Paper

Semi-automatic test system for characterization of ASIC/MPWS

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Abstract—A measurement system for integrated circuit testing has been developed. It consists of a semi-automatic probe station and a set of measurement equipment controlled by commercially available measurement software. The probe station is controlled by dedicated software. Both the measurement and station-control software communicate using the DDE protocol. The measurement system is flexible. It is particularly suitable for semi-automatic testing of multi-project wafers. Output data generated by the system is used for the characterization of the CMOS technologies.

Keywords*— *automatic testing, diagnostics of technology, multi-project wafers.

1. Introduction

Semi-automatic test system developed by the Industrial Institute of Electronics (IIE) and Institute of Electron Technology (IET) is used to test wafers containing different types of structures and to characterize diagnostics structures irregularly distributed across the wafer. Testing of standard wafers with uniformly distributed structures is also possible.

The system contains probing and measurement subsystems and is controlled by a PC working under the MS Windows operating system. Both subsystems consist of control application (software) and related hardware.

In this paper the system is described and an application example is shown. The intentions of the authors concerning future work are presented, too.

2. Motivation

Numerous application-specific integrated circuits (ASICs) are designed and manufactured in the Institute of Electron Technology. Dedicated test structures, which accompany the ASICs, are used for characterization of technologies and verification of ICs designs. Testing of both standard wafers with uniformly distributed structures and multi-project wafers (the so-called MPWs) containing different types of structures is of great importance.

In order to meet this requirement a semi-automatic IC testing system has been developed in the Industrial Institute of Electronics and implemented in the IET. The system consists of several hardware and software components, designed and manufactured in the IET. The components are now available commercially.

The testing system and all its hardware and software components are described in detail below. Communication between the software packages is presented, too. The operation of the system is described and illustrated by a practical example. Finally, possible future improvements of the system are discussed.

3. System structure

The testing system consists of the following components (Fig. 1):

- probe station (redesigned version of a standard device) controlled by the ELECT program;
- Keithley SMU236/7 units (connected with a device-under-test (DUT) via Keithley switching matrix 707A), controlled by the METRICS program, available commercially.

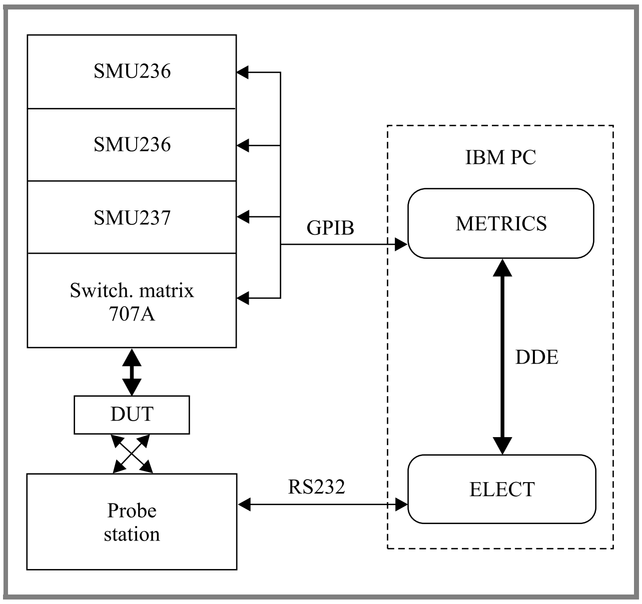


Fig. 1. Block diagram of the testing system.

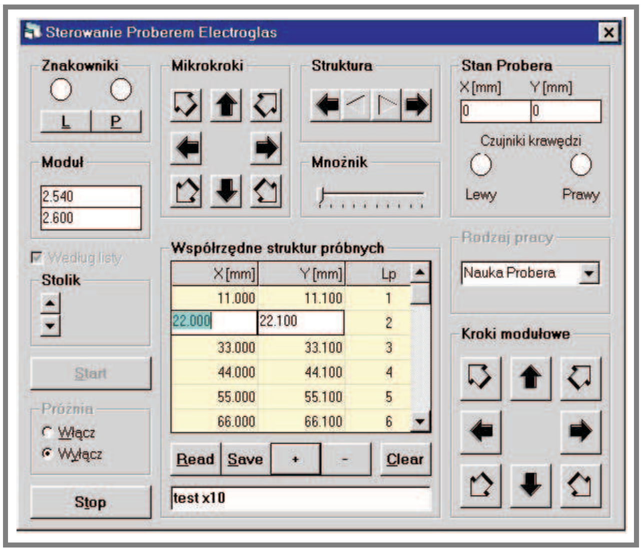
3.1. Probe station and ELECT program

The probe station is equipped with a set of probe cards dedicated to testing of specific DUTs. At present individual micromanipulators are not available.

The ELECT program is fully responsible for the operation of the probe station. The following operations are available:

- navigation of the chuck; the resolution of chuck positioning is 5 μm; this enables measurement of devices with small pads;

- adjustment of the chuck position and orientation; these options are necessary for proper movement of the chuck during automatic testing;
- testing of the chuck positioning repeatability;
- start of measurement;
- acquisition of measurement results obtained by METRICS.



Stan Probera: X [mm] 0, Y [mm] 0

Moduł: 2.540, 2.600

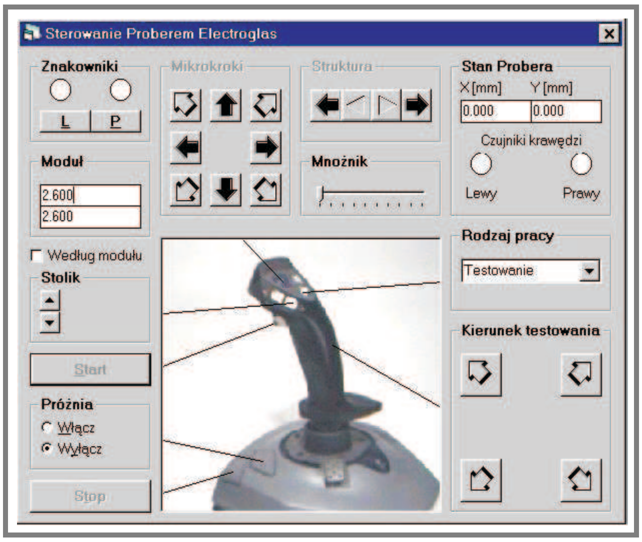
Rodzaj pracy: Nauka Probera

Próżnia: ○ Włącz ● Wyłącz

X [mm]	Y [mm]	Lp
11.000	11.100	1
22.000	22.100	2
33.000	33.100	3
44.000	44.100	4
55.000	55.100	5
66.000	66.100	6

test x10

Fig. 2. The main form of ELECT in the session preparation mode with a grid containing the list of co-ordinates.



Stan Probera: X [mm] 0.000, Y [mm] 0.000

Moduł: 2.600, 2.600

☐ Według modułu

Rodzaj pracy: Testowanie

Próżnia: ○ Włącz ● Wyłącz

Fig. 3. The main form of ELECT in the session runtime mode.

The ELECT application co-operates with the probing station via a RS232 interface. The application can operate in two ways: session preparation (control form shown in Fig. 2) and session runtime (Fig. 3).

3.2. Measurement equipment and METRICS program

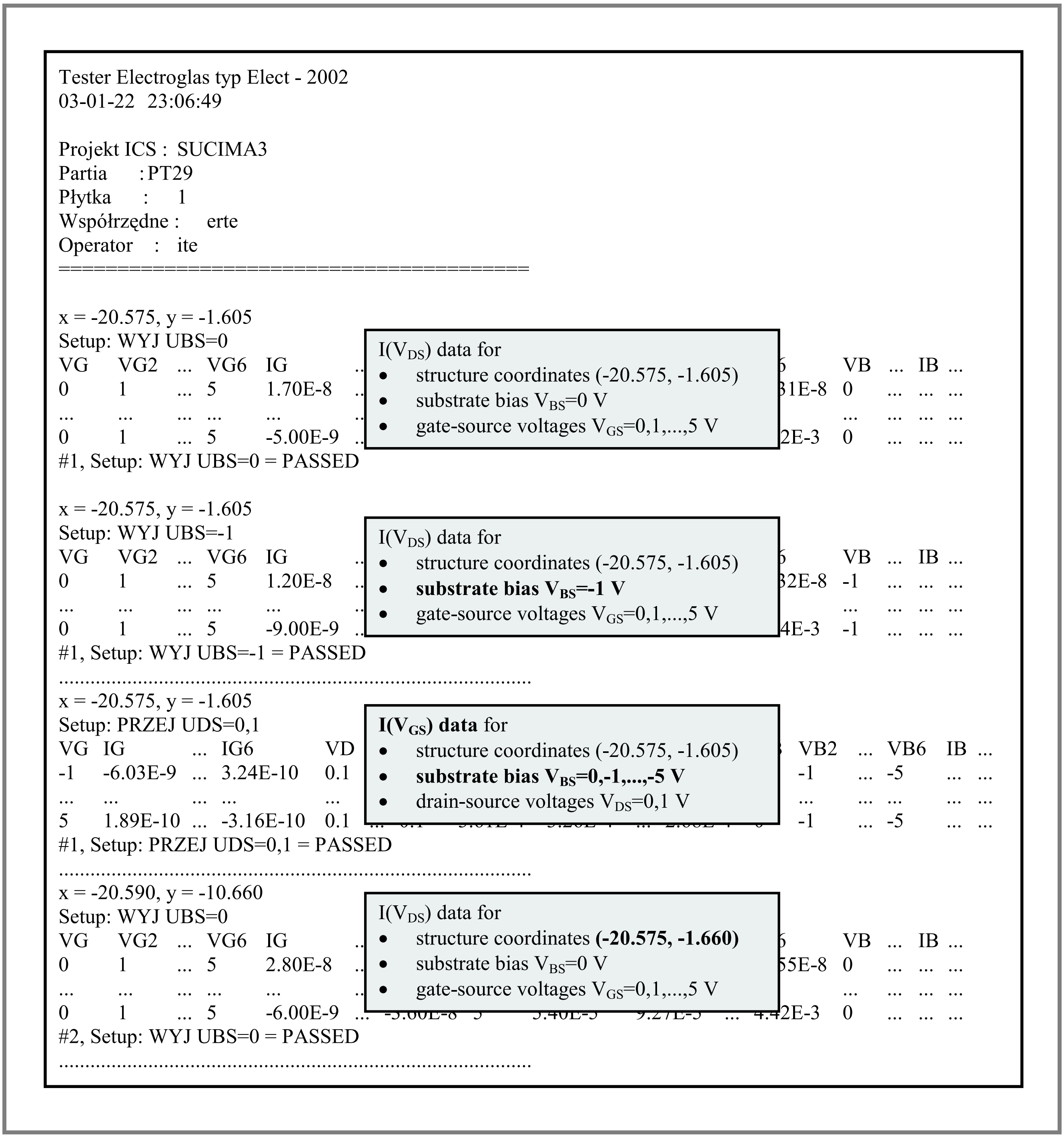
The measurement subsystem is the standard System 93 I-V delivered by Keithley. At the moment the subsystem contains three DC source-measure units (SMUs), a switching matrix, a synchronisation unit (not shown in Fig. 1) and METRICS, that is the control application. Other equipment may be added in the future. The application and measurement units are interfaced by GPIB.
The METRICS program is used to :

- arrange internal data-base consisting of the so-called projects; the project stores measurement configurations as well as measurement data;
- arrange the measurement projects; the project is a collection of the so-called setups;
- arrange the measurement setups; the setup defines a single measurement configuration and stores data obtained recently using this configuration;
- specify measurement configuration using a graphical editor (definition of connections of the SMUs with DUT nodes, configuration of the switching matrix, if used; definition of the SMUs input data);
- define additional calculations performed upon measured data; simple extraction of parameters of the measured devices may be done; post-processing formulae are stored in the measurement setups;
- define internal tests upon measured data;
- program measurement devices, switching matrix and trigger controller;
- arrange a sequence of measurements (e.g., selected setups may be executed once or repeatedly);
- trigger the measurements;
- receive measured data from the measurement equipment and store it in the internal memory of the corresponding setup;
- visualise measured data;
- export measured data; data can be exported as text files and as MS Excel worksheets; these files may be used for further processing.

Measurement projects may be created using the METRICS independently from the other parts of the system. Thus METRICS may be used either as a stand-alone application or may be invoked by ELECT. The communication between these two programs is described in the next chapter.

3.3. Communication between ELECT and METRICS

Both software packages of the system co-operate using the dynamic data exchange (DDE) software interface [1–3]. METRICS works as a DDE server and ELECT as a DDE client. ELECT sends commands to METRICS. Then it receives measurement results obtained after the execution of all setups in the project selected in the appropriate text



```
Tester Electroglas typ Elect - 2002
03-01-22  23:06:49

Projekt ICS :  SUCIMA3
Partia      : PT29
Płytka      :    1
Współrzędne :    erte
Operator    :  ite
========================================

x = -20.575, y = -1.605
Setup: WYJ UBS=0
VG    VG2  ...  VG6   IG         ..                                  5      VB  ...  IB ...
0     1    ...  5     1.70E-8    ..                                  31E-8  0   ...  ... ...
...   ...  ...  ...   ...        ..                                         ... ...  ... ...
0     1    ...  5     -5.00E-9   ..                                  2E-3   0   ...  ... ...
#1, Setup: WYJ UBS=0 = PASSED

x = -20.575, y = -1.605
Setup: WYJ UBS=-1
VG    VG2  ...  VG6   IG         ..                                  5      VB  ...  IB ...
0     1    ...  5     1.20E-8    ..                                  32E-8  -1  ...  ... ...
...   ...  ...  ...   ...        ..                                         ... ...  ... ...
0     1    ...  5     -9.00E-9   ..                                  4E-3   -1  ...  ... ...
#1, Setup: WYJ UBS=-1 = PASSED
..........................................................................................
x = -20.575, y = -1.605
Setup: PRZEJ UDS=0,1
VG  IG         ...  IG6         VD                                   3  VB2  ...  VB6  IB  ...
-1  -6.03E-9   ...  3.24E-10    0.1                                     -1   ...  -5   ... ...
... ...        ...  ...         ...                                     ...  ...  ...  ... ...
5   1.89E-10   ...  -3.16E-10   0.1                                     -1   ...  -5   ... ...
#1, Setup: PRZEJ UDS=0,1 = PASSED
..........................................................................................
x = -20.590, y = -10.660
Setup: WYJ UBS=0
VG    VG2  ...  VG6   IG         ..                                  5      VB  ...  IB ...
0     1    ...  5     2.80E-8    ..                                  55E-8  0   ...  ... ...
...   ...  ...  ...   ...        ..                                         ... ...  ... ...
0     1    ...  5     -6.00E-9   ...                                 4.42E-3 0  ...  ... ...
#2, Setup: WYJ UBS=0 = PASSED
..........................................................................................
```

I(V_{DS}) data for
- structure coordinates (-20.575, -1.605)
- substrate bias V_{BS}=0 V
- gate-source voltages V_{GS}=0,1,...,5 V

I(V_{DS}) data for
- structure coordinates (-20.575, -1.605)
- **substrate bias V_{BS}=-1 V**
- gate-source voltages V_{GS}=0,1,...,5 V

I(V_{GS}) data for
- structure coordinates (-20.575, -1.605)
- **substrate bias V_{BS}=0,-1,...,-5 V**
- drain-source voltages V_{DS}=0,1 V

I(V_{DS}) data for
- structure coordinates **(-20.575, -1.660)**
- substrate bias V_{BS}=0 V
- gate-source voltages V_{GS}=0,1,...,5 V

Fig. 4. Contents of the text file written by ELECT program; each section corresponds to a single setup of METRICS project SUCIMA3.

box of the main ELECT form. After the measurements ELECT stores all results in a text file. At the top of the file there is a header containing:

- date/time of measurements;
- user, lot and wafer identifiers;
- project file name;
- name of the file, which contains the co-ordinates list.

These data are saved as a file of the comma separated values (CSV) format. The data obtained for the given setup and for the given structure are also marked with a setup identifier, structure (die) co-ordinates and measurement results. The detailed structure of the result file (e.g., names of setups, number of results, etc.) is adjusted automatically, according to the project executed by METRICS (Fig. 4). This file can be easily imported by other standard applications, e.g., MS Excel, in order to extract physical parameters of structures.

4. System operation

The preparation of the measurement session can be done separately for ELECT and METRICS. The collections of measurement set-ups are prepared in the METRICS environment in a standard way. Next they are stored in a native format of the METRICS application.

Probing station requires a list of co-ordinates of the structures to be tested. This list can be created using the ELECT during the learning session. Then the user moves the chuck of the probing station to appropriate position, using a joystick or a mouse and stores this position in the list shown in Fig. 2. The complete list can be saved next in a text file. The list of co-ordinates can be also prepared using an external text editor or directly in the grid component in the main form of the ELECT program. The list of co-ordinates is necessary if the test structures irregularly distributed on the wafer are to be measured. In other case, module dimensions of the structure must be used.

The probing station is tested while the ELECT application is loaded. Afterwards, the user can start operations. First a wafer should be placed on the chuck and carefully aligned. Next the chuck moves to the central position. The user may then adjust precisely the position of the central structure. After confirming adjustment, (0,0) co-ordinates are assigned to the central structure and the user can choose another structure as a starting point. The testing may start under the condition that the initial direction is specified. The co-ordinates of the tested structure are displayed in a control window. The progress of wafer testing may be also shown if the co-ordinate list is used. In the case of a wafer with uniformly distributed structures one or two edge sensor must be used.

ELECT and METRICS work concurrently during wafer testing. The necessary data are exchanged between them through a DDE channel as follow:

1. ELECT requests test information from METRICS.
2. METRICS sends test names to ELECT.
3. ELECT sends a DDE message *Start measure*.
4. METRICS starts execution of the project.
5. When the execution is finished, METRICS sends message *Pass* or *Fail* accordingly to the test result.
6. If ELECT receives the message *Ready*, the probing station moves the chuck to the next position (from the list or using structure module dimensions) and requests test results from METRICS.
7. METRICS sends a DDE message containing test results.
8. When result transfer and chuck movement are completed, ELECT appends the test results of the structure to the result file and sends a DDE message *Start measure*.

Execution of Step 4 through Step 8 continues until the coordinates list is exhausted or all structures on the wafer are measured.

Prior to starting measurements, the user must write the name of the METRICS project in the ELECT window.

If MERTICS is not running during the execution of Step 1 ELECT invokes it automatically and the project file name is used to load the project.

Measurements of the wafer can be terminated or stopped temporarily after finishing tests of a given structure.

The header of the output file contains:

- measurement date;
- user; lot and wafer identifiers;
- METRICS project (set-up collection) specification and co-ordinate file name.

The results of structure testing are organized in blocks containing:

- structure co-ordinates;
- sub-blocks with set-up name and variables, values, and PASS/FAILED classification related to the set-up.

The probing station can use up to two inkers (2 inkers are used for delayed inking). If the station uses a structure module at least one edge sensor must be connected. In this case the station can be also controlled by a test system through the standard hardware interface, but structure co-ordinates are lost then.

4.1. Example of data

The ELECT/METRICS measurement system has been used for characterization of CMOS devices fabricated on thick-film SOI wafers. The process sequence to fabricate such devices is currently being developed by IET to be applied in the fabrication of monolithic pixel detectors. These unique devices are to detect ionizing radiation in medical applications [3]. The TSSOI test structure is the main tool for the characterization of the new technology [4]. It contains not only numerous devices like transistors, diodes, capacitors, resistive paths but also digital cells. I-V characteristics are measured using the ELECT/METRICS system. The results are used subsequently to extract process and device parameters. An example of the measured output chcracteristics of a n-channel MOSFET are shown in Fig. 5 together with SPICE simulations. The parameters of the MOSFETs models required by the simulations were obtained using the MOSTXX extraction tool developed recently in the IET [5].

It should be mentioned that TSSOI structures are not the only test structures fabricated in IET. Thus the flexibility of the ELECT program (I-V data were measured on structures selected according to a list of co-ordinates) appears to be very important.

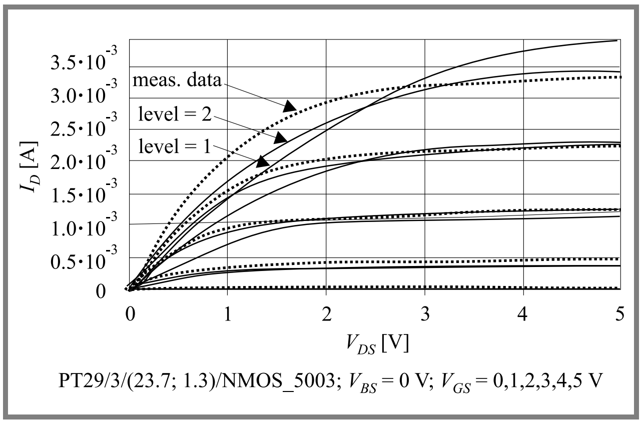


Fig. 5. Measured and simulated output characteristics of an n-channel MOSFET fabricated on a thick-film SOI wafer (W/L = 50 μm/3 μm).

In the case of measurements of multi-project wafers each test structure requires a separate METRICS project file. Also separate probe cards and co-ordinates lists files may be necessary.

5. Perspectives, future work

The presented system will be used for measurements required by detailed characterization of the fabrication process, as well as for measurements necessary for faster, parametric testing. In this case wafers mapping seems to be very relevant. Thus future efforts to improve the automatic testing system will be concentrated on the implementation of mapping. An additional application will be developed for this purpose.

METRICS application is a general-purpose measurement tool, it is, however, subject to certain limitations. Thus it will be necessary to develop dedicated measurement programs using high-level languages, such as C++ or Delphi/Pascal. In order to use them for the purposes of automatic testing it will be necessary to combine them with ELECT via the DDE protocol. Thus development of ELECT code seems to be the next important task in the presented system.

6. Conclusion

A measurement system for automatic testing of integrated circuits has been developed. It consists of a semi-automatic probe station and measurement equipment controlled by commercial measurement software. The probe station is controlled by dedicated software developed in IET. Both programs communicate using a DDE protocol but may also operate independently. The measurement system is flexible. It enables testing of both standard wafers and multi-project wafers to be tested using edge sensors and lists of co-ordinates, respectively.

Output data generated by the system is accepted by the extraction software used in IET for the characterization of the CMOS fabrication process. The system is under development. Future work will concentrate on wafer mapping and establishment of links to other dedicated measurement programs in order to use them in automatic testing.

References

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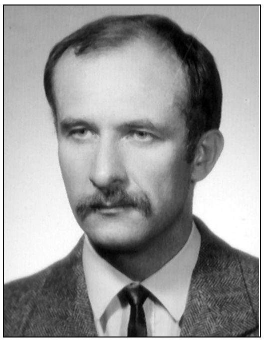

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Andrzej Kociubiński – for biography, see this issue, p. 92.

Daniel Tomaszewski – for biography, see this issue, p. 93.