Low energy muon study of the p-n interface in chalcopyrite solar cells

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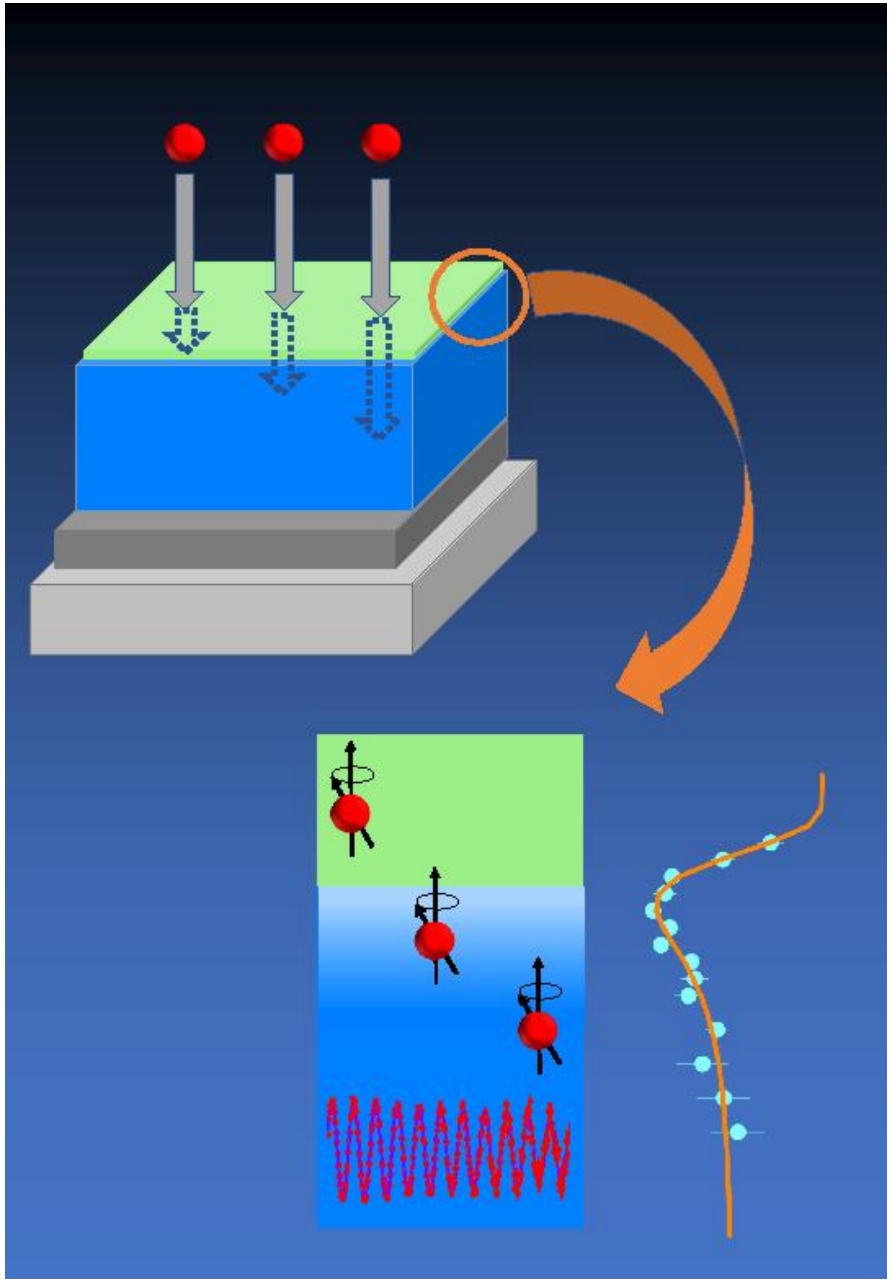

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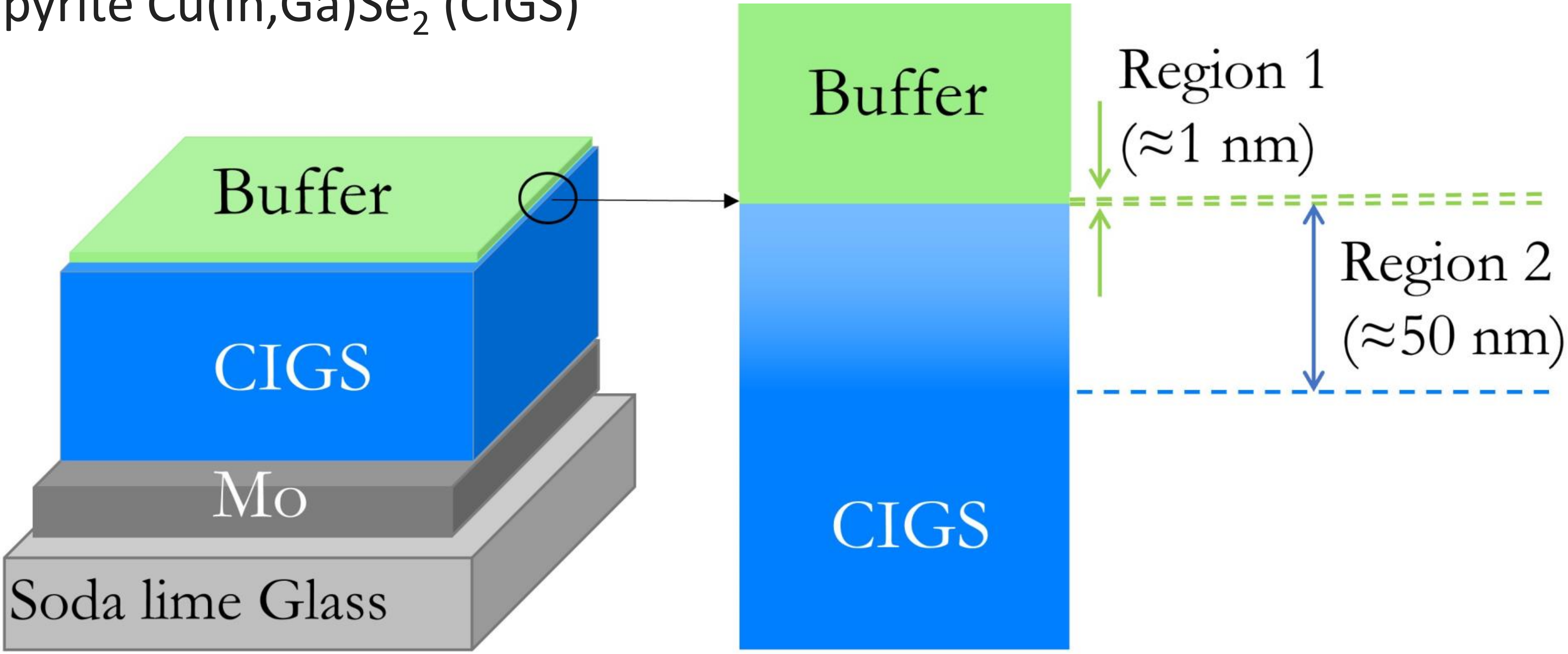
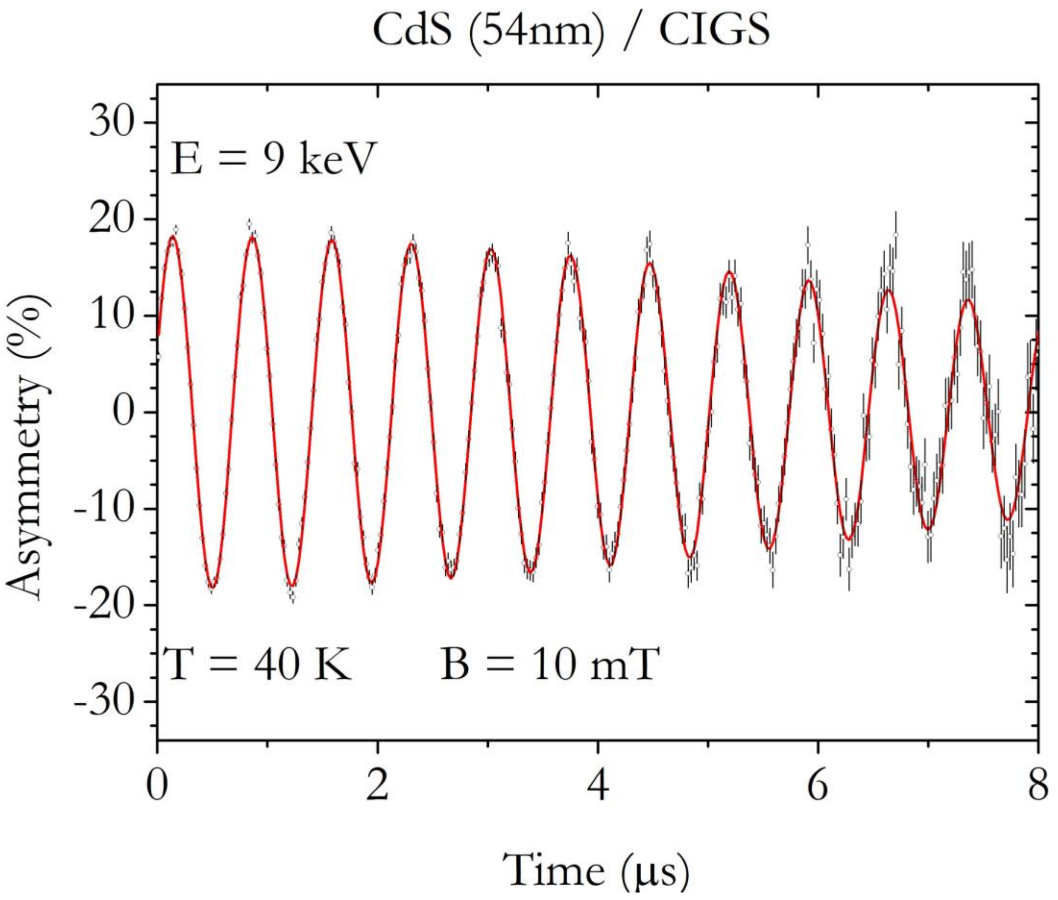
Samples

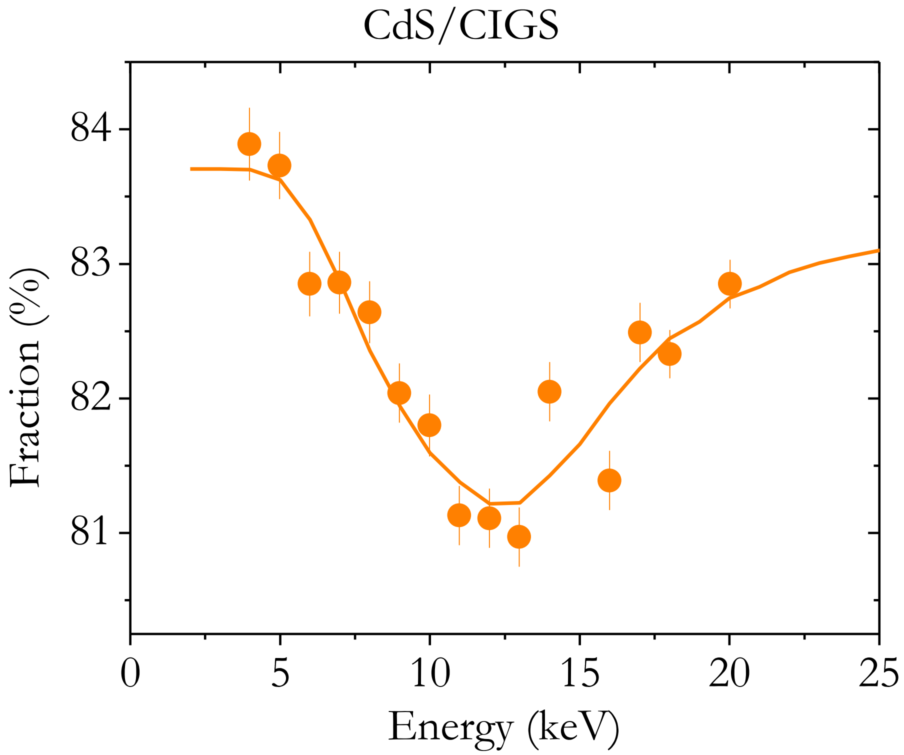
cover layer: CdS, ZnSnO, Al_2O_3 and SiO_2

Absorber: chalcopyrite $Cu(In,Ga)Se_2$ (CIGS)



LEM measurements





change of diamagnetic fraction with implantation energy

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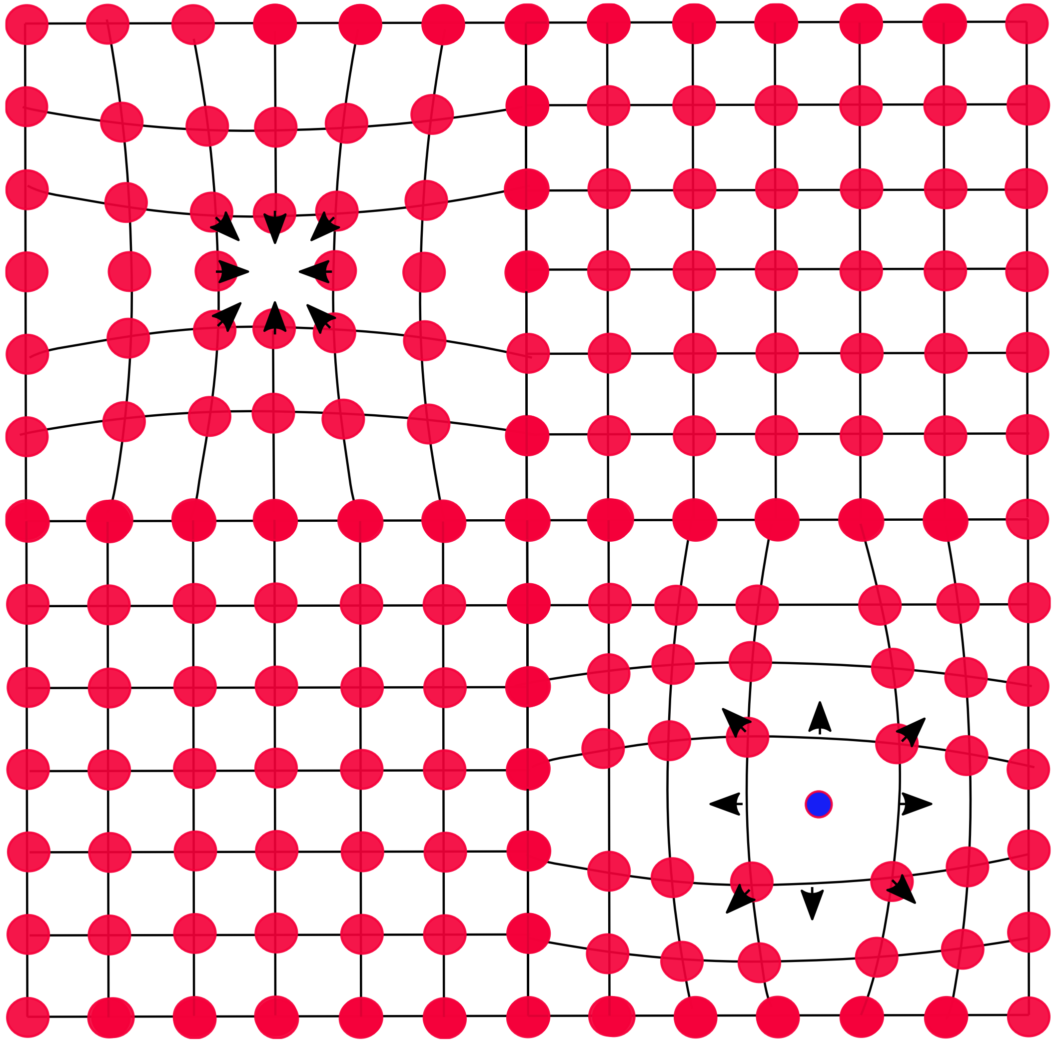
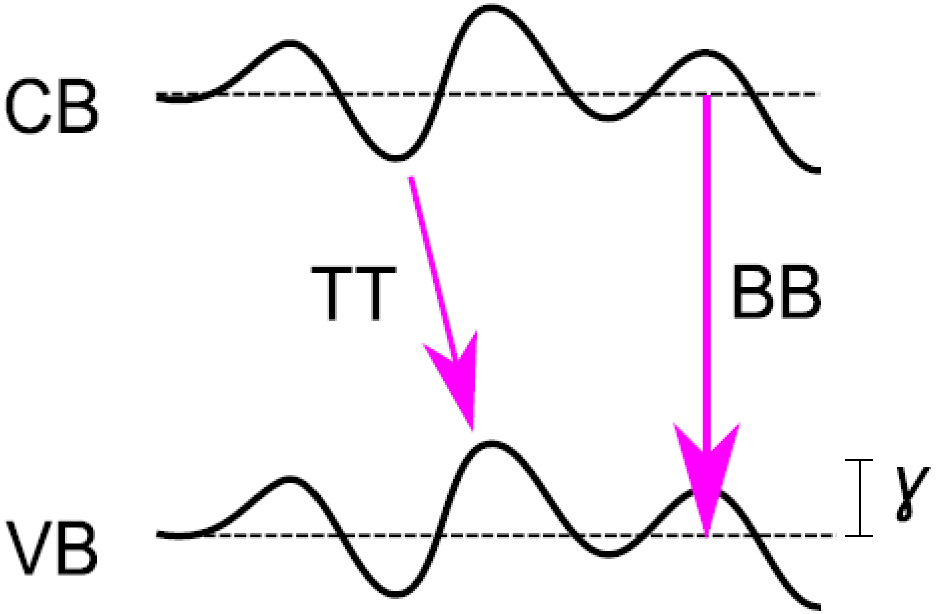
1.What causes the dip?

2. Where is the dip situated (in CIGS? in the cover layer? in both?) ?

Defect-induced strain fields

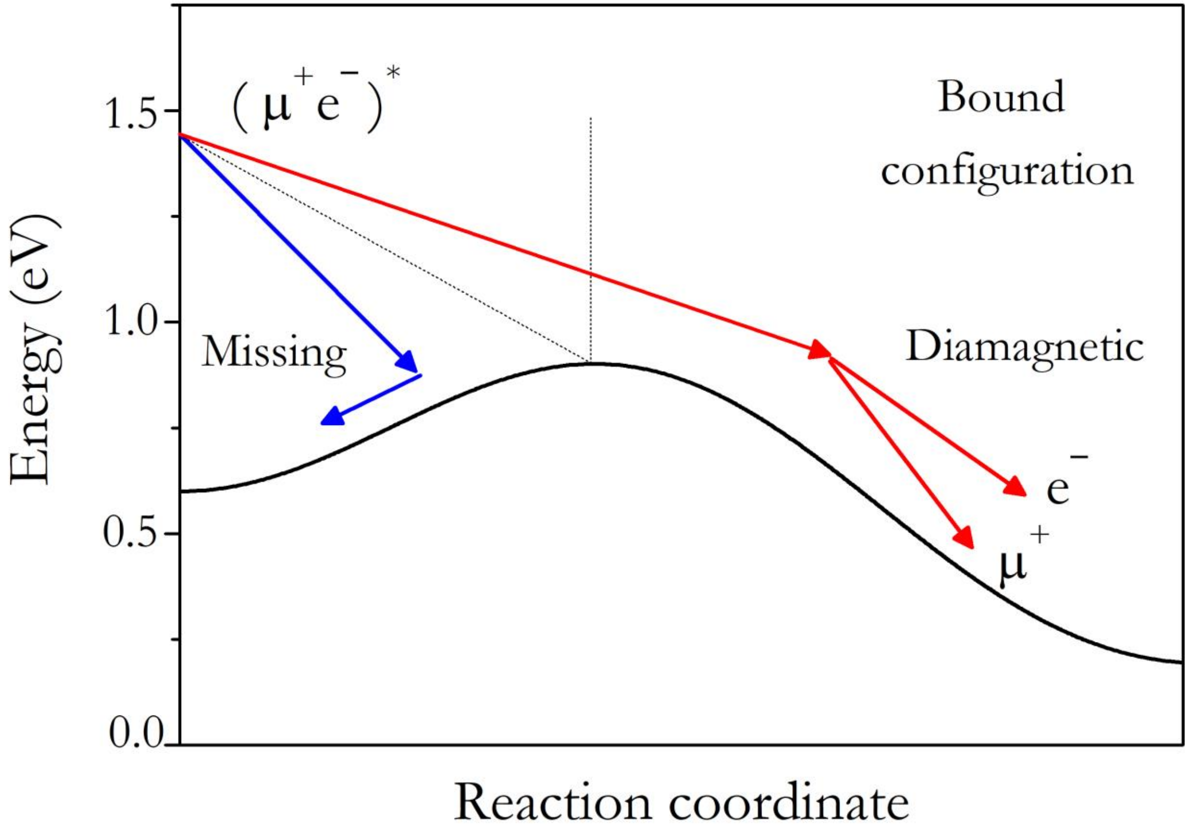


Electron Potential Fluctuations (tail states)

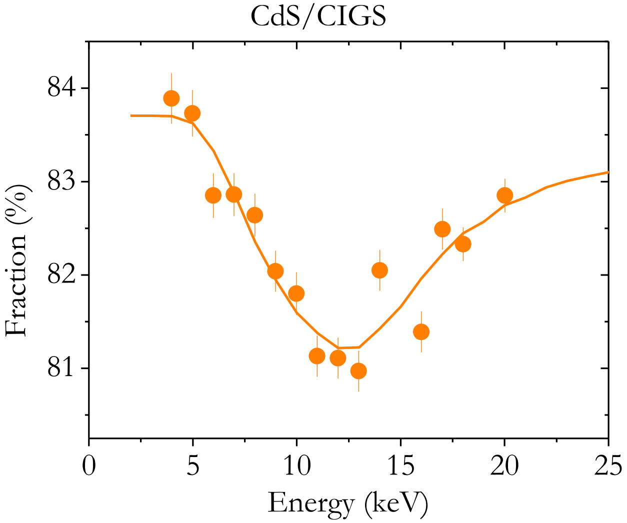


The model

- The formation of the diamagnetic bound state requires lattice rearrangement, which can be described as a potential barrier.
- Lattice strain induced by defects increases the barrier height and reduces the formation probability of the bound diamagnetic state.
- That is the origin of the dip in the diamagnetic signal: the muon probe is sensing a defect region.



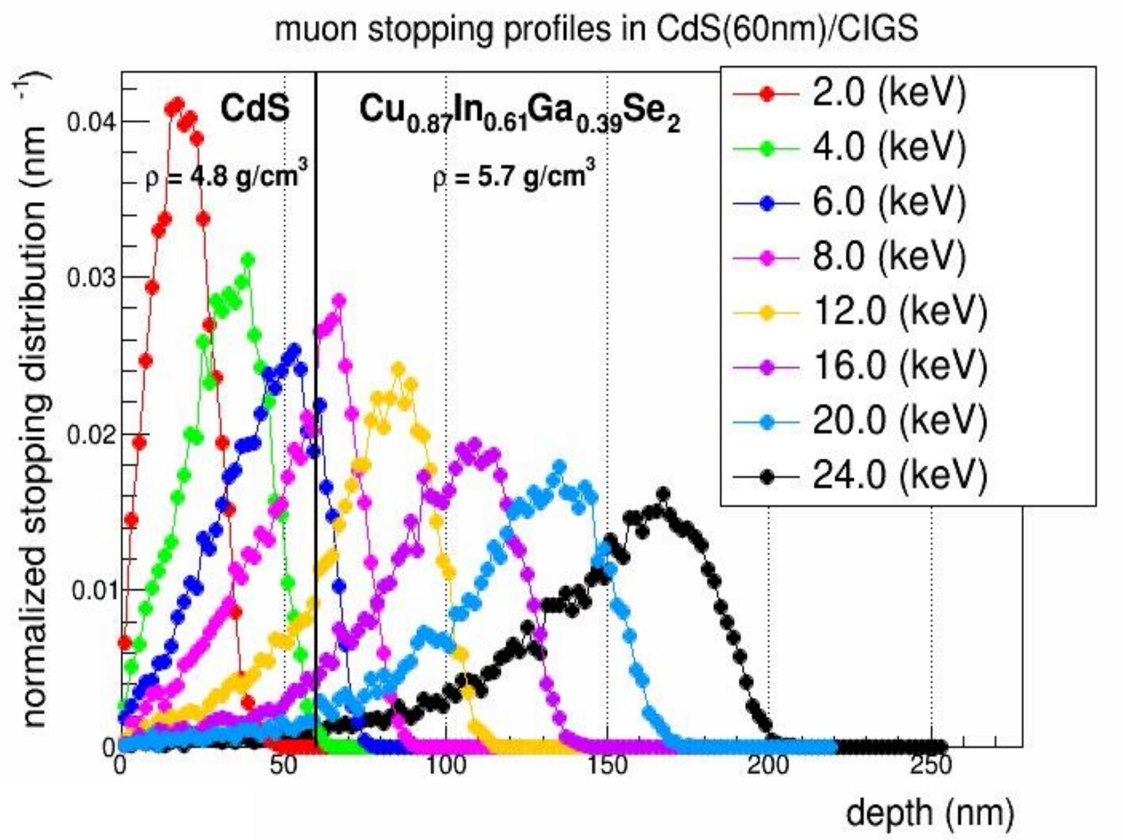
Where is the dip situated?
Using resolution information from TRIM.SP



$$f_{\text{dia}}^{\text{exp.}}(E) = \int_0^\infty P(x,E)\, f_{\text{dia}}(x)\, dx$$

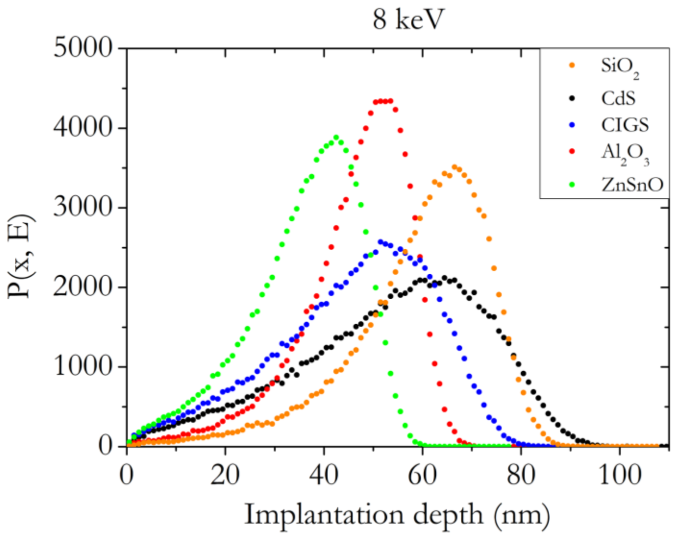
- The experimental $f_{\text{dia}}(E)$ is the result from a convolution of the real $f_{\text{dia}}(x)$ with the normalized stopping distribution P(x,E), obtained by Monte Carlo simulations (TRIM.SP).

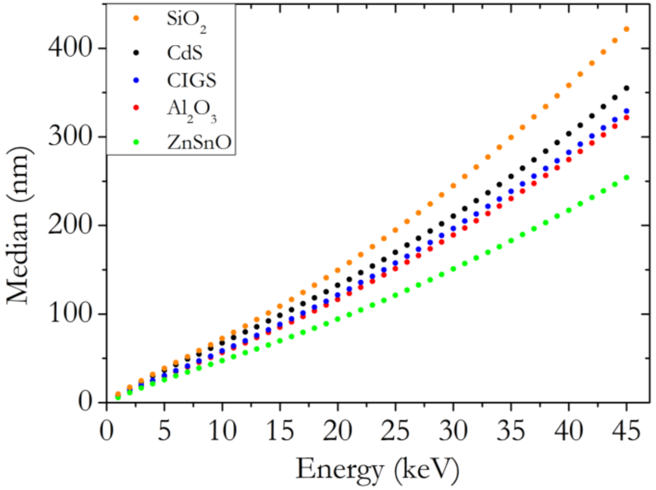
The real profile $f_{\text{dia}}(x)$ is washed out because not all muons stop at the same depth.



Unfolding the depth profile

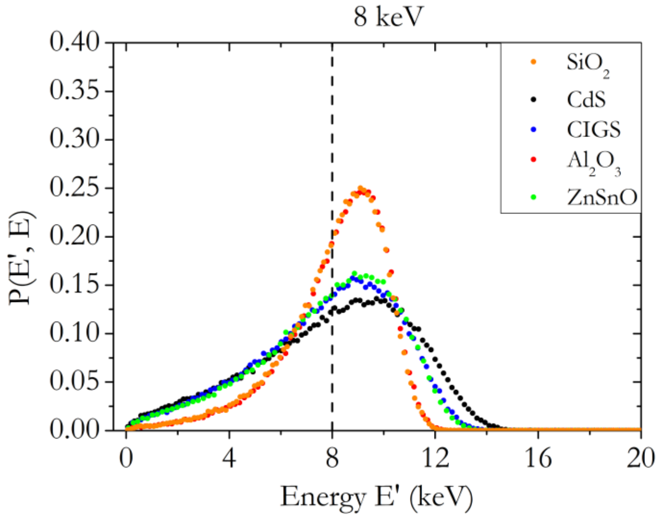
poster session I : #145 Ribeiro et al. “Unfolding of the depth profiles with universal-range distribution functions”





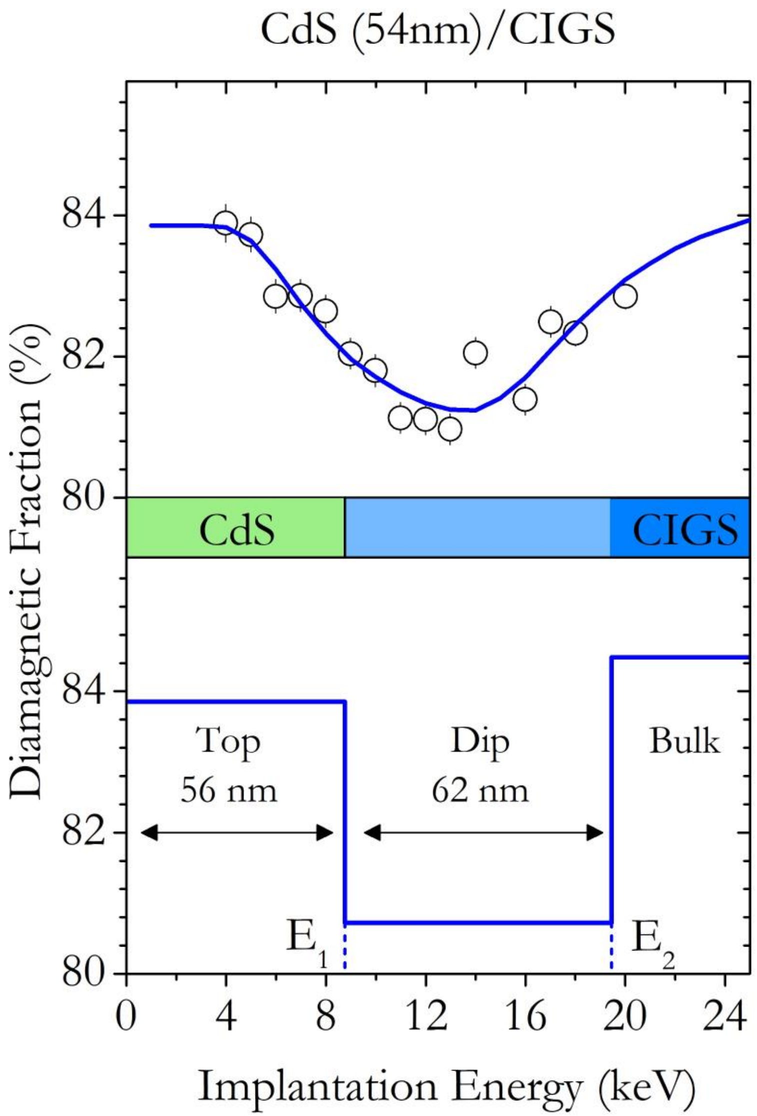
x = f(E’)

$$P(E',E)\,\mathrm{d}E' = P(x,E)\,\mathrm{d}x = P(x,E)\frac{\mathrm{d}x}{\mathrm{d}E'}\,\mathrm{d}E'$$



$$f_{\mathrm{dia}}^{\mathrm{exp.}}(E) = \int_0^\infty P(E',E)\, f_{\mathrm{dia}}(E')\, dE'$$

results



$$f_{\text{dia}}^{\text{exp.}}(E) = \int_0^\infty P(E', E)\, f_{\text{dia}}(E')\, dE'$$

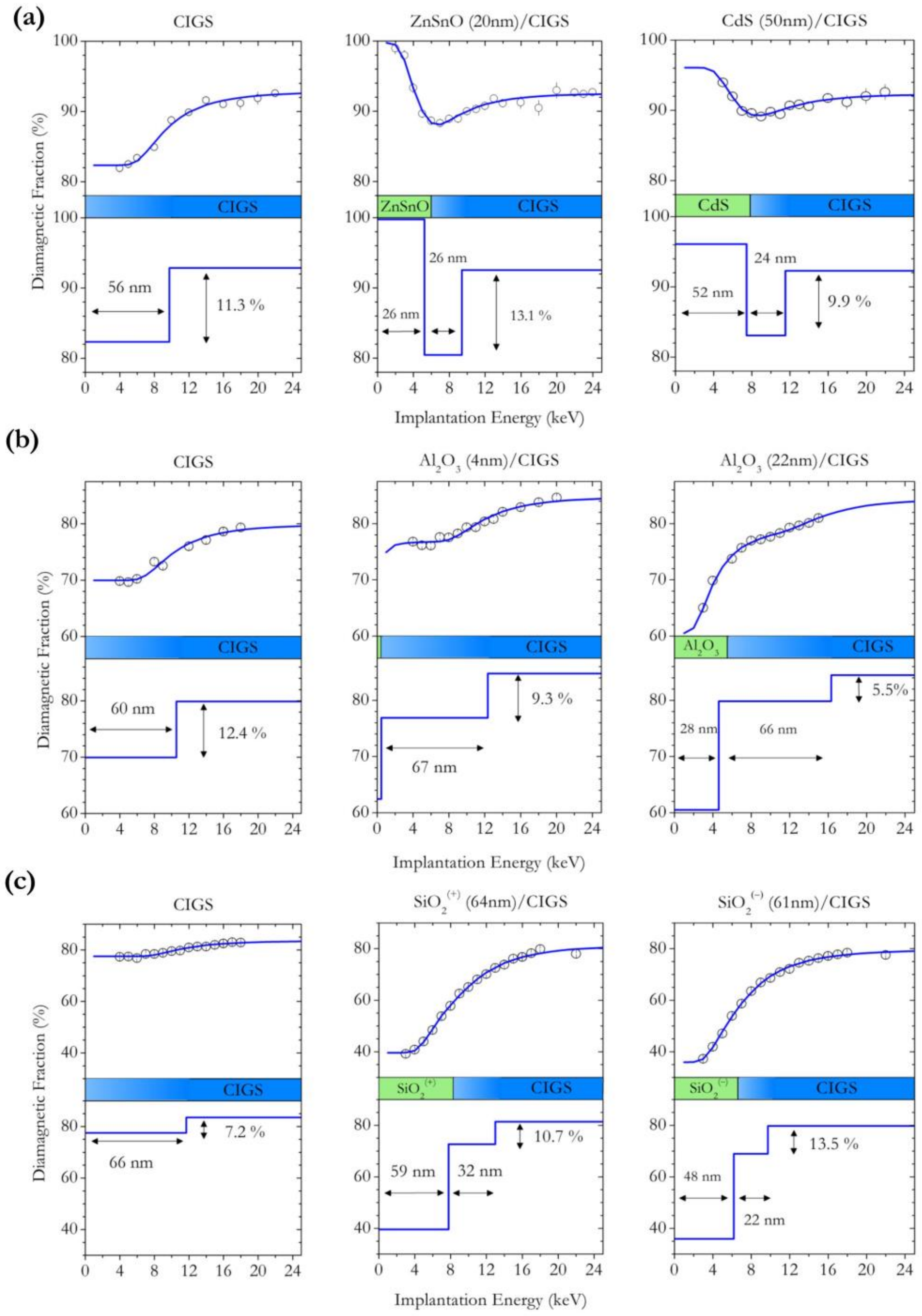
- the trial function for $f_{\text{dia}}(E')$ is a simple three step function with 5 adjustable parameters. A fit is performed to obtain the parameters that lead to the best description of the experimental data $f_{\text{dia}}^{\text{exp.}}(E)$
- the relation $x = f(E')$ is used to convert E_1 and E_2-E_1 in widths measured in nm.
- The best fit to the trial function shows that the lattice is more perturbed **in the near-interface region, on the side of the absorber**, than further inward in the sample.

Changing cover layers

(a) : unconvered CIGS and the effect of ZnSnO and CdS covers

(b) : effect of Al2O3 with different widths on the same uncovered CIGS

(c) : effect of SiO2 with different surface charges on the same uncovered CIGS

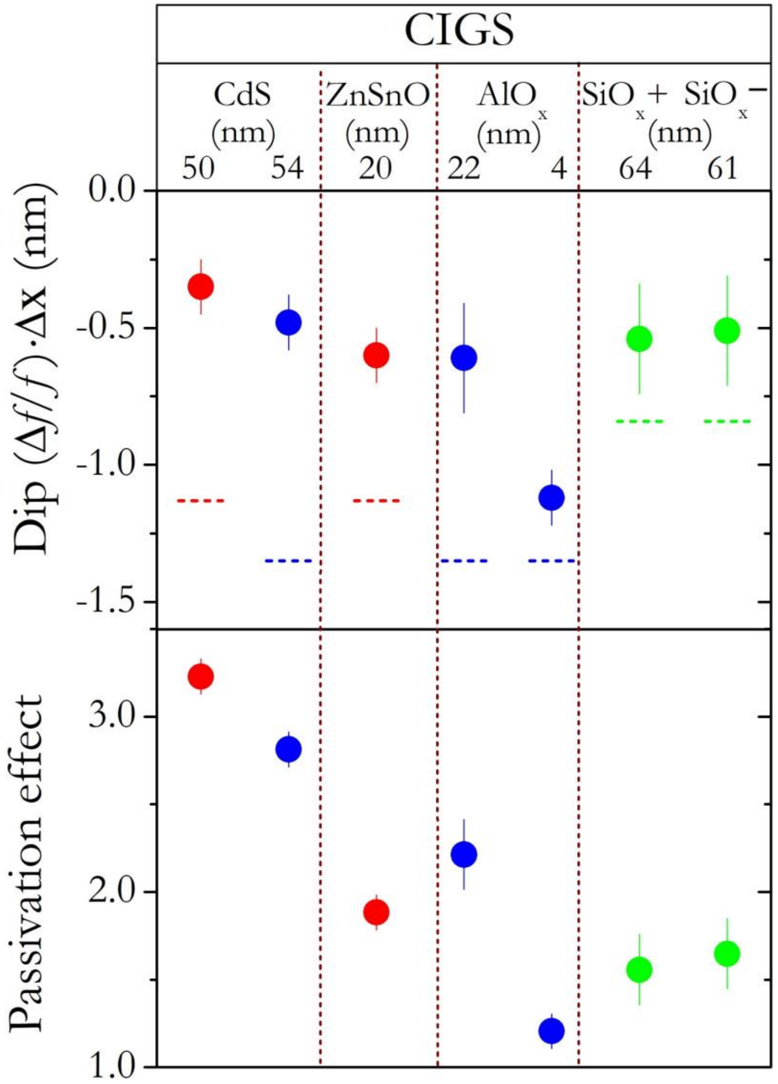


Measuring passivation of bulk defects near the p-n junction

- the passivation effect near the p-n region is quantified : it is defined as the dip size of the uncovered film divided by the dip size of the covered film.

- CdS provides the best defect passivation.

- Oxide materials are less effective.



Conclusions

- Slow muons are sensitive only to a region near the p-n interface (region 2) , which is more disturbed than the inner part of CIGS.
- A disturbed interface region is associated with interface recombination losses, affecting the device efficiency. It is important to distinguish contributions from regions 1 and 2.
- Slow muons allows us to separate contributions from region 1 and 2, not possible with other techniques.
- Using slow muons, it is possible to make a quantitative characterization of the effect of various buffer/cover layers on the passivation of bulk defects in this region.