

# The contrast mechanisms of LL-BSE electrons from Hybridization & Band Gaps

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Keywords: carbon hybrids, GFP, band gaps, Low loss BSE, plasmons, phonons

**Abstract:** Low Loss BSE electrons become visible on a very narrow energy and angular distribution around the primary beam axis of the SEM. They are projected from a lens with high energetic dispersion in the backplane and filtered to minimize multiple inelastic electron scattering. LL-BSE electrons show contrast not from atomic numbers, but from resonances, band gaps and ionization losses. LL-BSE behave very nonlinear<sup>1,2</sup> in contrast but are characteristic for the bonding strength (resonance). They can be used to characterize oxidization states of elements, polymers and protein (unstained). To understand the new contrast mechanisms experiments with hybrids, polymers and all kinds of different oxidization states of elements were made. Essential for the contrast at low landing energies is not any more the atomic number or density as contrast mechanism, but only the bonding structure of the outer shell electrons<sup>1</sup>. My findings show that *plasmons, phonons, hybridization and band gaps* are the dominating contrast mechanisms in the low voltage regime below 2 kV. The resulting electron energy loss is characteristic and significant for the bonding type. These electrons are double stage filtered projected from a lens with high dispersion in the backplane. To understand the influence on contrast from bonding, experiments were made with polymorphs of carbon. The classical two modifications are graphite and diamond also known as  $sp^2$  and  $sp^3$  hybrids. One can see graphite brighter than diamond (Fig.1). Both modifications can be identified via the crystallographic characteristics - hexagonal and cubic angles. At 900 Volt and below we are far away from Bragg conditions and diamond as the cubic modification shows independent from the orientation (111) or (110) the same contrast. The same is for graphite. Since all carbon modifications are element 6, the atomic number as contrast must also be excluded. Also the density - diamond is higher in density and appears darker than graphite - must be excluded as contrast mechanism. The only difference is the valence electron configuration as sigma- and pi-electrons. The delocalized pi-electron in the graphite requires around 8 eV to be replaced by the primary beam and is responsible for the high contrast (Fig.1). The result of this key experiment is, that we are independent from the atomic number and the density! Experiments were made with non-mixable block co-polymers and waxes with known molecular structure. Band gaps follow the same contrast mechanisms (plasmonic resonance) and can be differentiated down to 0.1eV Fig.2

<sup>1</sup> Jaksch H., Contrast mechanisms of low loss Backscattered Electrons in Field emission SEM, EMAS conference May 2011, Angers, France (Paper)

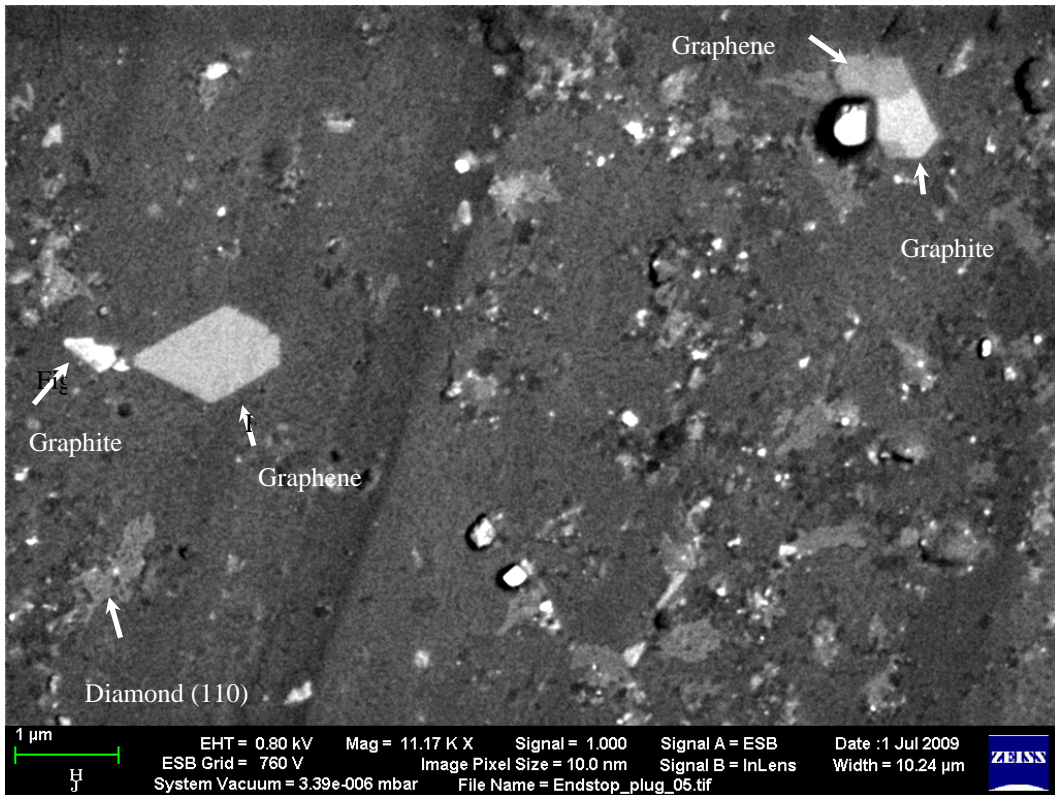


Fig. 1: On this sample of allotropic carbon modification we can clearly see that diamond is darker than Graphite, although it has the higher density. Graphene (hex) can be distinguished via the sigma bonding from the graphite with one pi-electron. This pi-electron produces the high contrast. Note that sigma bonding always makes the same contrast. Diamond and Graphene can be distinguished via crystallographic angles.

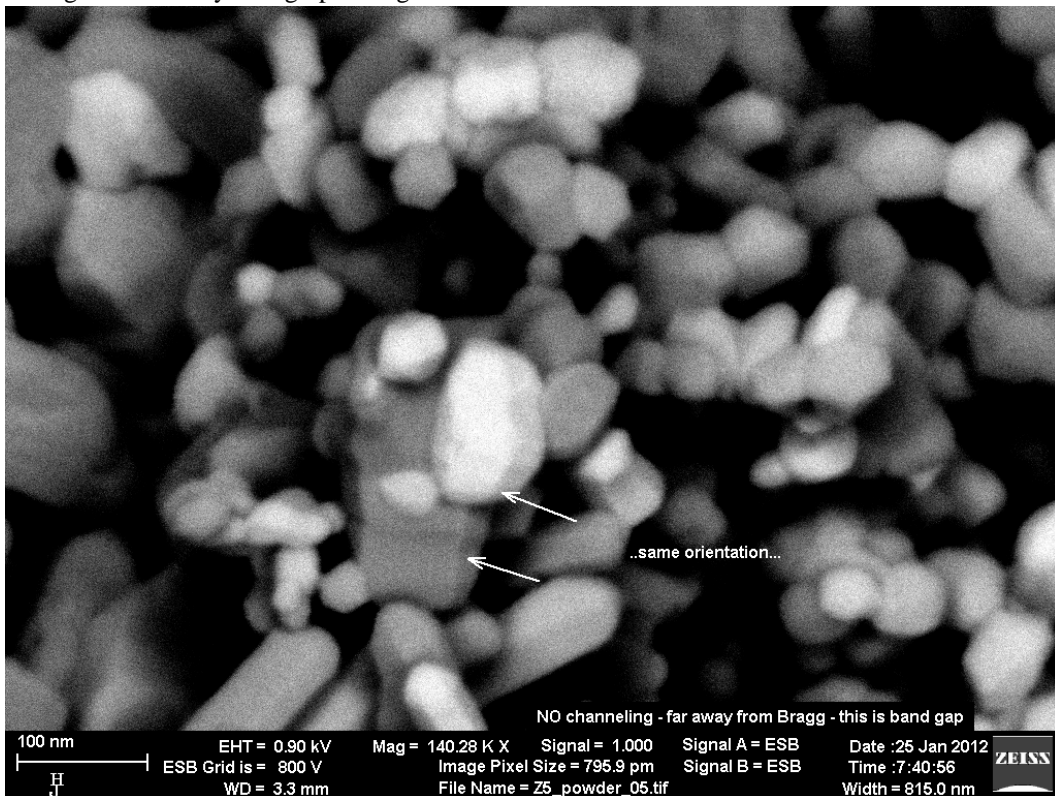


Fig. 2: On this sample different band gaps (3.35, 3.25, 3.39 eV) of ZnO are seen. The values were determined by UV-VIS (0.01eV error). The contrast is produced by different plasmons from small concentration of dopands. This is not channeling! The indexed crystals show the same orientation but dramatically different contrast. One can clearly see different contrast from the 3 band gaps.