RHEED SIGNAL SAMPLING DEVICE

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Abstract — *Monitoring the intensity of the reflected spot in a RHEED image is the most important method used to control the growth of semiconductor crystals in facilities like for example MBE. In some application the availability of the spot intensity signal as an analog voltage is also useful to realize a feedback between the growth dynamics and the external parameters of the plant, such as the cells temperatures and the synchronization of the shutters. Although said analog signal could be obtained by using a photo-detector near the RHEED screen or grabbing and digitizing the RHEED image, these methods are troublesome or expensive respectively. In this paper a simple and cheap solution, based on a synchronized sample and hold operation on the composite video signal, is proposed.*

1 INTRODUCTION

On-line control of semiconductor crystal growth is one of the most important target of a series of specialized measurement systems utilized in research laboratories. Among the most important growth techniques there is the MBE[1] (Molecular Beam Epitaxy), consisting of layer by layer material deposition by means of controlled opening an closing of chemical shutters that can modulate the atomic flux building up the crystal surface (see fig. 1).

One of the most important way of controlling the state of the surface building-up in the MBE chamber is the RHEED (Reflected High Energy Electron Diffraction) analysis. It consists of a beam of electrons that hit the growing crystal surface at a very low incidence angle. The electrons are reflected and refracted by the sample toward a phosphor screen. The diffraction of the beam with the surface will produce a light/dark pattern on the detector that give real-time information on the atomic structure of the interface. In Fig. 2 a typical RHEED image is shown, displaying a central spot caused by direct reflection of the electron beam and lateral images caused by the interaction with the atomic structure of the surface.

One of the most important source of information in a RHEED image is given by the intensity of the central spot of the diffraction image. If we report the intensity of that spot in a graph with respect to time, the resulting waveform is that of a damped oscillation. It is possible to show that every complete cycle of the signal corresponds to the build up of a complete atomic layer on the surface. The decreasing amplitude of the oscillation is caused by the fact that the first atoms being deposited on the surface produce almost perfect layers, and that the subsequent ones are less and less mono-atomic layers. It is also know that, by utilizing the central spot RHEED signal intensity to adequately feedback the opening and closing of the shutters, it is possible to build an almost perfect crystal, where the quality of the atomic layers deposited do not decrease with thickness[2].

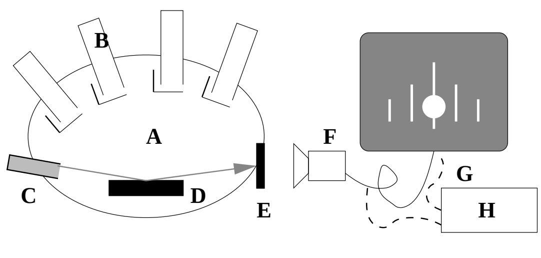

Figure 1: Structure of a RHEED detector in an MBE facility. A) MBE chamber; B) chemical sources with their shutters; C) electron beam source; D) substrate support and growing crystal; E) RHEED detector; F) TTL camera; G) Monitor screen reproducing the RHEED signal showing a typical diffraction pattern; H) the proposed video-rheed sampling device.

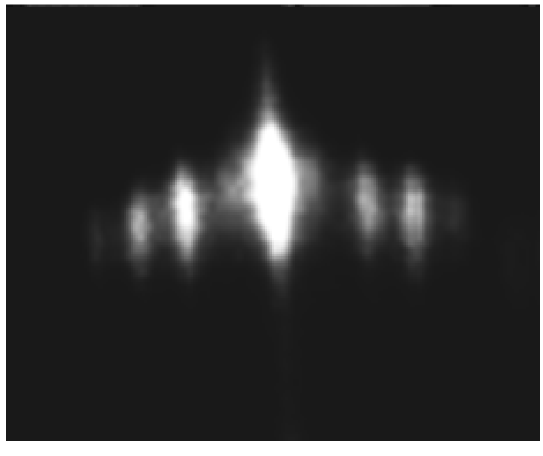

Figure 2: Example of a typical RHEED image. The pattern of lights and darks area give information on the atomic structure of the sample surface.

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1.1 Measurement of spot intensity.

To design a simple enough feedback system, it is necessary to measure the intensity of the central white spot of the RHEED image. This was traditionally done in two ways: the first, using a photodiode detector near the RHEED luminescent screen, with a current amplifier; the second, using a frame grabber card in a PC that could sample the spot intensity. The LED solution is cheap, but cumbersome to utilize; selecting the position of the spot is a time-consuming and often frustrating job. Furthermore, the presence of the photo-detector would disturb the diffraction image on the TV monitor. The second approach is surely versatile and simple to use, but quite expensive.

In this paper a new solution is proposed. An apparatus was designed[3] to sample the CCD camera signal in order to output an analogic voltage proportional to the spot luminosity. At the same time, the original image is sent to the TV monitor, and the position (along with the horizontal and vertical dimension) of the transducer spot can be controlled by means of a graphics cursor.

The instrument is very simple to use, versatile (the measurement point can be chosen by the operator), fast and very cheap. A prototype has been built and tested; it is currently used in the Madrid Microelectronics Institute to control the MBE facility located there. The main advantage with respect the frame grabber solution is its greatly reduced cost (at least twenty times cheaper).

2 VIDEO-SAMPLER STRUCTURE

The idea behind the video-sampler is to utilize the video composite signal that, in every MBE system on the market, is available to the user. RHEED image is a grayscale image, so the information of the luminosity of any point in the screen is available as a voltage in the video composite signal at the appropriate instant of time. By synchronizing a sample and hold circuit on the video signal it is possible to extract the required information.

2.1 Overview of the video-sampler operation.

In Fig. 3 some of the signals used and processed by the video-sampler device are shown. From now on, all the references to video signals will refers to a black-and-white (grayscale) signal. The first two signal from the top represent a simplified version of the video signal from the CCD camera: the upper trace shows a composite synchronization signal and the second one the luminance signal. The synchronism signal contain the horizontal synchronization pulses (the short ones) that trigger the start of a new line on the screen, and the vertical synchronization pulses that start a new screen (half-frame, to be exact). In PAL video standard codification, vertical sync pulses are present every 20 ms and horizontal sync pulses every 62.5 μs. Between horizontal pulses lies the luminance signal which is, after conditioning, responsible of controlling the intensity of the electron beam on the Cathode Ray Tube (CRT) that will visualize the image.

The video-sampler operation is based on the sampling of the luminance signal. The sample signal is generated by synchronizing a cascade of monostable multivibrator circuits on

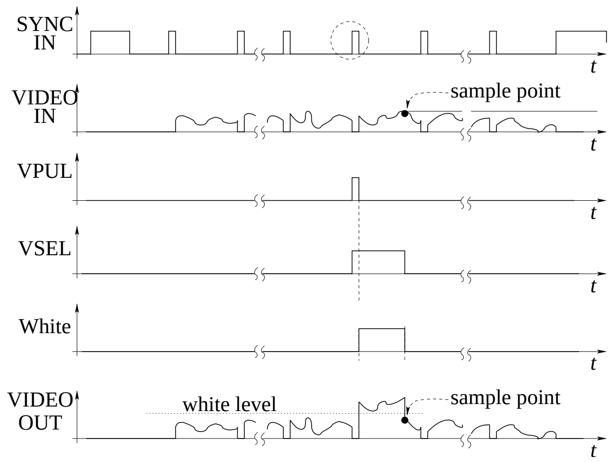

Figure 3: Video-sampler operation principle. From top to bottom, video synchronism, video luminance signal in input, three different internal synchronization signals and the video luminance signal in output are represented. Vertical axes are voltages (in arbitrary scale). .

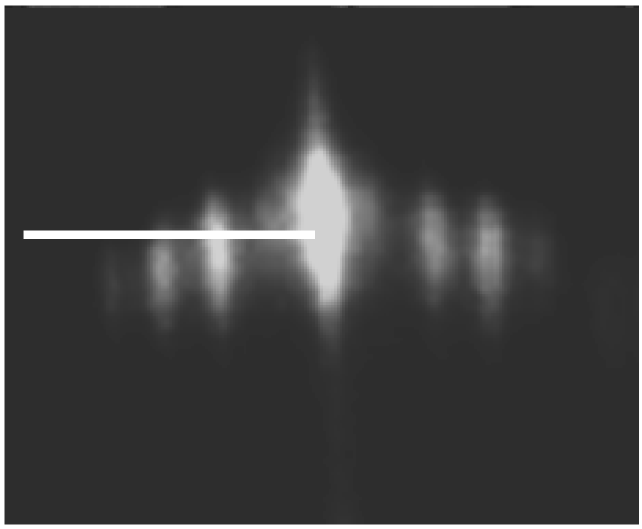

Figure 4: The image when the marker visualization is on. At the end of the white line there is the sampled point. .

the vertical and horizontal sync pulses, and letting the user manipulate, by means of a pair of knobs, the delays introduced to select the exact spot to be sampled. To simplify the selection, the output of one of the monostables is optionally added (with appropriate amplification and offset) to the video signal, generating a “mark” on the CRT that extend from the start of the line to the selected measurement point on the image (see Fig. 4).

2.2 Detailed structure of the instrument.

The detailed block structure of the video-sampler is reported in Fig. 5. The video signal is separated into synchronism (SYNC IN) and luminance (called “video in” in the diagram) with a general purpose IC. Should the signal being obtained from a color camera, a low pass filtering is needed to eliminate the chroma part from it. The sync signal is separated into the

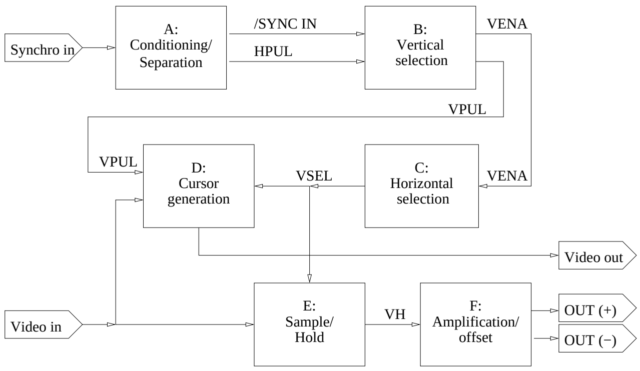

Figure 5: Block structure of the video sampler. .

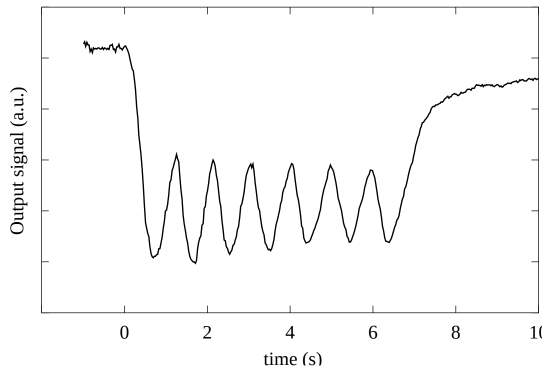

Figure 6: Example of RHEED measurement taken by the video-sampler, showing the growth of 7 atomic layers. *Courtesy of J.P. Silveira and F. Briones, IMM, Madrid*.

vertical one (VSYNC) and the horizontal one, and the signal conditioned to fit in the logical levels of the digital circuit, TTL in the case of the prototype, by block A.

Block B performs the vertical selection, generating a pulse that starts with a fixed but user-adjustable delay from the vertical synchronism signal of the original video, and that last a little less than one horizontal line (in the PAL prototype, about 55 μs; VENA on the diagram). That signal is then logically *and*ed with the horizontal synchronism signal obtaining the selection of just one horizontal line for every half-frame. In block C a similar elaboration is performed, generating a fixed-duration pulse (VSEL) at an adjustable delay from the start of the line. One of the intermediate signal is then sent to the mark generator (D) to obtain the effect of a visible cursor on the screen, as shown in Fig. 4.

Finally, the signal VSEL is used as the sample signal for a fast sample and hold circuit (E) built around the Harris HA-5330. That way the intensity of the spot is sampled every 20 ms and maintained at the output till the next sampling time. More precisely, at every semi-frame the sampled intensity switches between two vertically adjacent point. At the output of the sample and hold, a 100 Hz low pass filtering is applied to smooth out the signal; the processing is concluded by the addition of an adjustable offset and a variable gain amplification (block F). The last block allows the adaptation of the range of the signal to final user.

3 PROTOTYPE AND MEASUREMENTS

A prototype of the video-sample device has been implemented[3] using standard general purpose IC's; with the same principle several different implementations are possible (for example, using a microcontroller for the selection logic and mark generation). The cost of the prototype has been estimated to be well under the 50 Euros.

The video-sampler prototype has been used (and is currently utilized routinely) in the RHEED measurements performed by the research group of the Instituto de Microelectrónica de Madrid (IMM, Institute of Microelectronics of Madrid) in all the tasks related to crystal growth. The signal generated by the video-sampler has been used to obtain phase-locked RHEED oscillation during the growth of III-V semiconductor crystals[2], and more recently to develop a stress-free growth technique. One example of such measurements is reported in Fig. 6, where the central spot intensity signal of the RHEED image shows the growth of seven atomic layers on the crystal.

At the time of the writing of this article, more sophisticated versions of the video-sampler are under final development stage. More in detail, a version which is able to average a selected rectangular zone of the image is in test phase, and a two-channel version is in the final design phase.

4 CONCLUSIONS

In order to obtain a voltage signal proportional to the reflected spot intensity of a RHEED image, a device based on the synchronized sampling of the video signal from a camera has ben designed and a prototype implemented. The device fulfilled the requirements of economicity and easyness of use; the prototype and a couple more versions are currently used in MBE systems to develop feedback-driven growth techniques.

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