterization of a-Siₙ,N₁₋ₙ:H based multilayers grown by PECVD". Amorphous Silicon Technology-1997, S. Wagner, M. Hack, E.A. Schiff, , R. Schropp, I. Shimizu Editors, Materials Research Society Symposium Proceedings, vol.467, Pittsburgh (PA) (1997)

[31] R. Rizzoli, R. Galloni, C. Summonte, R. Pinghini, E. Centurioni, F. Zignani, A. Desalvo, P. Rava, A. Madan "Study of a-Si:H/c-Si Heterojunctions for PV applications". Amorphous Silicon Technology-1997, S. Wagner, M. Hack, E.A. Schiff, , R. Schropp, I. Shimizu Editors, Materials Research Society Symposium Proceedings, vol.467, p.807, Pittsburgh (PA) (1997)

[32] C. Summonte, R. Rizzoli, R. Galloni, F. Giorgis, F. Giuliani, C.F. Pirri, E. Tresso, A. Desalvo, F. Zignani, P. Rava. "Photoluminescence and electroluminescence properties of a-Siₙ,N₁₋ₙ:H based superlattice structures". Journal of Non-Crystalline Solids, 227-230, 1127-1131, Elsevier (1998)

[33] F. Giorgis, F. Giulian, C.F. Pirri, P. Mandracci, P. Rava, R. Reitanlo, L. Calcagnio, P. Musumeci. "Carbon rich a-Siₓ₋ₓCₓ:H films: an investigation on radiative recombination properties” Amorphous Silicon Technology-1998, S. Wagner, M. Hack, E.A. Schiff, , R. Schropp, I. Shimizu Editors, Materials Research Society Symposium Proceedings, Pittsburgh (PA) (1998)

[34] F. Giorgis, G. D’Agneili, F. DeZan, F. Impavido, C.F. Pirri, P. Rava, E. Tresso. "Structural and optoelectronic properties of a-SiC:H and a-SiN:H films for applications as wide band gap semiconductors". Vuoto Scienza e Tecnologia, Pàtron (Bologna) (1997)

[35] P. Rava, F. Giulian, F. Giorgis, C.F. Pirri, E. Tresso, P. Mandracci, C. Summonte, R. Rizzoli, A. Desalvo. "Amorphous silicon nitrogen alloys deposited by PECVD under hydrogen dilution conditions". Physics of Semiconductor Devices, V. Kumar and S.K. Agarwal (Eds.), Narosa Publishing House, New Delhi, India (1998)