

# ID27: AN INDUSTRIAL TXRF FACILITY

F. COMIN, M. NAVIZET, P. MANGIAGALLI AND G. APOSTOLO

ESRF, EXPERIMENTS DIVISION

The ESRF-TXRF facility will soon provide silicon manufacturing companies with an analytical centralized TXRF service capable of detection limits for contaminants at the wafer surfaces below  $10^8$  at/cm<sup>2</sup>.

**M**etallic contaminants at the surface of silicon wafer seriously hinder the performances of integrated circuits. The present non-destructive method used in production plants for measuring surface contamination, Total Reflection X-ray Fluorescence (TXRF) approaches its limits, while the quest for smaller and smaller design rule in device technology imposes lower and lower limits of tolerance. The National Technology Roadmap for Semiconductor published by Sematech, Inc. [1] has already programmed the transition from laboratory-based analytical services to synchrotron-radiation-based installations. In the early 90s the pioneering work of many groups opened the way to the use of synchrotron radiation to industrial TXRF applications [2, 3, 4]. At the ESRF a test experiment was performed a little more than one year ago [5] in order to verify the possibility of attaining the sensitivities envisaged by the Sematech Roadmap while keeping the wafer in a convenient horizontal attitude. The outcome of the test experiment actually showed that the many orders of magnitude of increase in brilliance not only permit the wafer to seat horizontally, but that mapping of the entire wafer surface is also possible in a reasonable amount of time. On the basis of these findings, a project financed by the ESRF, semiconductor companies, research laboratories and the European MEDEA\*\* program was launched in July 1997 for the set-up of an industrial permanent instrument. The TXRF facility will offer the possibility to map the concentration of contaminants with an initial detection limit of  $10^9$  at/cm<sup>2</sup> for 1999 to be pushed

down to  $10^8$  at/cm<sup>2</sup> in the following years. The wafer size can be either 200 or 300 mm and the pixel size about one cm<sup>2</sup>. The project envisages also the detection of low Z elements at least down to sodium, thus requiring excitation beams below the silicon K threshold.

- Need to preserve the polarization and collimation of the beam for maximum rejection of the elastically scattered radiation at the detector.
- Need of a monochromator with fixed-exit beam to avoid the re-alignment of the wafer position at each change of energy.

## OPTICS

The key issues that have been taken into account for the definition of the optical layout of the installation can be summarized as follows:

- Need of a wide energy range from 1 keV to 40 keV for optimizing the detection sensitivity for every element.
- Need to reject as much as possible the harmonic content of the x-ray beam to limit detection problems with standard solid state energy dispersive detectors.

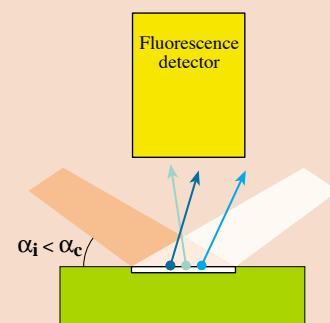
## THE PHOTON SOURCE

The best way to reject harmonics is, of course, to start without harmonics. The Insertion Devices Group analyzed the possibility of manufacturing an aperiodic undulator that will have the «harmonics» well displaced from where they should be if they were normal harmonics. From their calculation the residual harmonic content of the undulator that is presently under construction is of a few per cent [6]. A further reduction of the harmonic

## THE TXRF TECHNIQUE

Total Reflection X-Ray Fluorescence (TXRF) analysis is a powerful tool for the identification and quantification of chemical elements at the femtogram level. TXRF is based on the conventional energy dispersive X-Ray Fluorescence (XRF) analysis technique. The identification of the different elements is obtained by exciting the atoms of the sample with an x-ray beam. Each excited atom will emit a fluorescence photon with a well-defined characteristic energy, which is the signature of its atomic species. The quantitative analysis of the fluorescence spectrum with an energy dispersive detector allows the identification and quantification of the elements present in the sample. TXRF differs from standard XRF only in the particular excitation geometry: the x-ray beam impinges on the sample with a very small glancing angle. Under these conditions the beam penetrates the sample only by a few tens of angstroms so that only the shallow

region close to the surface is probed. This excitation geometry simultaneously reduces the background and enhances the sensitivity of the technique, which is now perfectly suited for the analysis of surface contamination. The combination of the TXRF technique with synchrotron radiation x-ray beams allows detection limits of the order of  $10^8$  at/cm<sup>2</sup> for transition metals, which means that a foreign impurity atom can be identified on the wafer surface among ten million silicon atoms.



\*\* Since 1997, the program «Micro-Electronics Development for European Applications» is meant to assist the European semiconductor industry in developing novel techniques. MEDEA has taken over from JESSI, the «Joint European Submicron Semiconductor Initiative», which ran out in 1996 after 8 years of operation.

content will be achieved at the monochromator by detuning the Si crystals and by an appropriate choice of multilayers.

## THE MONOCHROMATOR

For maximum reliability the x-ray monochromator is based on a single rotation motion following well-established concepts. The dispersing elements are a silicon (111) channel-cut for the energy range 2.8 – 40 keV and a multilayer pair for the low energy range [7]. The high brilliance of the ESRF leaves the possibility of using the sharp Si(111) reflection without deterioration of the TXRF performances. This allows chemical recognition of the impurity atoms by collection of XANES spectra around the threshold of the atomic species of interest.

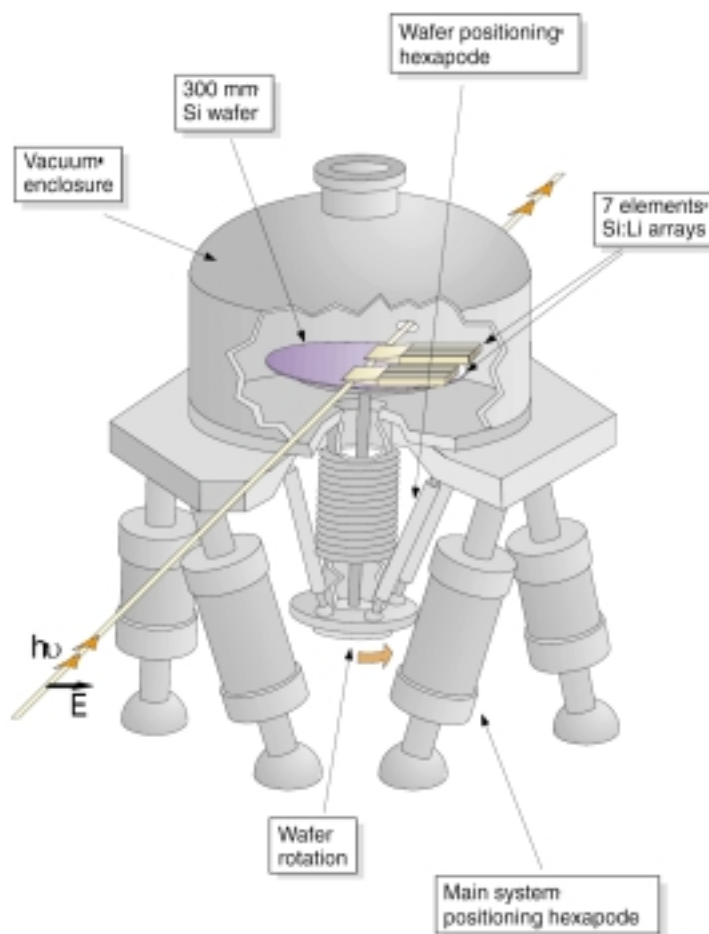
## THE TXRF SET-UP

The TXRF end-station is located in a shielded hutch of about 25 m<sup>2</sup> embedded in a class 100 laminar flow. The station encompasses: a loading robot that transfers the wafers from standard cassettes to a load-lock vessel; a high vacuum handler that transfers the wafer from the interlock loading chamber to the measuring position in the main TXRF chamber, a set of two 7-element linear arrays of Si(Li) detectors for the parallel acquisition of the fluorescence spectra, and a wafer chuck/manipulator for the correct positioning of the wafer onto the x-ray beam and for rotating the wafer around its vertical axis in order to perform the impurity mapping over the whole surface of the wafer.

The 14 channels of the detector are split into two independent arrays for servicing/reliability purposes.

Due to the grazing incidence, the beam illuminates a strip on the sample, the use of 14 independent detector channels, each of which looks to a 10.5 mm wide portion of this strip allows an easy mapping of the entire surface of the wafer just by rotating the sample and collecting data in parallel from the detector array.

This geometry greatly simplifies the mechanical requirements for the wafer handling, but implies that either the spatial resolution or the sensitivity for the outer portion of the wafer is somewhat lower than for the central one.



## TIME SCHEDULE

The facility will start its commissioning phase early in 1999 with the first tests on real 300 mm wafers. This will lead to a field assessment of the specifications attained and further tests are already envisaged to ascertain which other opportunities can be exploited with the instrument. Two directions seem particularly interesting, namely the possibility of performing XANES spectroscopy in selected atomic species for the chemical identification of the contaminant and the detection of carbon species via electron spectroscopy techniques. ■

### REFERENCES

- [1] <http://notes.sematech.org/97melec.html>.
- [2] A. Iida, *Adv. In X-ray Anal.*, 35 (1992) 795.
- [3] R. Rieder et al., *Nucl. Instr. and Meth. In Phys. Res. A355*, 648-653 (1995).
- [4] P. Pianetta et al. *Rev. Sci. Instrum.* 66, 1293 (1995).
- [5] L. Ortega et al., *Journal of Synch. Radiation*, 5, 1064-1066 (1998).
- [6] J. Chavanne et al., *EPAC 98 conference, Stockholm*.
- [7] F. Comin et al., *SPIE Proc. Intern. Symp. On Optical Science, Eng., and Instr. San Diego, July (1998)*.