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Elastic Recoil Detection using Heavy Ion beam

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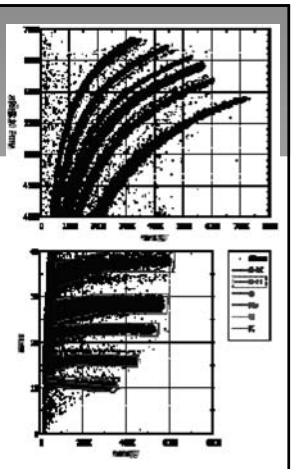
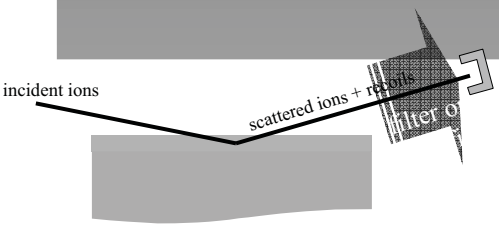
Elastic Recoil Detection (ERD)





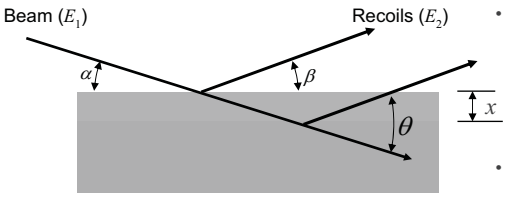
- He beam
  - ERD complementary to RBS for H detection
  - Low H dE/dx × absorber = bad depth resolution
    - Electrostatic filters can do a good job
  - Still, the contribution of the other elements to the RBS spectrum are piled up on each other
- Since atoms contained in the material are recoiled, we can detect them and get a spectrum for each
  - Requires beam heavy enough and of enough high energy to recoil target atoms

$$E_2 = \frac{4M_1M_2}{(M_1+M_2)^2}\cos^2(\theta)E_1$$

HI-ERD: the big artillery

...although IMEC has a nice implementation of ERD-TOF on a 1.7 MV Tandetron

From one ion to several ions



$$Nt(x) = \frac{Yield}{slope}\frac{\partial S(x)}{\partial x}\frac{\sin\alpha}{\left(\frac{d\sigma}{d\Omega}\right)\Delta\Omega q}$$

$$S(x) = K\frac{1}{\sin\alpha}\int_0^x \frac{dE_1(x')}{dx}dx' + \frac{1}{\sin\beta}\int_0^x \frac{dE_2(x')}{dx}dx'$$

- Heavy ions
  - Higher stopping power: potentially better depth resolution
  - Damage? More event per incident ion
- Need to know for the heavy ion beam and each recoil
  - Stopping power in compounds
  - Energy straggling
  - Detector calibration
  - Detector resolution
  - Multiple scattering
    - $(Z_1Z_2/E)^2 + + +$

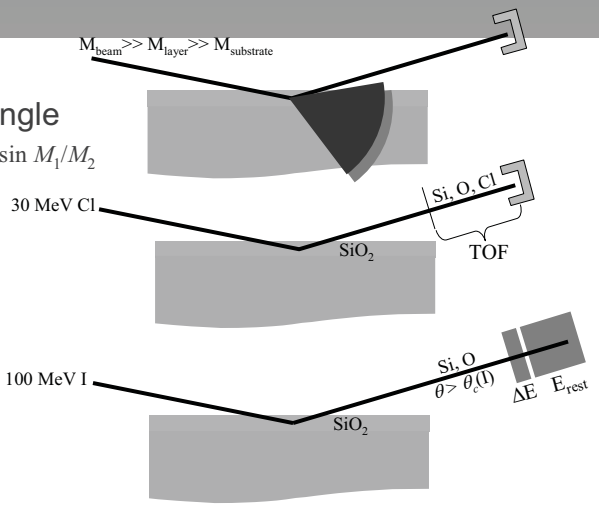
Main ion identification systems

- critical angle

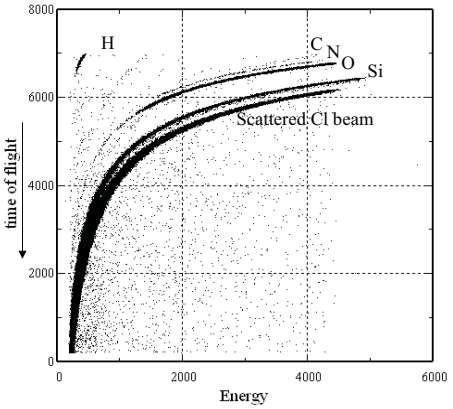
  $\theta_{scat} < \arcsin M_1/M_2$

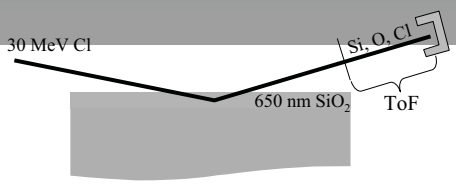
- TOF

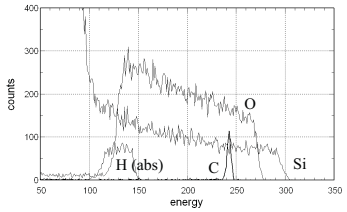
- E-ΔE



Time-of-Flight

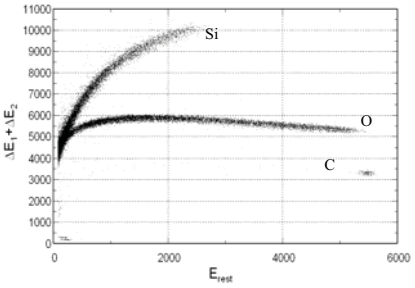


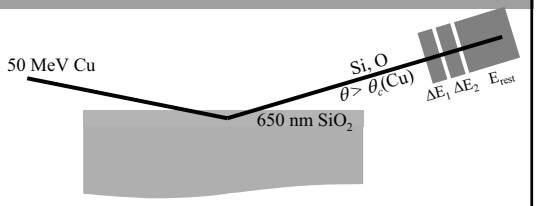


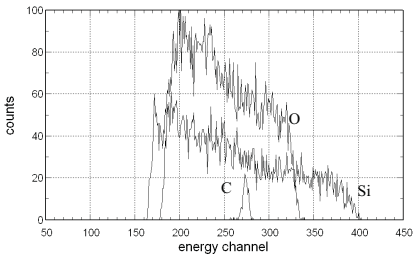


+ good energy resolution
+ energy from time (calibration once)
– small solid angle (<1 mstr)
– detection efficiency problems Z ≤ 4

E-ΔE (gas counter)



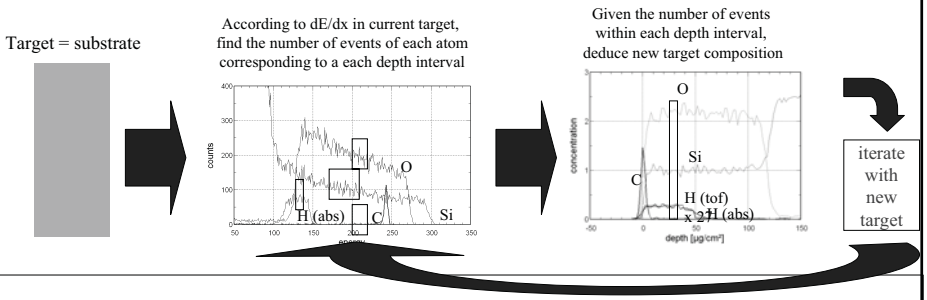




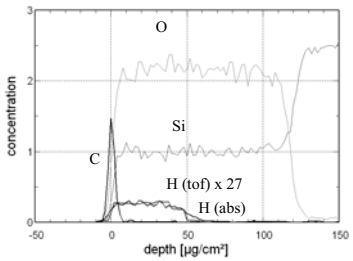
+ large solid angle
+ angular resolution (blocking)
– energy resolution not very good due to straggling in entrance membrane
– H won't stop in the detector: SBD at the end

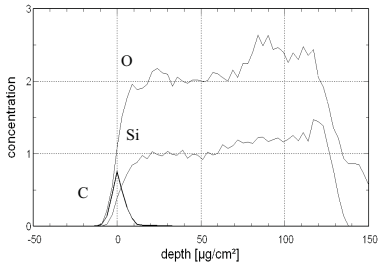
Depth profiles from HI-ERD spectra

- Depth profiles
  - One spectrum per target atom
    - Sometimes, heavy elements from HI-RBS
  - Iterative procedure to extract depth profiles
    - Depth profile still contains all energy broadening effects: simulation needed to account for them



Comparing depth profiles of TOF & gas-counter





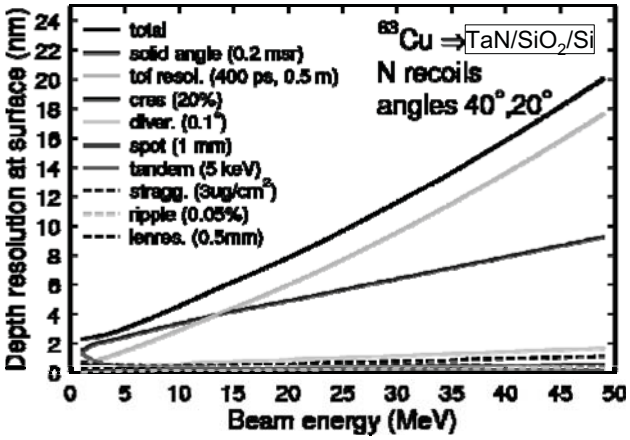
(all events: kinetic correction)

- depth resolution*:
  - from carbon peak: σ=2.4±0.1 g/cm²
  - SiO_2/Si interface: 4.9±0.4 g/cm²
    - shallower angle of detection
- depth range ~ 250 g/cm² with 50 MeV Cu
  (1 g/cm² ~ 4-5 nm)

- depth resolution*:
  - from carbon peak: 3.7±0.1 g/cm²
  - SiO_2/Si interface: 4.7±1.0 g/cm²
- sensitivity: 25x less incident ions for an equivalent number of events

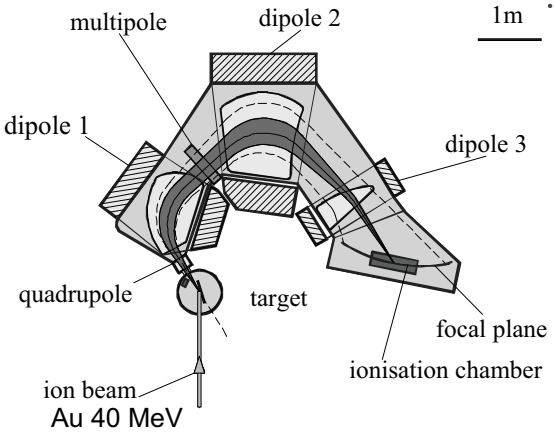
*assumption: instrumental/method resolution dominates over interface thickness

TOF: the smallest the speed, the longest the time



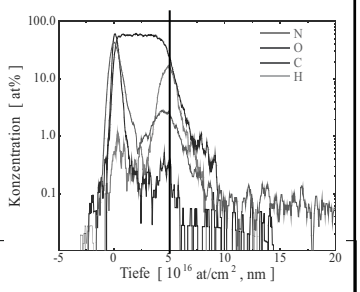
From K. Arstila presentation at CRP-Lisbon, referring to S. Giangrandi presentation at IBA 2007

HI-ERD: The very big artillery



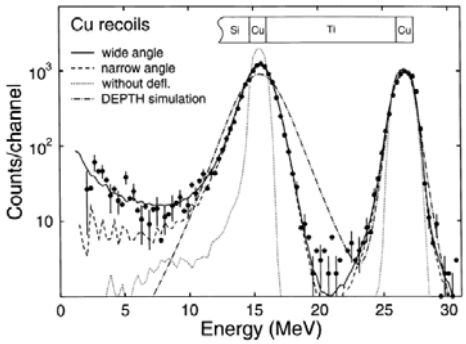
From G. Dollinger presentation at CRP on HI-ERD, Lisbon (2007/11)

- UniBwMünchen (Dollinger et al.)
  - Q3D magnetic spectro.
  - large solid angle: 12 msr
  - energy resolution $\Delta E/E = 5\times10^{-4}$ at 5 msr
  - depth resolution < 1 nm



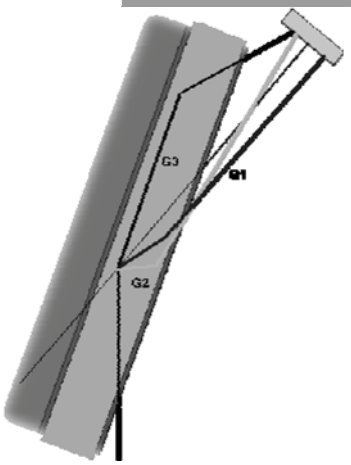
Effect of multiple scattering on HI-ERD spectrum

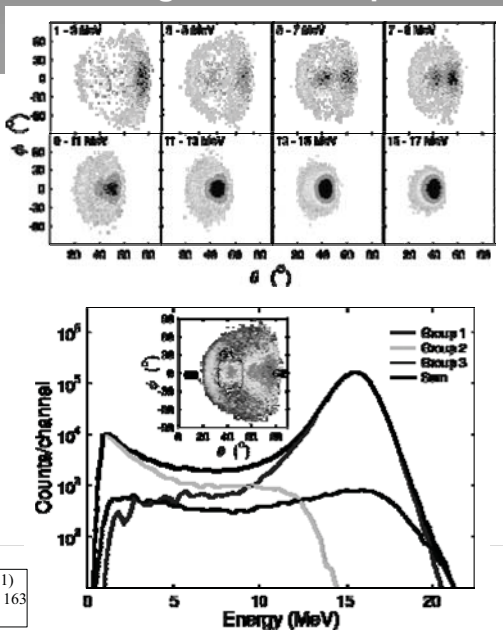
53 MeV I → 23 nm Cu / 200 nm Ti / 23 nm Cu / Si (20° in, 20° out)



K. Arstila, T. Sajavaara, J. Keinonen, NIMB **174** (2001) 163

Effect of multiple scattering on HI-ERD spectrum





From K. Arstila presentation at CRP on HI-ERD, Lisbon (2007/11)
See also K. Arstila, T. Sajavaara, J. Keinonen, NIMB 174 (2001) 163

Conclusion

- HI-ERD: attractive concept as one gets a separate spectrum for each target element
- Requires big artillery if depth of probe > 100 nm is required
- ERD-TOF on a Tandetron:
  - excellent depth resolution near surface
  - depth resolution degrades quickly due to MS
  - problem of detection efficiency for light elements: normalise to ERD-absorber
- In general, main contribution to depth resolution quickly becomes MS
  - Grazing incidence, asymmetric contributions
  - MC simulation to analyse