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Nanoscale characterisation of $CuInGaSe_2$/CdS structures grown by Pulsed Electron Deposition

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CuInGaSe2 (CIGS) is considered one of the most promising materials as absorber layer in photovoltaic cells thanks to its properties [1].
Many efforts are in the research of low-cost processes for the preparation of CIGS. To this aim a promising vacuum technique for the deposition of CIGS films is the pulsed electron deposition (PED) [2] that is based on a high voltage (10-20 kV) electron beam generated trough ionized gas inside a vacuum chamber. The electron beam is then driven by an insulating tube up to the material target to be ablated. The target is prepared under high pressure and high temperature conditions to obtain the hardness and compactness with the requested composition useful for the ablation. Low-cost, good deposition rate and scalability of the process are peculiar characteristics of this technique.
The present work deals with the nanoscale study of structural, physical and chemical properties of CIGS/CdS layers grown by PED on glass substrates. Conventional and high resolution transmission electron microscopy (TEM), energy filtered imaging and energy-dispersive (EDX) X-ray spectroscopy have been used to correlate the growth parameters and *in situ* annealing procedures with grain dimensions, orientation and elemental segregation, interface quality, in-depth composition and interdiffusion mechanisms.
Fig. 1 shows a high resolution TEM image a typical CdS/CIGS interface. The epitaxial correlation between CdS and CIGS and the good match between the layers are shown. Plan view and cross sectional TEM imaging revealed a columnar structure of the CIGS layer with grains of about 100 nm whose main orientation was along [112] direction. After *in situ* annealing treatments, an average dimension of 500 nm was achieved. Energy filtered TEM investigations (Fig. 2) and EDX elemental maps at low magnification show the top CdS layer thickness to be constant with a uniform coverage. Further, no intermixing between CIGS and CdS, as well as no elemental segregation at the grain boundaries have been found within the accuracy of the techniques. The elemental in-depth distribution and concentration of the CIGS layers have been studied by cross sectional EDX spectroscopy and imaging (FIG. 3). A substantial constant distribution and a perfect agreement with the expected nominal values of Cu, In, Ga and Se concentration have been found.
All the above studies have been employed to optimize the functional properties of the structures which eventually led to the realization of good quality devices as shown by the I-V and C-V curves reported in Fig. 4. The junction shows a good rectifying ratio despite the presence of a high series resistance. The carrier concentration extracted from the C-V profile is of a few 10^{15} cm^{-3} and an increase of carrier concentration toward the CIGS/Mo interface is observed, in agreement with reference [3]. Finally, the results are also discussed on the basis of scanning capacitance spectroscopy studies at the nanoscale in an SPM system.
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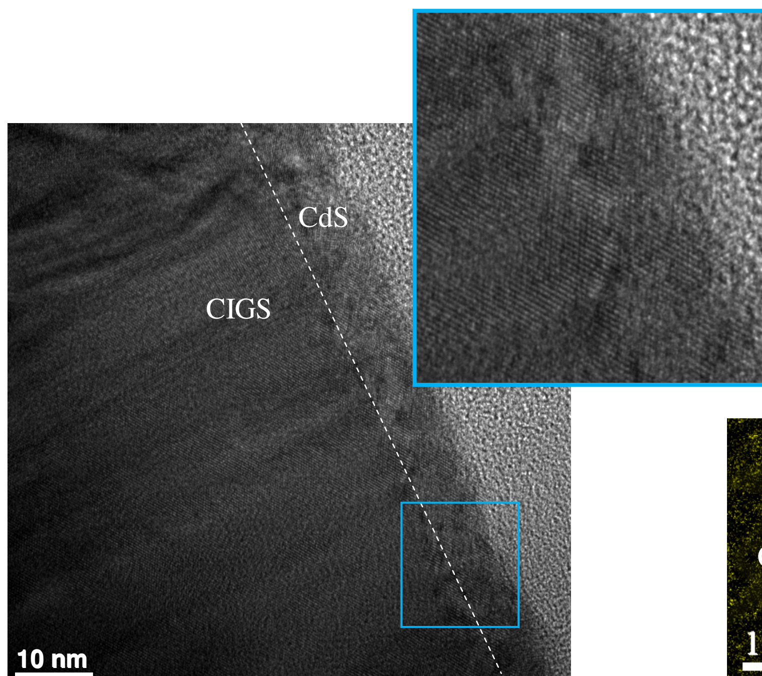

FIG. 1. High resolution TEM image of the CdS/CIGSstructure. The approximate position of the interface is indicated by the dashed line.

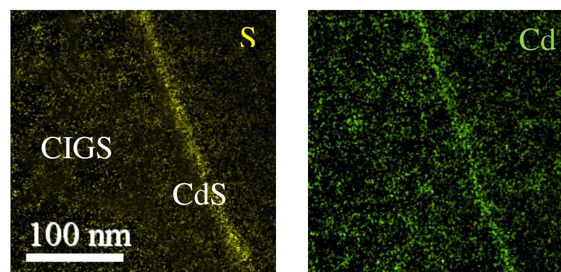

FIG. 2. Sulfur and Cadmium signal obtained by energy filtered TEM .

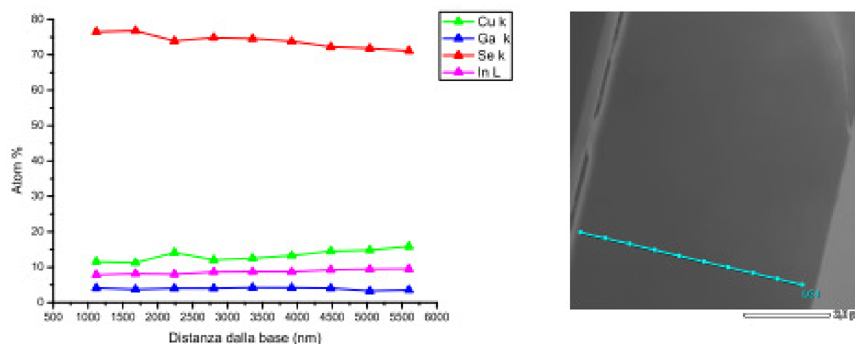

FIG.3 In depth profile over the CIGS layer obtained by EDX spectroscopy.

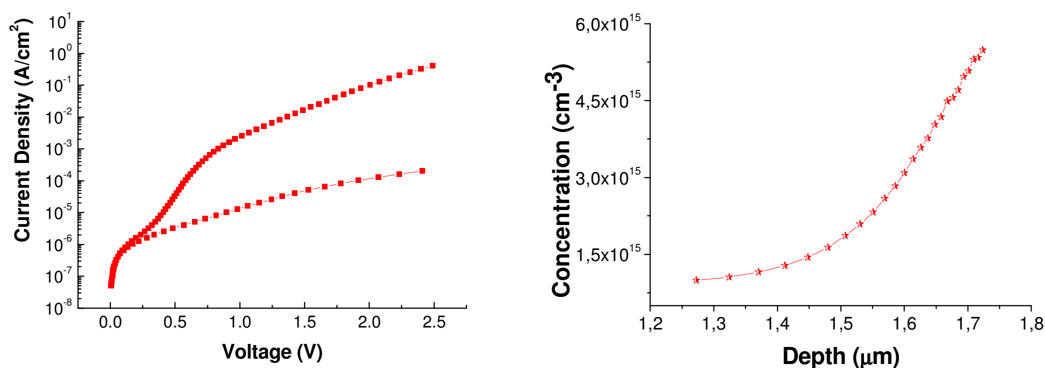

FIG.4. I-V profile and depth distribution of carrier concentration in the CIGS layer.

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