Sub-Surface Object Characterization using Backscattered Electrons

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Introduction

Due to the increased 3-D complexity of microelectronic devices, one of the main goals of modern metrology is critical dimension measurements of sub-surface features, without using destructive techniques, i.e. techniques which can be employed in the production process. The information backscattered electrons (BSE) can provide depends on the escape depth of BSEs from the material and can be in the range of microns. Understanding the collected BSE signal means understanding the mechanism of interaction between the incident electron beam and the material, the volume of interaction itself, and interaction between the BSE signal during the course of its exit from the sample.

Methods

By obtaining detailed information on the BSEs, we can extract the depth, thickness and lateral resolution of sub-surface objects. The first approach is by measuring the energy of electrons and constructing their spectrum which exhibits a peak close the primary energy of electrons. By increasing the depth of the sub-surface object, the peak position and intensity of the spectrum will shift since electrons will have a longer path in the sample, and thus lose more energy.

The second approach is by measuring the angular distribution of BSEs. As electrons reach greater depths inside the sample, the probability that they reach the surface is higher for shorter path lengths, thus the peak position of the angular distribution shifts toward smaller angles (closer to the incident beam direction). As such, measuring the shift in the peak position of angular distribution allows us also to measure depth.

The Energetic Distribution Approach

Specimen

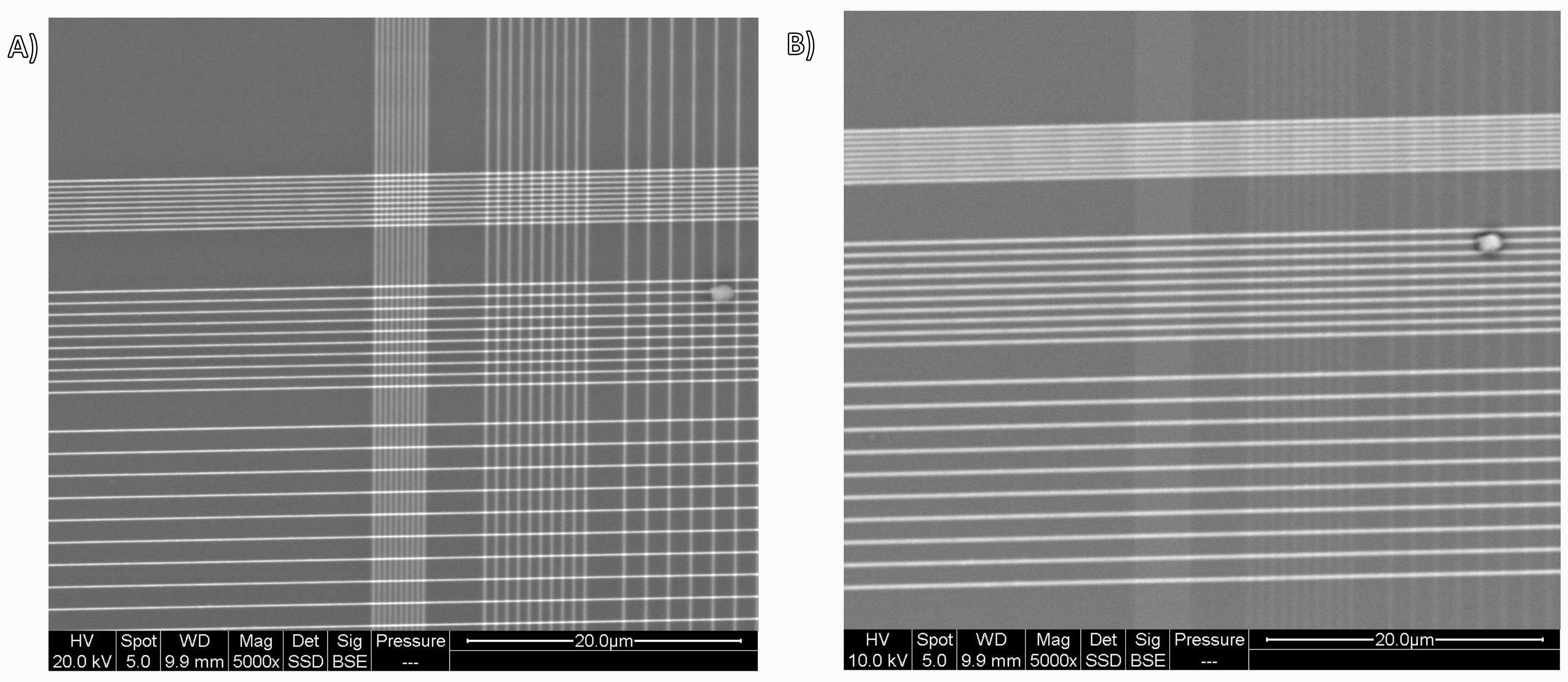


Figure 1 : The specimen used consisted of Au stripes embedded in 400nm of SiO_2 at 200nm and 400nm depth, with A) 20keV and B) 10keV primary energy showing the ability to extract depth information using primary energy variation.

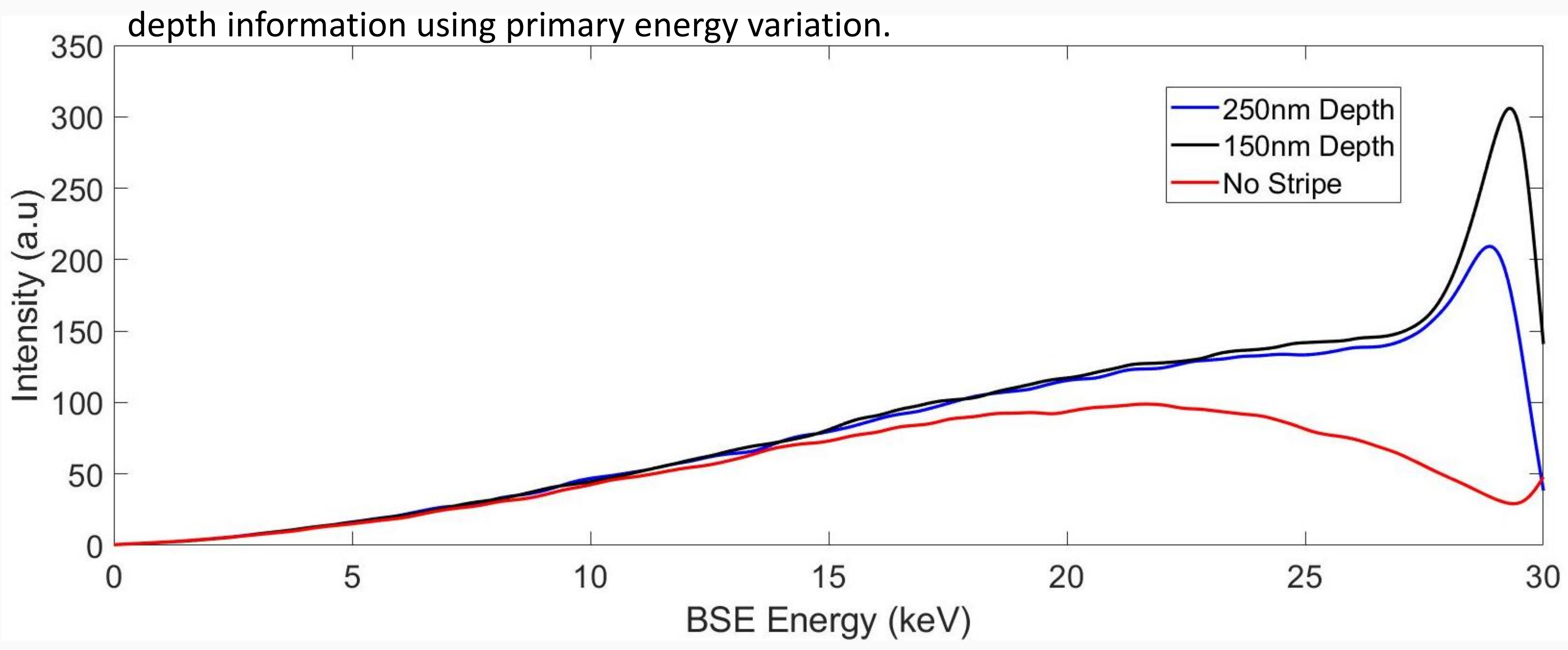


Figure 2: BSE spectrum for different configurations showing the shift in the peak height and position as influenced by the depth and thickness of the Au stripes. No stripe represents the spectrum of 400nm of SiO_2 on the Si substrate.

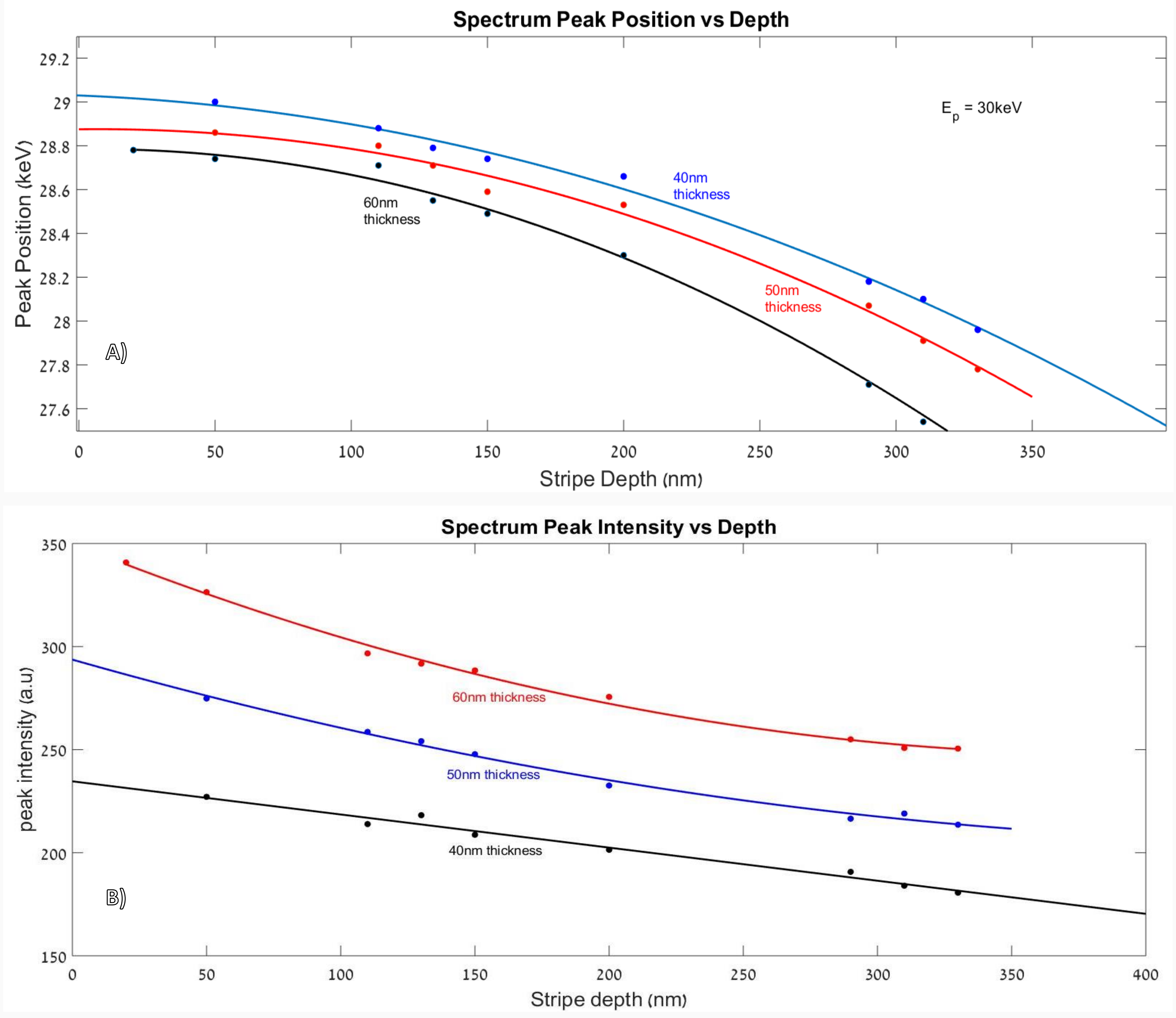
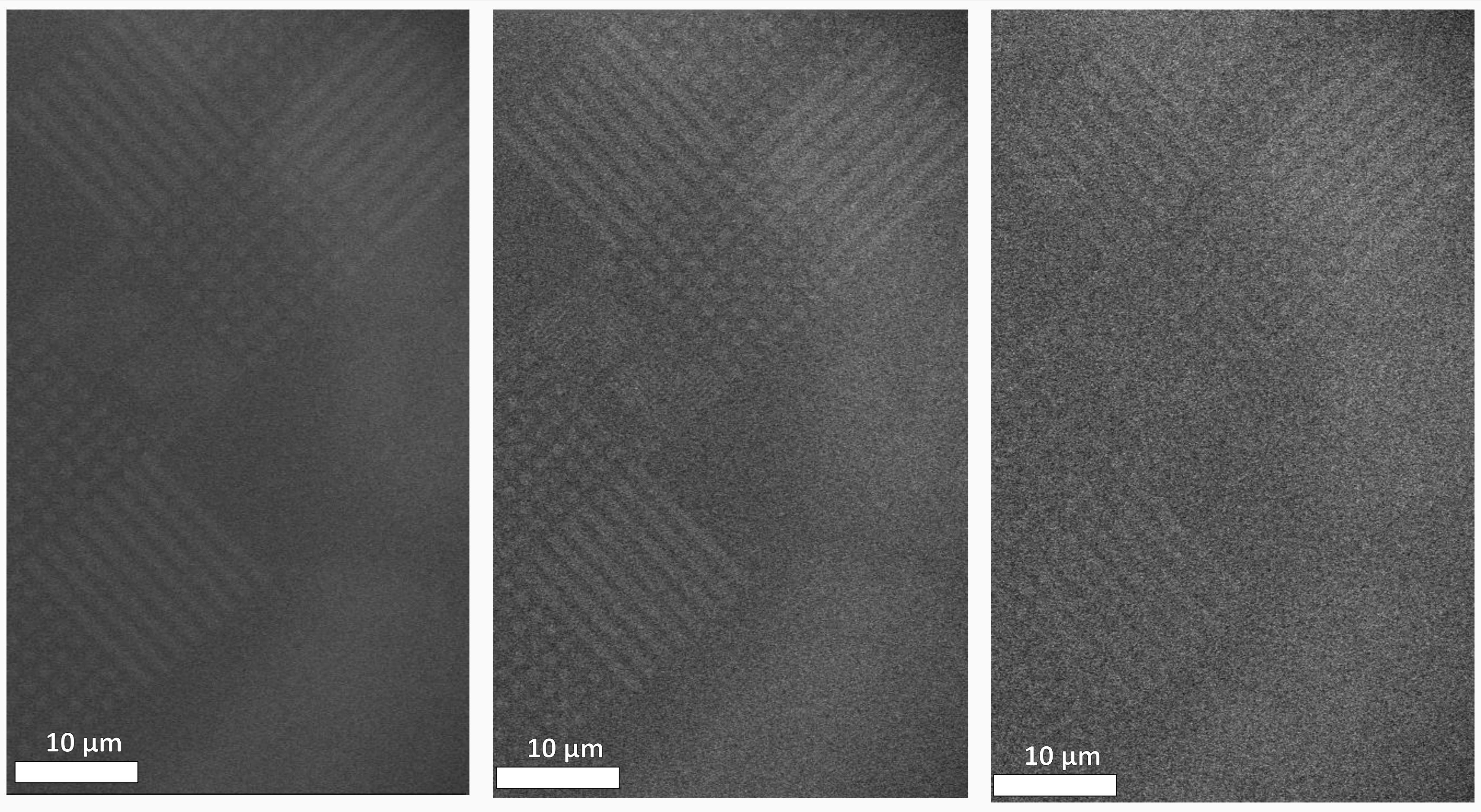


Figure 3: (A) BSE spectrum peak position as a function of depth and thickness of the Au stripes. The peak position for different thickness with same depth can vary which requires using the peak height as a second parameter seen in (B) to determine the true depth of the stripes.

The Angular Distribution Approach.



10 keV 11 keV 15 keV

Figure 4: Images of Au patterns embedded inside SiO_2 at 320nm of depth acquired using an in-lens detector. As the energy increases the electron scattering angle most probable shifts to higher angles away from the beam direction, thus never reaching the in-lens detector.

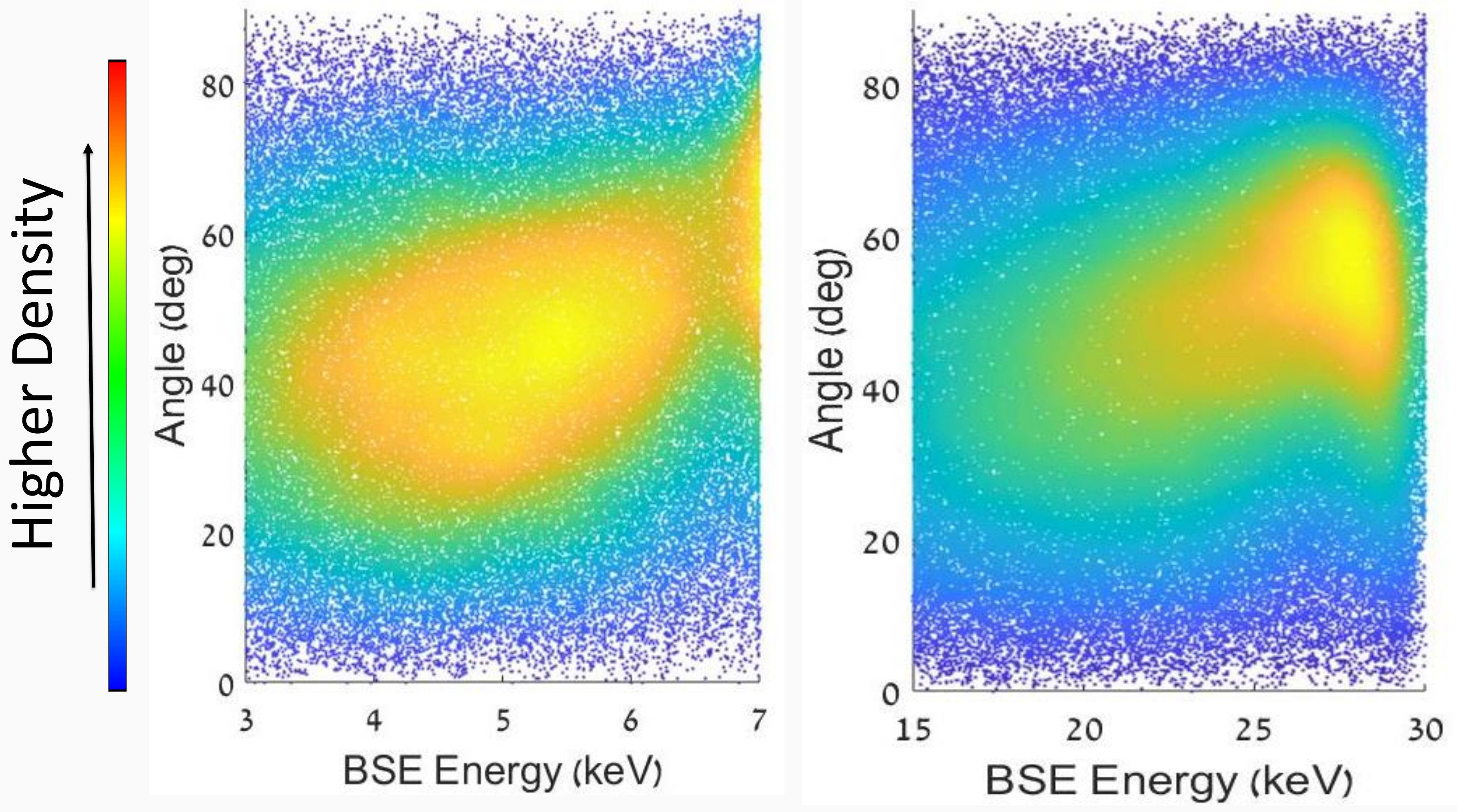


Figure 5 : Density maps of the escape angle of BSEs as a function of their energy showing the shift in the density from low escape angle to a higher one with increasing the primary energy of electrons which contributes to better signal as seen in figure 4.

Summary and Conclusions

- Depth information can be extracted from both the angular and energetic characteristics of BSEs by varying the primary energy of electrons and measure the signal obtained.
- The peak height and position of the BSE spectrum contains information about the depth and thickness of sub-surface objects.
- The angular distribution spectrum of BSEs exhibit the same behavior as the energy spectrum with peak position shifting as a function of depth and thickness.
- Further research required to develop detector designs with the capability to extract the information on the BSEs.