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A LIGHT SPOT SCANNING AUTOMATED APPARATUS FOR HIGH RESISTIVITY SEMICONDUCTORS

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ABSTRACT

The automation of a Light Spot Scanning apparatus is described to be used for spatial uniformity profiling of semiconductor samples. A crystal is mounted on a minicomputer controlled X-Y translation stage and it is illuminated by a well focused He-Ne laser beam. A general purpose AD/DA acquisition system was built up and used to measure the photocurrent when the light spot was scanning the whole sample surface. On line treatement of the acquired data allows to obtain a homogeneity map of the sample under test. The apparatus is described in full details and some examples are presented of photocurrent maps for a high resistivity detector grade CdTe single crystal.

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1. - INTRODUCTION

Cadmium Telluride and Mercury Iodide are very interesting high resistivity materials for the preparation of gamma and X-ray detectors operating at room temperature with good efficiency (Scharager et al. 1980). One of the most important problems effecting the performances of this kind of detectors is the spatial uniformity of the semiconductor crystal. Therefore, it is very useful to have at one's disposal a technique of semiconductor profiling which allows a quick identification of the most homogeneous and best quality regions in a crystal. In this respect, Light Spot Scanning (LSS) is a well known technique for the analysis of photosensitive semiconductors (Tihanyi and Pasztor 1967, Potter and Sawyer 1968, Schuler 1967 and McMahron 1971). The photoscanning can be used both for a qualitative homogeneity analysis, and for a point by point measurment of some physical parameters effecting the device performances (resistivity, minority carrier diffusion lenght, etc...) in different regions of the sample. In particular, Tove and Slapa (1977 and 1978) proved that LSS can be used to study CdTe and HgI_2 detector grade crystals.

In this paper we describe a computer controlled LSS acquisition system set up in order to investigate the spatial uniformity of high resistivity detector grade CdTe crystals. Unlike LSS systems described in the literature, which used a scanning light beam on a fixed sample, our system consists of a fixed well focused light beam exciting a specimen mounted on a micrometric X-Y translation stage. A minicomputer interfaced logic controls the step by step scanning of the mechanical table and synchronously acquires the photoresponse data. Because of high resistivity of crystals to investigate, a continuous light beam is used, and thus a d.c. photocurrent is measured. However, the described system can be easily adapted to the analysis of low resistivity photosensitive semiconductors and devices, by using a chopped light beam and a synchronous detection of the generated photoresponse (see, as an example, Lile and Davis 1975).

2. - GENERAL OUTLINE OF THE APPARATUS

The photocurrent through a semiconductor sample illuminated by a light beam depends on some physical parameters (resistivity, charge carrier lifetime, etc...). Tove and Slapa (1978) have widely discussed the case of a high resistivity semiconductor. They have shown that, when a small light spot reaches different regions of the sample, the photocurrent values depend on the local properties and so photocurrent profiling can be used to investigate spatial homogeneity in the crystal. Furthermore, if photocurrent measurements are carried out for different values of the applied bias, a more quantitative information can be obtained about both the local resistivity and the contact behaviour. Our system has been designed in order to allow the execution of both kind of analysis. In fact, both the position of the sample under the fixed light beam and the applied voltage are computer controlled. So, by measuring the photocurrent point by point, a homogeneity map can be easily obtained; moreover, by performing the measurement scans for different values of the biasing voltage, a map of the investigated physical parameter can also be obtained.

A schematic outline of our LSS system is shown in Fig. 1. The sample is mounted on a X-Y

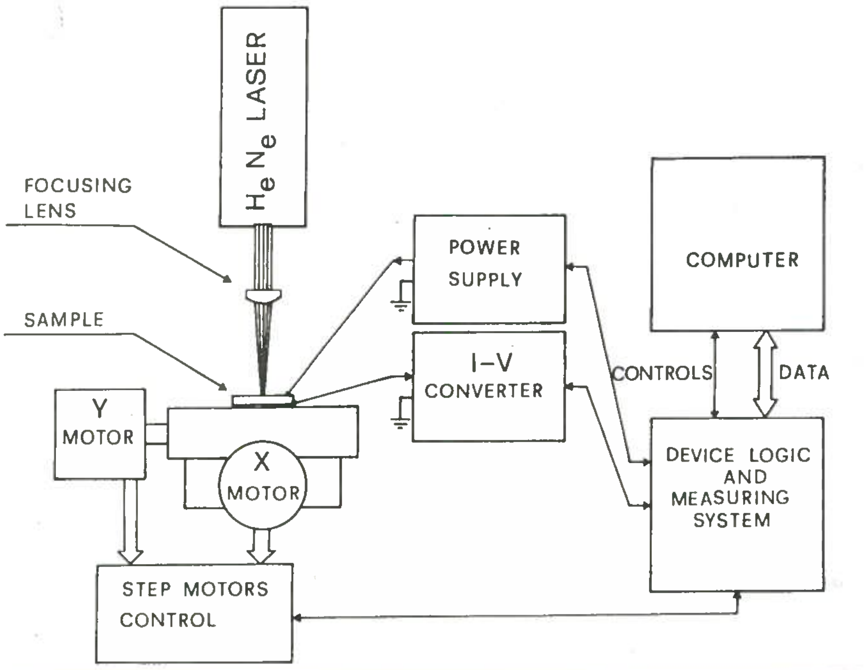

FIG. 1 - Schematic outline of the Light Spot Scanning system.

micrometric translation stage, made by a couple of tables Micro-Controle mod. MR 50-16, with a resolution of about 1 μm. This X-Y table has been equipped with two stepper motors (8-phase unipolar stepper motor from Philips mod. ID29) whose torque is 240 nNm at the driving frequency; each 3° 45' angular step of the motor corresponds to a linear displacement of 10.4 μm.

The optical system consists of a 5mW He-Ne laser having a $1/e^2$ beam diameter of 2mm, equipped with a Melles Griot laser line focusing singlet lens which assures a light spot with a 7.4 μm radius at the optimal focal lenght of 2.15 cm.

The biasing voltage is set by the computer in the range 0-500V by means of a 12 bits DAC converter (Datel mod. HK12BGC) whose 0-5V unipolar output is fed into an error amplifier for the regulation of the 500V fixed output of an ORTEC 456 very low ripple power supply. The circuit drawing for the voltage amplifer controller is reported in Fig. 2a.

The photocurrent is converted in a voltage level in the range 0-10V by a current to voltage converter an then digitized by means of a 12 bits ADC converter (Dated mod. HX12BMC) as shown in Fig. 2b.

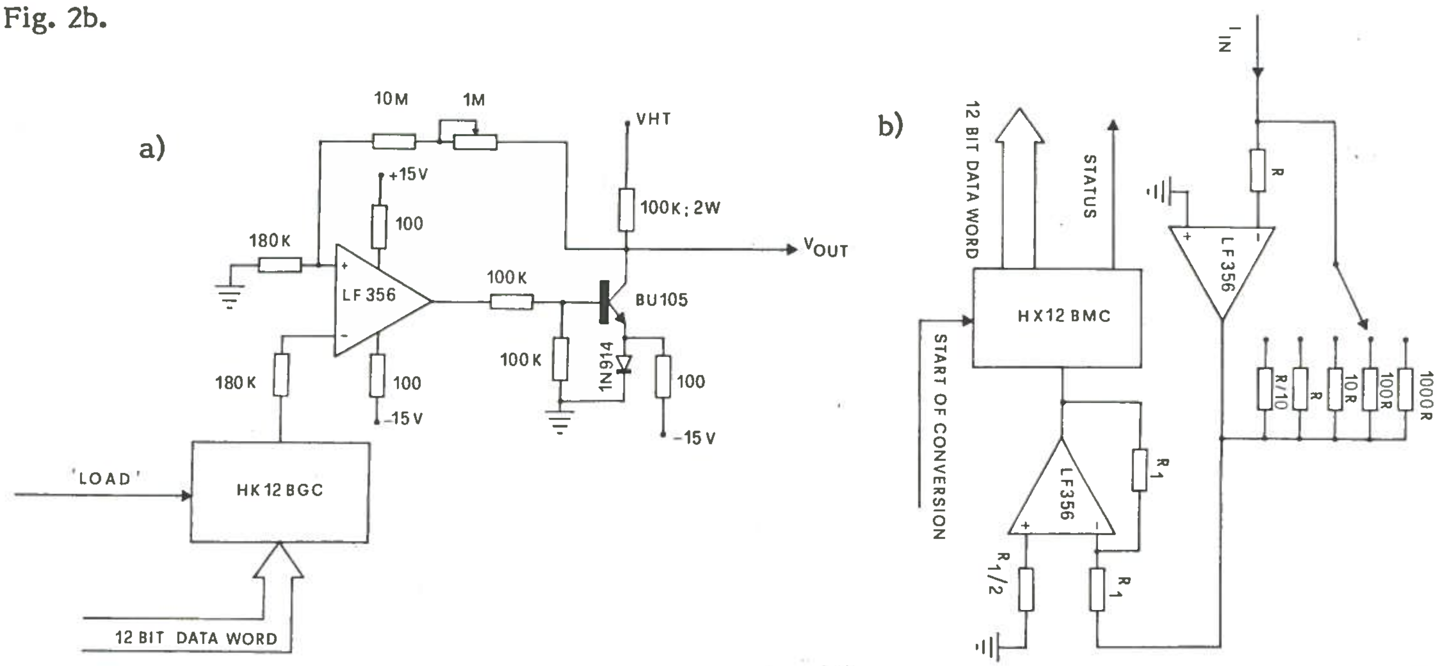

FIG. 2 - Details of the AD/DA apparatus: a) Biasing circuit through a DAC and a voltage amplifier controller; b) Photocurrent to voltage converter and acquisition ADC.

3. - THE CONTROL ELECTRONICS

The control circuit has the following functions:

1) to set the bias for the sample to the programmed value;
2) to acquire the photocurrent data through the I-V converter;
3) to start and control the operation of the servomotor circuit;
4) to receive from and transfer to the computer data and control signals;
5) to control the time sequence of all these operations.

Because of the slowness of our data acquisition system, as will be seen more clearly in the following, and to allow optimum operation of the minicomputer system, in a multiuser environment, we chose a hardware interrupt option for the device logic.

A schematic drawing of the control circuit and its connections with the servo-motor electronics and the computer is shown in Fig. 3. The on-line connection with the Digital Unibus of a PDP 11/34

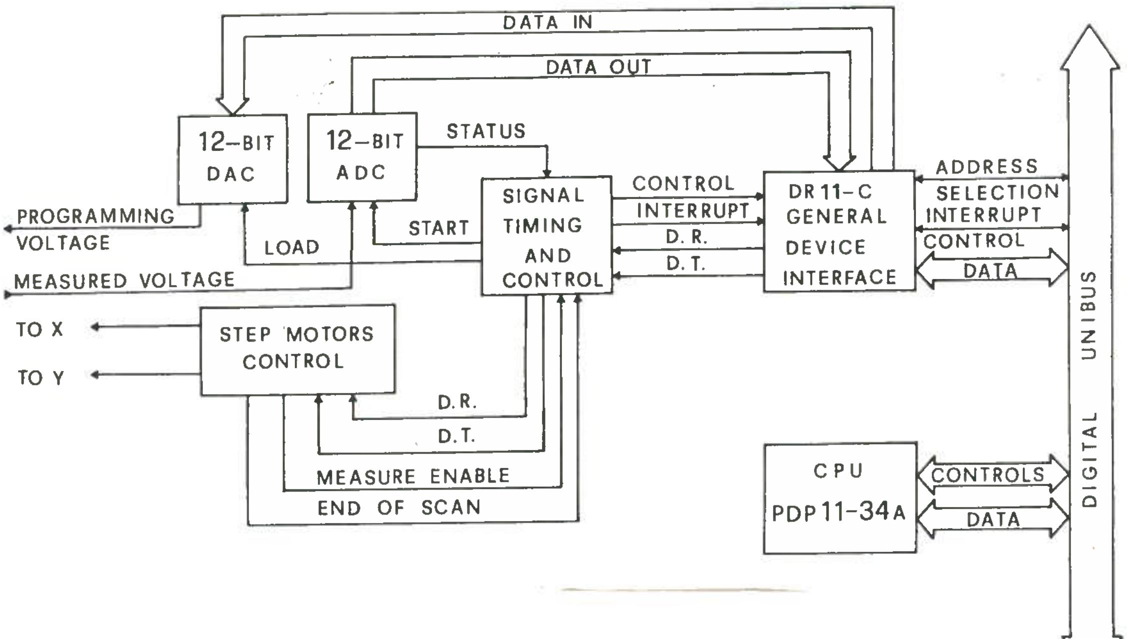

FIG. 3 - Schematic drawing of the on-line controlled logic.

minicomputer is performed via a DR-11C general purpose interface with parallel I/O. To control the operation sequence of the acquisition system we have made use of Data Ready (DR), Data Transmitted (DT) and Interrupt Request (IR) lines and of a few bits in the Control and Status Register (CSR) of the interface.

A privileged task, whose flowchart is in Fig. 4, is memory installed and waits for execution of the interrupt service routine. The operation begins with a manual start that puts the whole system in a known quiescent state, while the starting value of the biasing voltage is software programmed into the output register of the interface and then, through the DAC converter, applied to the sample. The next step is the reading of the photocurrent value, through the ADC converter, into the input register of the interface.

When the two I/O operations are completed, the interface sets DR and DT lines and the control circuit makes use of these signals to start the servomotor logic. At the end of each translation step an "End of motion" signal is sent by the motor driving circuit to the timing and control board; this signal, suitably delayed, constitutes

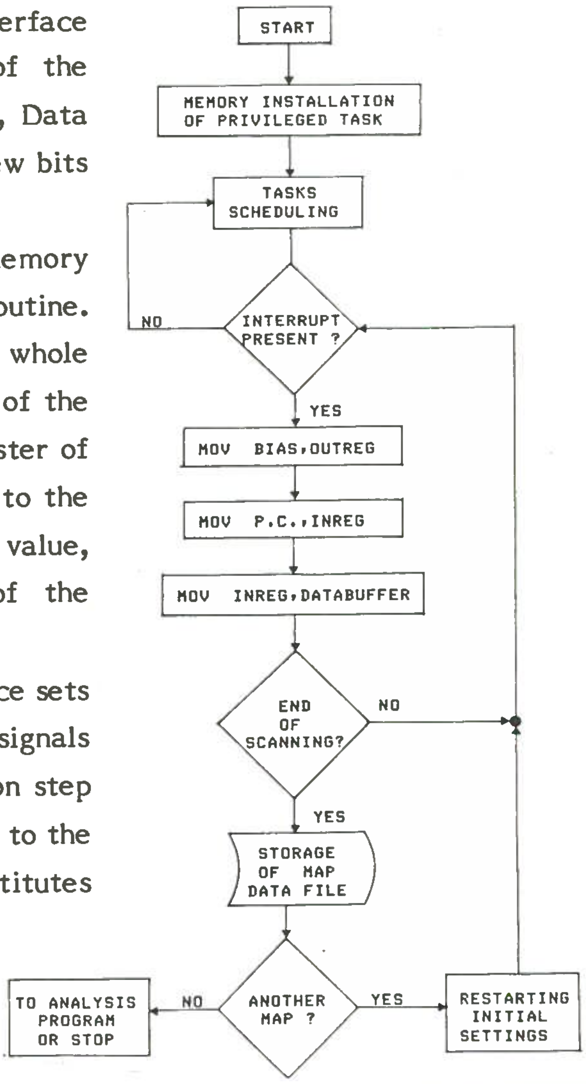

FIG. 4 - Task flowchart for the interrupt service and data acquisition routine.

the new interrupt request. The delay value can be initially set in the range 0.1-10 sec and is used to allow that photocurrent reaches its steady-state value. In fact, in higly compensated material as CdTe, quite long times can be necessary in order to reach steady-state conditions because of the presence of deep trapping levels.

The control circuit for servomotors is made up of four counting sections which allow to send the programmed stepping pulse train to the X or Y motor. The counting sections can be presetted by means of thumb-switches in order to independently define the number of motor steps for each linear scan and the total number of scans both along the X and Y direction. The details of the electronic circuit for servomotor control are described alsewhere (Iacobelli et al. 1981).

The scanning sequence is the following:

1) the prefixed number of steps along the X direction is performed;
2) one step along the Y-axis is made and the direction of X motion is inverted;
3) the next line is scanned in the X direction;
4) the operation goes on as long as the prefixed total number of X and Y scans is accomplished. When the entire scan is completed, the control electronics sets a bit in the control and status register of the interface and this bit is software tested as a condition for "End of Scanning".

4. - APPLICATION EXAMPLES

The automated LSS system described in the previour sections have been set up in order to anlalyze detector grade CdTe crystals. Crystals were grown in our laboratory by the Travelling Heater Method (Wald et al., 1978). So obtained ingots, often, do not result as a unique single crystal, but show a few single crystals grow along different crystallographic directions. In order to prepare good gamma-ray detector, it is necessary to separe these single crystals. Moreover, the ingot can present defects and impurities, such as Tellurium inclusions, which negatively affect the detector performances. Then, it is very important to identify the best crystals and/or the best quality regions in each crystal, before detector preparation.

From the ignots, different samples have been cut with thicknesses ranging between 0.5 and 2 mm. The surfaces of these samples have been carefully lapped and polished with diamond pastes of grain size as small as 1/4 μm. Then, they have been coated with two gold films, by vacuum evaporation, in a sandwich arrangement; top contact was sufficiently thin (about 200 A) to be semitrasparent to the laser beam. The sample resistivities, previously measured with the Van der Pauw method, ranged between 10^6 and 10^8 Ω cm. The preparated devices showed capacities of about 10 pF and dark currents of about 100 nA, at a bias voltage of 200V.

Typical scans along a single line are shown in Fig. 5, for different values of the bias voltage. For a positive bias to the top contact, a quite high photocurrent is measured (Fig. 5a), while there is no appreciable photoresponse for negative bias (Fig. 5b). This is in good agreement with the p-type conductivity of the investigated crystals (Tove P.A. 1978). In Fig. 5a it can be also observed that the relative photoresponse of different crystal regions changes at increasing voltage. A few single line scans must be performed at different bias values before measuring the photocurrent for the entire crystal, in order to ascertain the best bias condition. Also the best delay time between measurements at consecutive points must be tested in order to read the correct stready-state value of the local photocurrent. Generally a delay time of 2 sec was used.

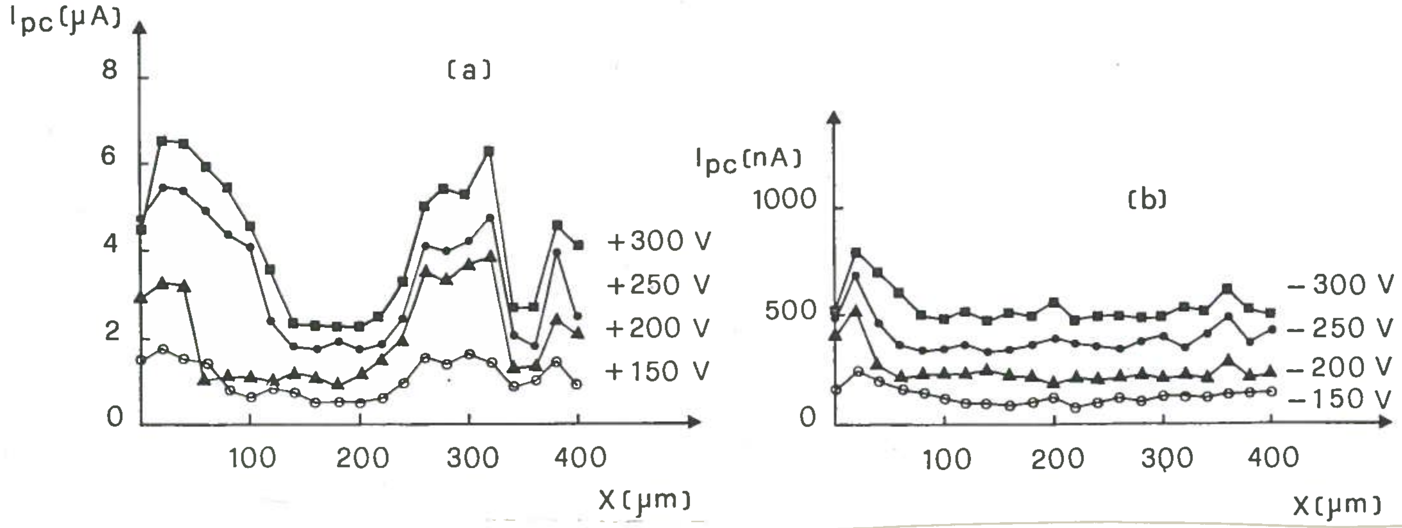

FIG. 5 - Typical single line scans for an Au/CdTe sample; a) with a positive and b) with a negative biasing voltage.

Once chosen the operating conditions, homogeneity maps can be executed. Two typical examples are shown in Fig. 6 and Fig. 7. The photocurrent values have been represented in these maps by using seven different alphanumeric symbols, each representing a segment of the entire photocurrent range, as shown in Fig. 6. Thus, the best quality regions, which give a higher photocurrent value, are represented by darker symbols. In Fig. 6 is reported the map of a square region of 4.00 mm in side lenght by a 40x40 matrix of mesuring points. The sample contour is sharply evidenced, so

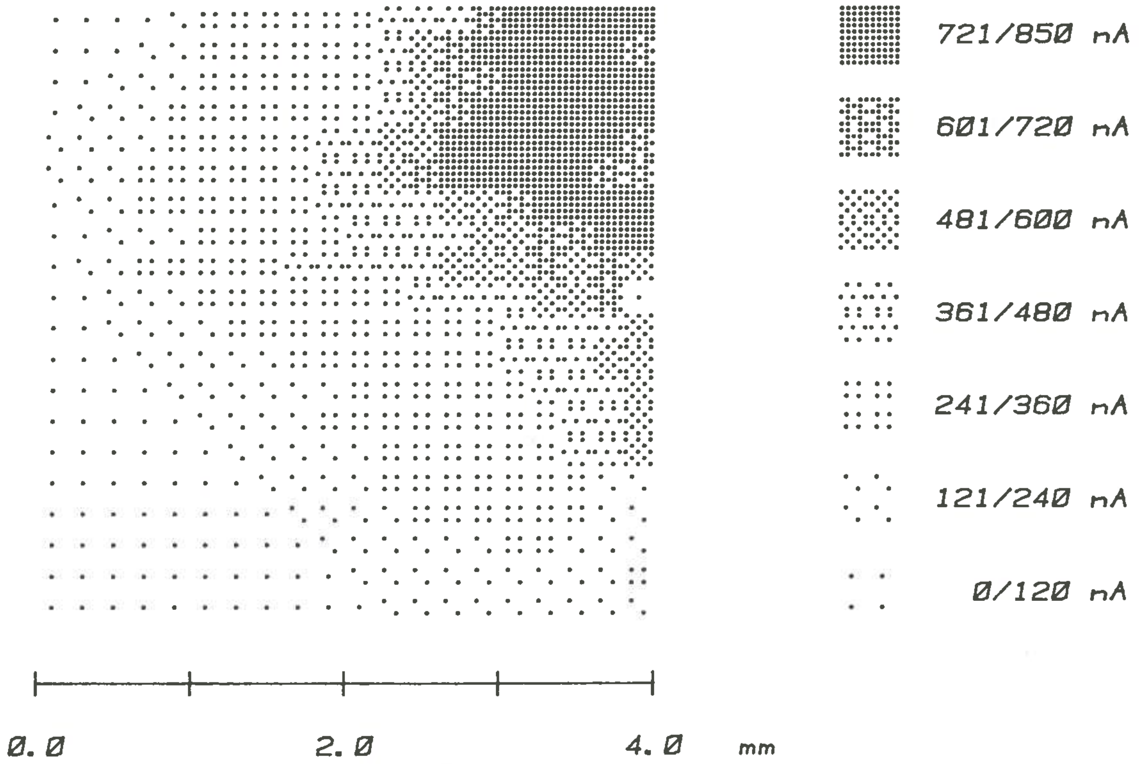

FIG. 6 - Homogeneity map of an Au/CdTe sample with a 16 mm^2 scanned surface.

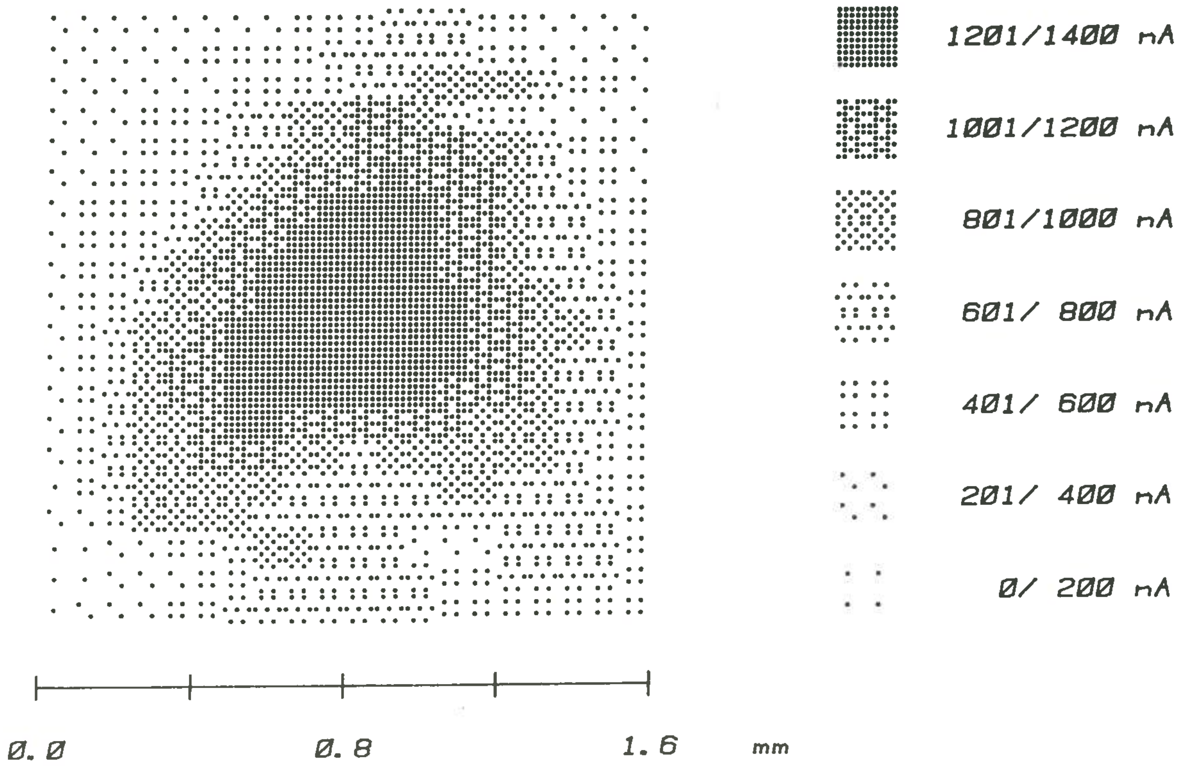

FIG. 7 - Photocurrent map of the same sample as in Fig. 6 but with a higher spatial resolution.

demonstrating, that there is no appreciable contribution to the photocurrent by light which reaches the specimen surface after some reflection. In Fig. 7 is shown a map recorded on the same sample with a greater resolution (80 μm for each step both in X and Y direction). In both cases, the entire map was recoded in about 55 min.

In conclusions, it is interesting to compare our system with LSS systems previously reported in literature. Most of described systems perform the optical scanning by mouving the light spot on the specimen surface by means of oscillating mirrors. The resulting map is usually displayed on a CRT monitor. Such systems are very useful for a quick and qualitative analysis but they present some problems:

i) the scanning area is quite restricted because of the limitate aperture of the focusing optics;
ii) the incidence angle of the moving light beam on the sample surface is not constant;
iii) the optical scanning must be sufficiently fast to be synchronous with the CRT raster.

As a matter of fact, if the light scanning is too fast, it is possible that the photoresponse does not reach its steady-state value and the homogeneity map is distorted.

On the contrary, our system presents some advantages:

i) the scanned area can be very large and it only depends on the working stroke of the X-Y table;
ii) the incidence angle of the light beam on the specimen surface is constant and then the optical geometry is very simple;
iii) the scanning speed can be sufficiently low to assure a true stready-state value of the local photoresponse;
iv) the homogeneity maps can be directly read in lenght units and thus can be easily used in the detector preparation;
v) the photocurrent values can be recorded in a memory mass device of the minicomputer as

functions of some parameters as the biasing voltage and afterwords they can be analysed for more quantitative information.

In conclusion we can state that a LSS system on line controlled by a minicomputer can give a very useful tool for studying and characterizing detector grade semiconductor samples.

REFERENCES

- G. Iacobelli, A. Quirini e A. Valentini, Movimento automatico X-Y di precisione controllato da un minielaboratore, Report INFN/TC-81/5.
- D.L. Lile and N.M. Davis, Semiconductor profiling using on optical probe, Solid-State Electronics 18, 699 (1975).
- R.E. Mc Mahron, Laser test ICs with light touch, Electronics 12/4, 92 (1971).
- C.N. Potter and D.E. Sawyer, A flying-spot scanner, Rev. Sci. Instr. 39, 180 (1968).
- A. Holtzer, C. Scharager, M. Schieber and P. Siffert, Performance comparison of standard CdTe and HgI_2 detectors IEEE Trans. Nucl. Sci. NS-27, 276 (1980).
- V. Schulker, Simple light spot scanner and its application on semiconductor nuclear particle detectors, Rev. Sci. Instr. 38, 1374 (1967).
- G. Boreg, M. Slapa and P.A. Tove, Nucl. Instr. & Meth 150, 55 (1978).
- M. Slapa and P.A. Tove, Rev. Phys. Appl. 12, 34ç (1977).
- N.G. Pasztor and J. Tihanyi, Solid-State Electronics 10, 235 (1967).
- G. Entine and V.F. Wald, Nucl. Instr. & Meth. 150, 13 (1978).