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A SYSTEM FOR MONITORING THE SPATIAL AND INTENSITY DISTRIBUTION ON CCD PATTERNS APPLIED TO IN SITU CHARACTERIZATION

Mario Carpentieri[1], *Juan Pedro Silveira*[2], *Romano Giannetti*[3]

(1) Università degli Studi di Messina, Messina, Italy
(2) Instituto de Microelectronica de Madrid (CNM-CSIC), Tres Cantos, Madrid, Spain
(3) Universidad Pontificia Comillas, Madrid, Spain

Abstract – The monitoring of a few critical parameters during epitaxal growth is necessary in order to obtain high quality III-V semiconductor heterostructures. We have developed an electronic circuit that is able to perform real-time analysis of the spatial distribution and intensity of RHEED (reflected high energy electron diffraction) patterns by means of a CCD camera. Besides being used for obtaining information from RHEED patterns, the new system can also be employed for *in situ* and real time stress measurements during molecular beam epitaxy of lattice mismatched heterostructures.

Keywords: Molecular Beam Epitaxy, FPGA, in situ monitoring.

1. INTRODUCTION

Molecular Beam Epitaxy (MBE)[1] is a growth technique for III-V semiconductors as well as for several other materials. High-quality layers can be produced with very abrupt interfaces and good control of thickness, doping, and composition. However, for this to be possible, expensive and complex equipment is required in addition to the MBE deposition system. Such equipment is in fact needed in order to estimate a number of parameters which dramatically influence the semiconductor growth process. As an example, the epitaxial surface during MBE growth is analyzed by means of RHEED patterns. This standard technique produces diffraction patterns which contains information related to the surface reconstruction and roughness. Another technique currently implemented in our laboratory is the real time, *in situ* measurement of the stress induced on the layer during the growth of compounds with different lattice parameter. This technique is based on the measurement of the stress induced bending of the substrate by using two parallel laser beams reflected by the surface of the layer (figure 1). The possibility of obtaining information on the stress during the growth may allow a better understanding of of the relaxation process occurring during the growth of self-assembled nanostructures [2,3] or during the growth of the buffer layers used for coupled mismatched layers [4]. Within such a framework, we have developed and tested an electronic system that, while characterized by reduced complexity and low cost, can provide significant improvements in the analysis of real time data coming from the equipment employed for monitoring the MBE growth.

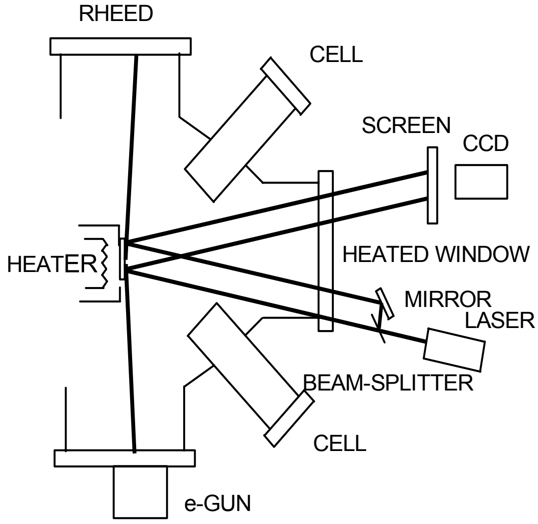

Fig. 1. Scheme of stress measurement and RHEED systems implemented on the MBE chamber.

Such a system, in fact, can be useful in all those cases in which real time and in situ structural information concerning the semiconductor growth can be obtained as a CCD pattern, regardless of the kind of technique used to probe the specimen.

The main function performed by the system is the accurate measurement of the distance between two light spots into the CCD image. Such a distance, in fact, is the most relevant parameter for a number of monitoring techniques during MBE growth.

2. PRINCIPLE OF OPERATION

The new electronic system works in a frequency range consistent with the MBE deposition process time scale.

A detailed block diagram of the measurement system is shown in figure 2. The video signal coming from the CCD camera is used as an input for the synchronism separator (LM1881), the visualization circuit unit (BLANK), and the analogic circuit block. The analogic block consists of a filter stage, a derivative stage and a comparator stage; the output of the comparator is the input to the digital block of the electronic circuit.

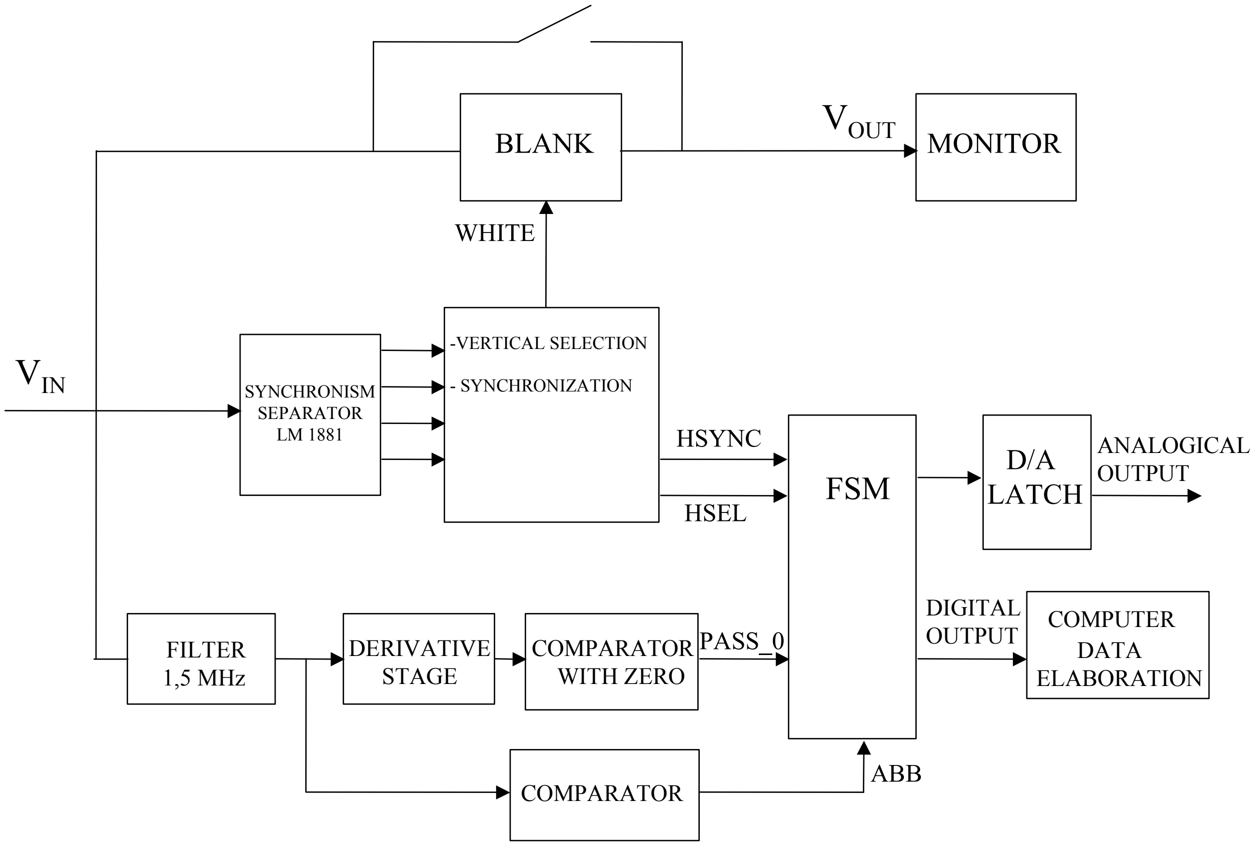

Fig. 2. Block structure of the measure system.

The basic idea is that the user has to be able to select a range of scan lines in the image, after which the circuit will elaborate the analogic video signal in order to output a voltage proportional to the distance between the two intensity (luminance) peaks present in the image. The input signal is a standard video baseband signal (1 V pp, 75 Ω) with a bandwidth of about 4 MHz. The signal is processed in order to separate the vertical, horizontal and frame synchronism signals. A vertical selection circuit (similar to the one described in [5]) is used to determine which section of the screen is of interest. An auxiliary blanking signal is generated by the selection circuit in order to have a visual feedback on the screen of the selected vertical range.

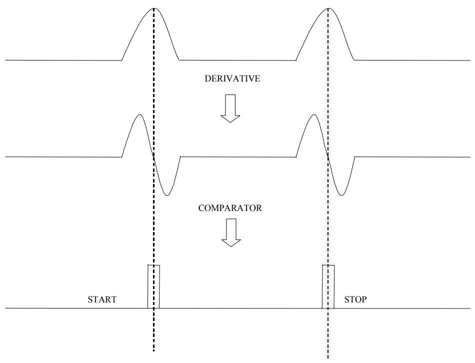

Fig. 3. Scheme of video signal before and after the derivative stage.

In parallel, the circuitry for analyzing the signal starts with a fourth order low pass Butterworth filter, with a cutoff frequency of about 1,5 MHz. This filter, besides amplifying the video signal up to the appropriate level, is needed in order to eliminate the synchro spikes and the chrominance components which may be possibly present. The following stage is a derivative circuit which does convert the signal peaks to pass-trough-zero events, with a parallel absolute value comparator that helps the logic to eliminate the spurious and noise-derived transition. Finally, the zero-crossing events are detected by a comparator, and delivered to the input of the digital block.

The digital block implements a state machine which, for every frame of the video signal and for every scan line, does compute the average distance between two significant peaks by using the zero-crossing events as start and stop signals for an high-resolution counter (figure 3).

The digital section also includes a block that generates the signals needed by the visualization circuit; finally a digital/analogical conversion block provides the analog output useful as a feedback to the control circuitry of the MBE facility. The digital section of the circuit is implemented with two FPGA of the family MAX7000S; the MAX-PLUS Altera software was used for programming.

The output of the measurement system is made available both in digital and in analogical form. The digital output can be processed by means of a PC in order to estimate the distance between the two light spots. The analogical output of the converter can be used for direct visualization onto an oscilloscope.

3. EXPERIMENTAL RESULTS

The system was used for elaborating the RHEED signal during the first layers deposition of GaAs on GaAs (figure 4). This standard measurement in MBE is performed in order to obtain the growth rate of the layers. The oscillations in RHEED patterns are considered to be related to changes in surface roughness during growth[1,6]. The equilibrium surface existing before growth is smooth, corresponding to high reflectivity of the electron reflected beam. As the growth starts, nucleation islands form at random positions onto the surface, leading to a decrease in reflectivity. These islands grow and ultimately produce another smooth surface, and it would be expected that the minimum in reflectivity would correspond to a 50% coverage by the growing layer. Therefore, each oscillation is associated to the completion of one single monolayer. The time measurement, as it is shown in figure 4, allows to directly obtain the growth rate in a very accurate way. This is an example of a fundamental parameter in the layers growth that is obtained with this system in an easier way when compared with standard techniques.

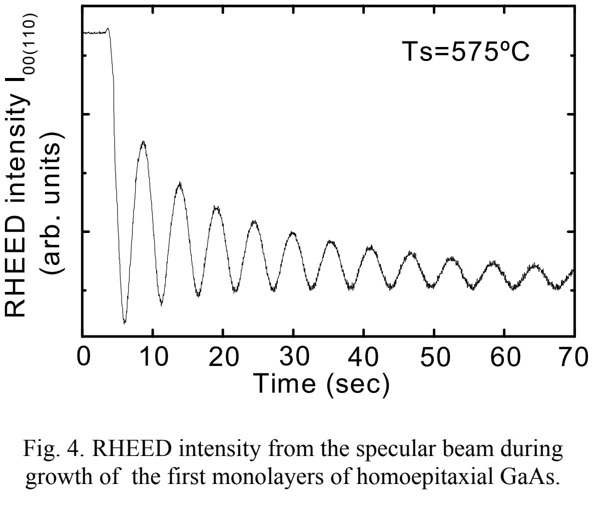

Fig. 4. RHEED intensity from the specular beam during growth of the first monolayers of homoepitaxial GaAs.

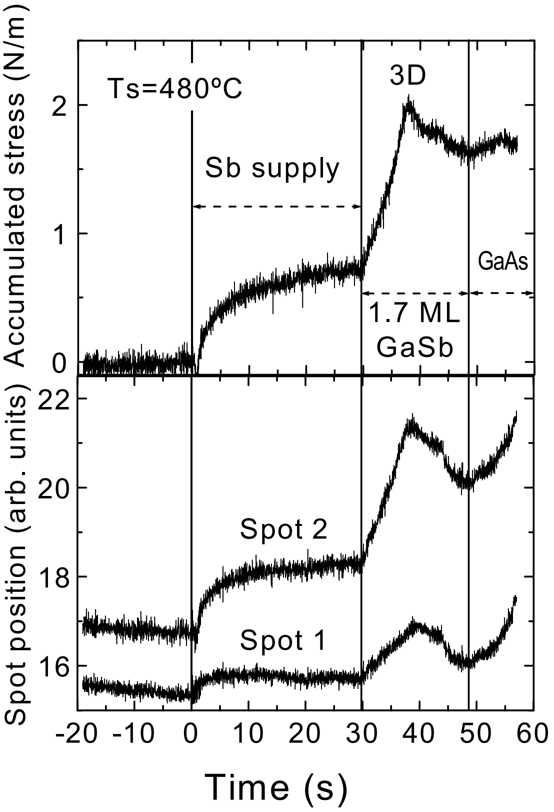

Fig. 5. The spot positions and the calculated accumulated stress during the growth of GaSb on GaAs. During GaSb deposition, a strong relaxation is observed in coincidence with the 3D structure formation.

Another application is the monitoring of the stress evolution during growth of mismatched heterostructures of III-V compounds. In a typical stress experiment during MBE growth of layers with different lattice parameter, as it is shown in figure 1, two parallel laser beams reflected by the sample strike a screen and the pattern is recorded by a CCD camera and fed to the monitoring system. The evolution of the distance between both spots can be directly related to the evolution of stress in the layer through geometrical and mechanical relations [2]. In figure 5, we present results from the growth of GaSb on GaAs. This system has a large lattice mismatch (7.8%), which promotes an elastic relaxation after the deposition of a few monolayers. At time equal zero the deposition of GaSb starts, and the sample bending due to the stress deflects the two beams. The increase of the distance between the spots is related with the bending of the layer. This distance evolution is related with the stress generated during growth and it allows to calculate the accumulated stress in the layer (top figure 5). The results reported in fig. 5 show an initial increase of stress at the beginning of the deposition of the of GaSb (lower slope and ulterior saturation level during supply of Sb only, and higher during GaSb deposition). After 0.7 monolayers of GaSb, a decrease of the stress is observed which can be related to the formation of tridimensional structures that relax the stress in an elastic mode. This strong relaxation process continues during the rest of GaSb deposition.

This real time, *in situ* can therefore be useful for a better understanding of the detailed mechanisms involved in the growth of mismatched heterostructures, which are the object of a large amount of investigation because of their potential use as the basis for new optoelectronic devices and as a way for obtaining nanostructures by self-organizing growth.

3. CONCLUSION

A prototype of a new electronic circuit which allows to automatically extract accurate information from CCD images obtained during MBE growth as a result of different monitoring techniques has been designed, built and tested. While allowing a considerable improvement in the accuracy of the results which can be obtained, it has a very simple structure and can be realized at a very low cost. This is clearly demonstrated by the preliminary results which have been obtained while testing the new instrument during actual MBE growths. Finally, it is worth mentioning that the system we have developed does not depend on the characteristics of the specific CCD camera which is employed and can be therefore easily integrated as part of almost any MBE facility.

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Authors:

PhD Student Mario Carpentieri, Università degli Studi di Messina, Dipartimento di Fisica della Materia e Tecnologie Fisiche Avanzate, Salita Sperone, 31 C.P. 57, 98166 Messina, Italy. Phone: +39.090.6765647, fax +39.090.391382,
E-mail: carpentieri@ingegneria.unime.it.

Prof. Juan Pedro Silveira, Instituto de Microelectronica de Madrid (CNM-CSIC). C/ Isaac Newton, 8, 28760-Tres Cantos, Madrid, Spain. Phone: +34 918060796, fax: +34 918060701,
E-mail: silveira@imm.cnm.csic.es.

Prof. Romano Giannetti, Universidad Pontificia Comillas de Madrid, Departamento de Electrónica y Automática, C/ Alberto Aguilera, 23-25, 28015 Madrid, Spain. Phone: +34 915422800, fax +34 915411132,
E-mail: romano@dea.icai.upco.es.