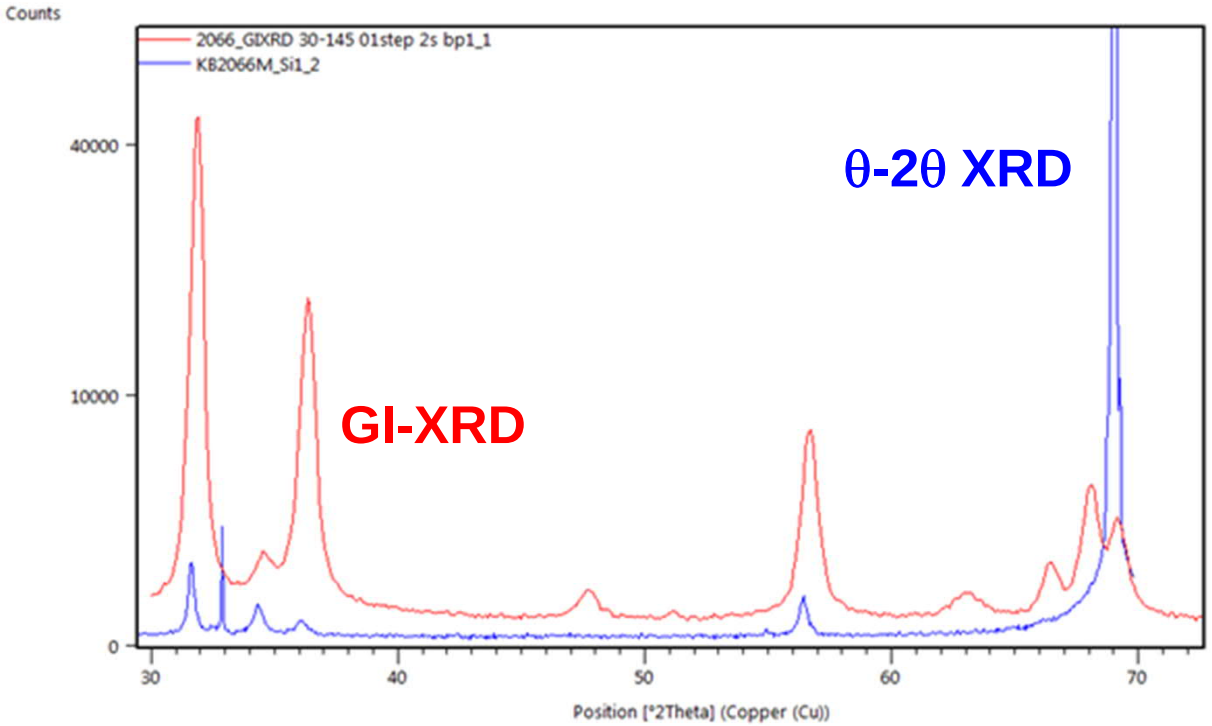
EXERCISE 6.1.

Here are ”ordinary” θ-2θ XRD (blue) and GI-XRD (red) patterns for a 200-nm ZnO thin film grown by ALD on a p-type (100) silicon wafer substrate. Explain the differences (and reasons) seen in the patterns.

In the blue pattern there are two sharper peaks seen around 33° and 69°; can you imagine any reason why they are sharper than the other peaks, i.e. what could be the origin of these peaks?

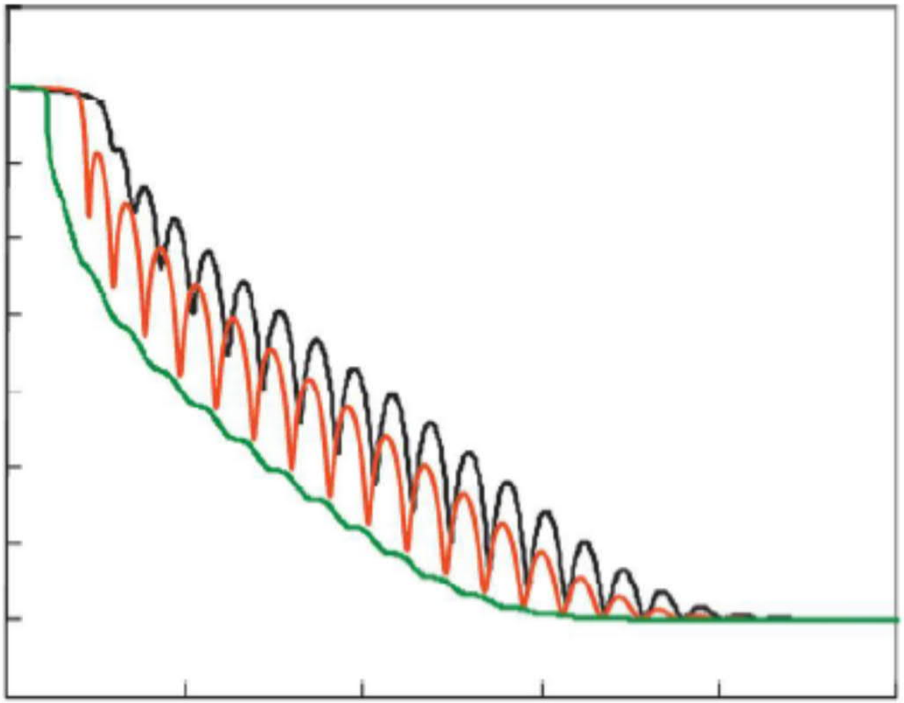


EXERCISE 6.2.

Here are XRR patterns (for the following thin films: SiO_2, Au and Cu.

Please assign the patterns to the correct films; most importantly, explain the reason for your assignment!

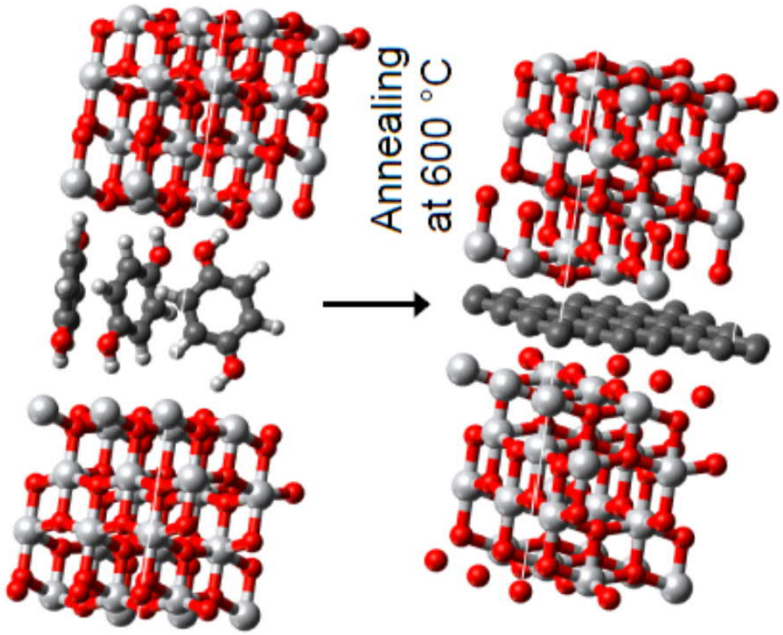
Can you also say something about the (relative) thicknesses of the three films; again, give the reason to your answer!

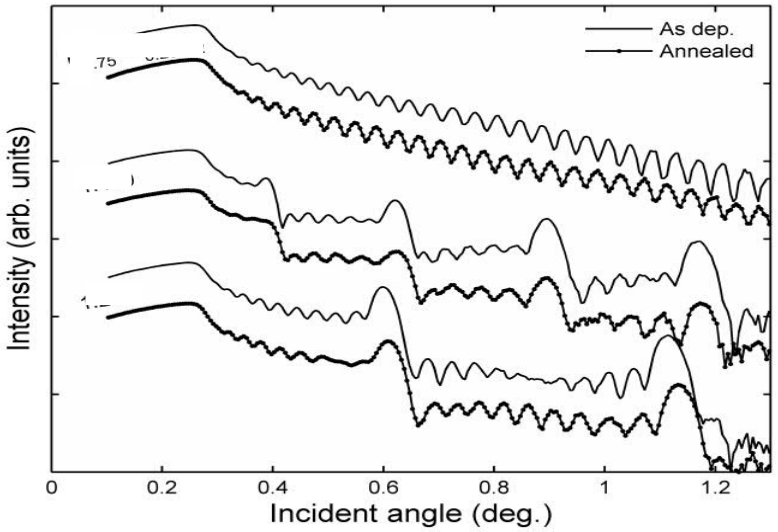


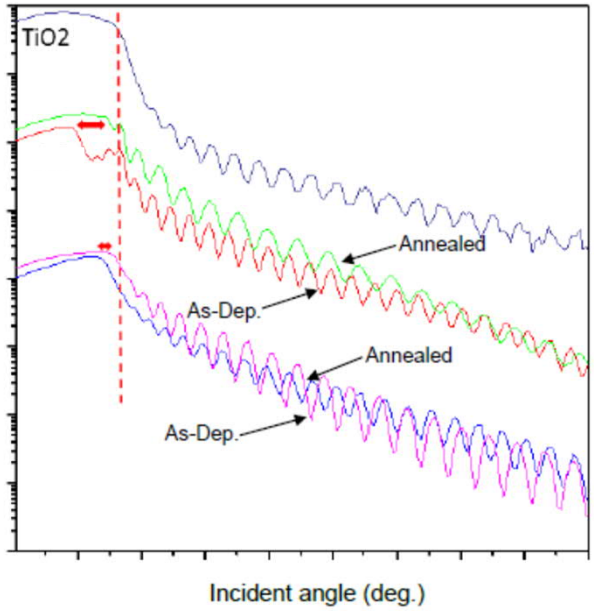
EXERCISE 6.3.

Here are XRR patterns for both as-deposited N x [TiO_2:benzene] superlattice films and the same films annealed in H_2 at 600 ^oC, which reduces the benzene layers into graphene layers. In the given XRR data figures, TiO_2 films are on the top, and thn two SL films below. From the left figure (N is small) you can see that the SL structure remains upon the annealing.

From the figure on the right (N is too large to distinguish the SL peaks as they overlap) you can make some observations concerning the DENSITY. Please discuss the effect of (i) adding benzene layers into TiO_2, and (ii) annealing, e.g. benzene → graphene transformation, on the density.





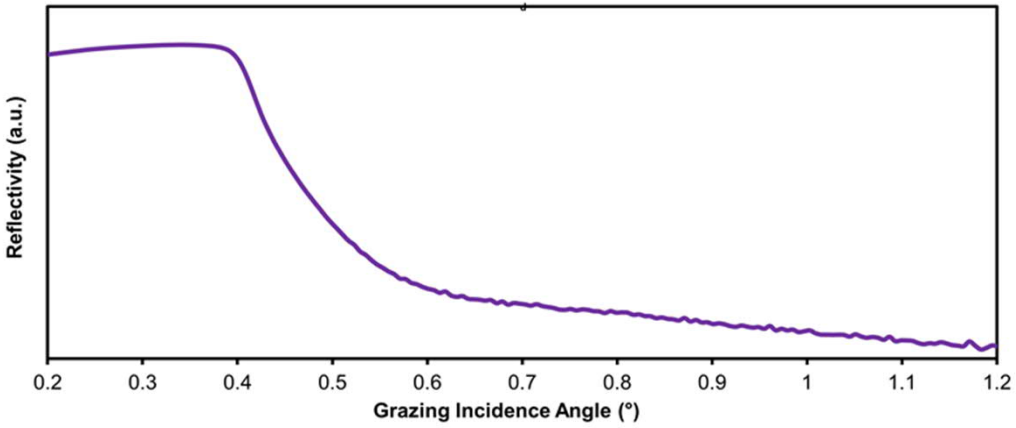


EXERCISE 6.4.

For these questions you should get answers directly from the practical exercise by Ramin.

A. **Two samples have similar XRR patterns but different GIXRD patterns. What could be the reason? Please, elaborate your reasoning?**

B. **Student deposited carefully an important thin film sample but the XRR pattern recorded for the sample (below) did not show any fringes. He then called the XRR device company to complain about the malfunction of the device. The company engineer however was convinced that the device works perfectly. What is your opinion?**



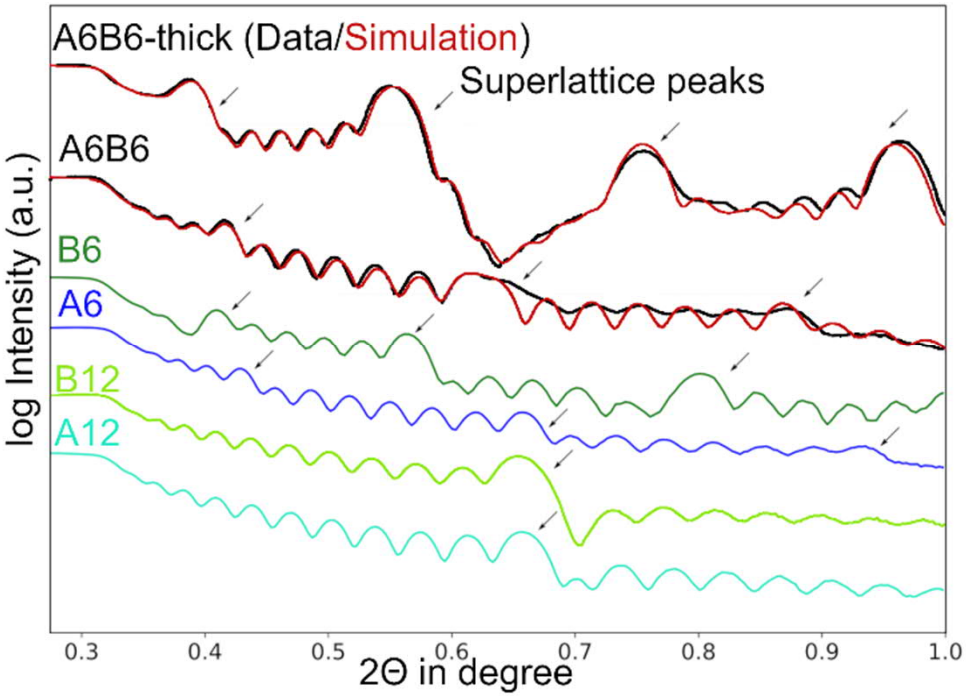
C. **What are the advantages of XRR fitting to other methods such as manually calculating the thickness?**

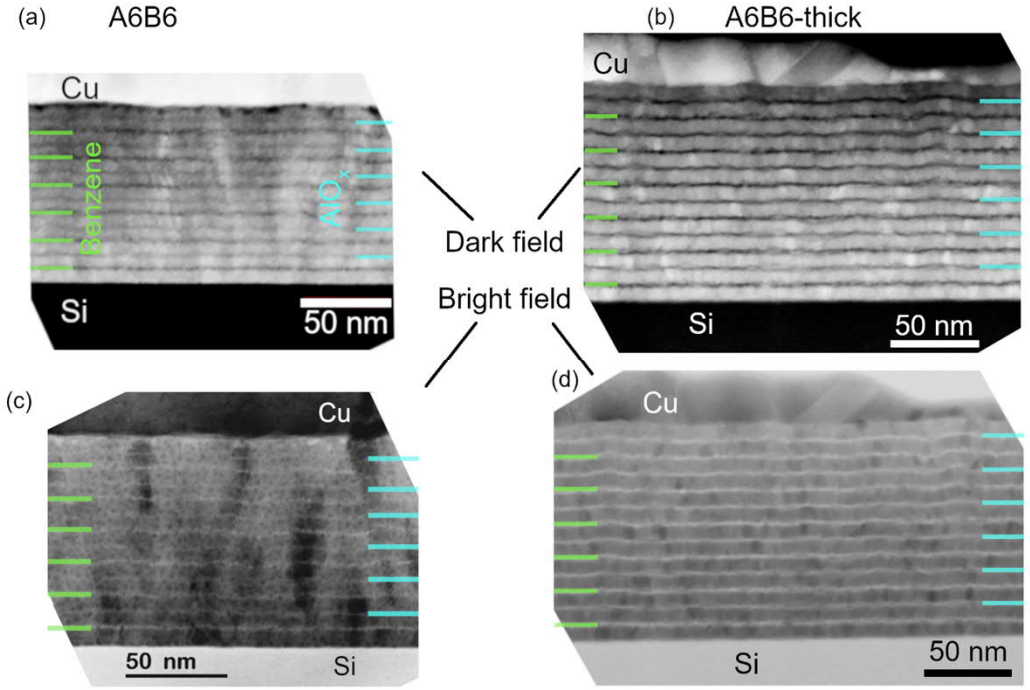
BONUS EXERCISE 6.5.

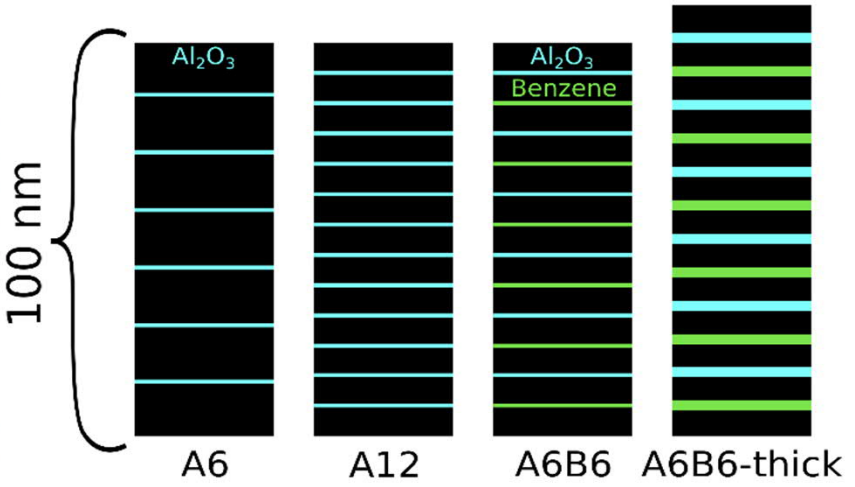
Here are XRR patterns for more complicated "hetero-type" ZnO-Al_2O_3/benzene superlattice thin films.

For comparison high-resolution TEM images are shown for the films as well.

BONUS QUESTION: Try to think why the XRR pattern for A6B6 resembles those of A6 and B6, not those of A12 and B12 ?







Additional reading can be requested by email from Maarit:
F. Krahl, Y. Ge & M. Karppinen, Characterization of ZnO/AlO_x/benzene thin-film heterostructures grown through ALD/MLD, *Manuscript* (2020).