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X-ray emission induced by low energy electrons

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The advantage of the x-ray emission induced by electrons, with respect to the x-ray fluorescence, or emission induced by photons, is that the interaction of the probe particles with the sample is selective in depth. Indeed, the electrons are slowing down along their path in the material. Then, by choosing an incident energy of the electrons near the threshold of the considered x-ray emission, only the superficial zone of the sample emits. The probed depth increases with a progressive increase of the energy of the incident electrons from the threshold.

From a simulation model [1,2], appropriate for describing the interaction of the low energy electrons with the matter, we calculate the in-depth distributions of the ionizations and consequently of the characteristic x-ray production. By using this model and the x-ray intensities measured at different incident electron energies, we deduce the depth distribution of the emitting atoms. The precision depends on the variation of the incident energy. When sufficiently small energy increments are used, we have shown that the analysis can be performed with a precision of the order of one nanometer [3].

The analysis of the buried interfaces is possible by this technique, by using a line emitted from an element present in the buried material. The incident electron energy must be such that the electrons having traversed the first material arrive in the second material with an energy near the appearance threshold of the chosen x-ray line. In these studies, it is important to determine the chemical interactions between the atoms present at the interface. Consequently, emissions of the soft x-ray range must be analyzed with a resolution sufficiently high for the changes due to the chemical environnement to be observed. For the emissions of this energy range, the fluorescence yield is generally small, making the emitted intensity weak. However, two factors partially compensate. The intensity of the Bremsstrahlung is weak, leading to a high peak/background ratio. The reabsorption of the radiation in the target is small.

Two choices in the experimental conditions can be made, either the analysis of a large surface, of the order of the cm^2, with a low electronic density or the analysis of a μm^2 surface with a higher electronic density. We dispose an apparatus [4] equipped of a Pierce electron gun having a spot diameter between 0.5 and 2 cm, and of an high-resolution curved-crystal spectrometer. The electronic density varies between 0.1 and 2 mA/cm^2. The target is cooled either by a water circuit or by a closed-cycle He circuit [5]. In these conditions, no modification of the sample is observed.

Interfaces between a film and a substrate have been studied. The thickness of the film is of some hundred nm, that is to say sufficiently thick to have the properties of the bulk[6]. Semiconductor/semiconductor, metal/metal, metal/semiconductor, metal/polymer and metal/ceramic have been analysed.

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We present below the study of the Mo (10 nm) / SiO2 (70 nm) system prepared by magnetron sputtering and PECVD. The Si Kß emission (3p -1s transition) has been analyzed with electrons of 2.2, 2.5 and 3 keV (cf. figure). At high energy the spectrum is that of the silica. At low energy, the spectrum can be fitted by a sum of silica and molybdenum silicides spectra showing the presence of compounds at the interface [7]. Formation of compounds occurs at this interface which is diffuse and extended on some nm. Examples of abrupt interfaces will be presented.

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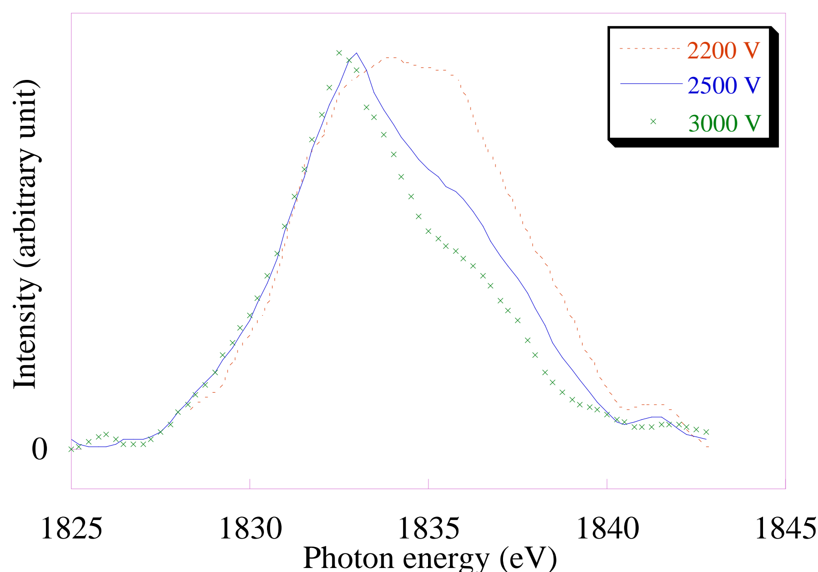

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