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# Contacting Nanospheres

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Understanding the origin of stresses at nanoscale contacts is crucial as nanoparticles find use in various applications where adhesion and wear are important. This study uses transmission electron microscopy (TEM) to investigate the stress fields created by contacting nanoparticles. The nanoparticles investigated here are silicon spheres produced by a plasma processing technique [1].

When two particles come in contact with one another it is energetically favorable for them to meet at an area rather than a point, forming a "nano grain-boundary". In this zero-load situation the stress is balanced by a compressive stress at the center of the contact and a tensile stress at the exterior. Consider the two spheres shown in the bright-field TEM images in Fig. 1 and 2. In Fig. 1 the particles are overlapping and no strain contrast is visible at the contact location. In Fig. 2, after the same pair of particles has been tilted such that the interface is edge on, the strain at the interface is clearly visible as seen by the typical strain-contrast contour. This strain contrast is the result of bent lattice planes which cause a local change in the diffraction conditions. Similar strain contrast has been observed in other particle systems including Fe/Ni, Mg, Ni and Au [2-4].

It is interesting to note that if both contacting particles were resting on the support film, as illustrated in Fig. 3, they would overlap by a specific distance. For these particles this distance would be approximately 6 nm, but the actual distance measured from the TEM image in Fig. 1 is 14 nm. This suggests that one of the particles is not in contact the support film but rather suspended above it. The orientation relationship between the two particles was determined by sequential tilting while monitoring the alpha- and beta-tilts of the sample holder, as indicated by the diffraction patterns in Fig. 3. Note that the strain contrast is no longer present after tilting.

The dark bands of contrast that run across the smaller particle (Fig. 1.) are caused by a twin boundary, commonly found in these nanoparticles [5], which is inclined to the electron beam. If twin boundaries are present in one of the contacting particles they frequently terminate at the particle-particle contact. This phenomenon has also been noted in metallic particles [6]. It is likely that twin forms a local flat region in an otherwise spherical particle. The twinned region thus increases the area of contact with neighboring particles such that they preferentially contact here, as seen in Fig. 4.

This study illustrates the use of the TEM to examine the stress fields created by particle-particle contact and the relationship of twin boundaries to these contacts. Sequential tilting of the nanoparticles was used to characterize the orientation relationship across the "grain boundary". The boundary gives insight into particle sintering which can be investigated by *in-situ* heating methods.

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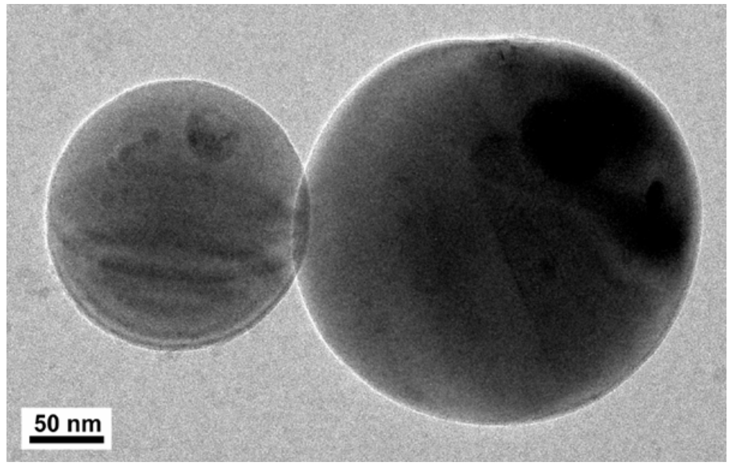


Fig. 1. (right) Bright-field image of two overlapping particles.

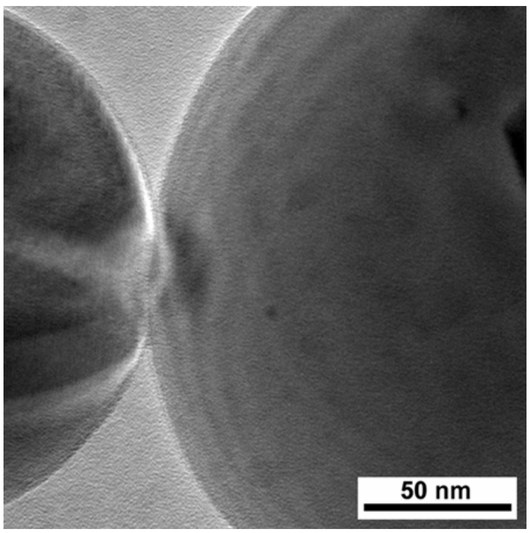


Fig. 2. (below) Higher magnification bright-field image of the contact after tilting the boundary edge on.

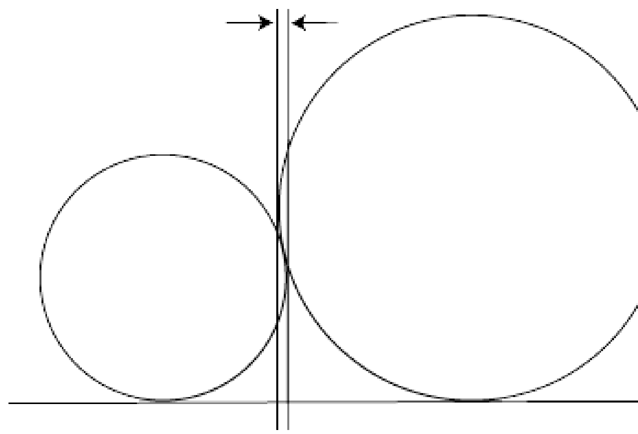

Fig. 3. Schematic showing the maximum overlap of two particles in contact with each other and the support film.

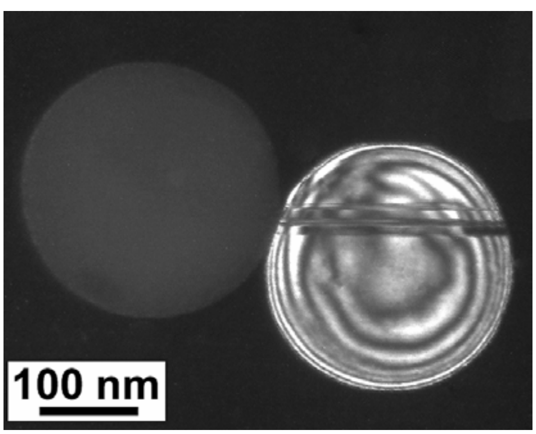


Fig. 4. (above) Dark-field image of two particles contacting at region of multiple twin boundaries.

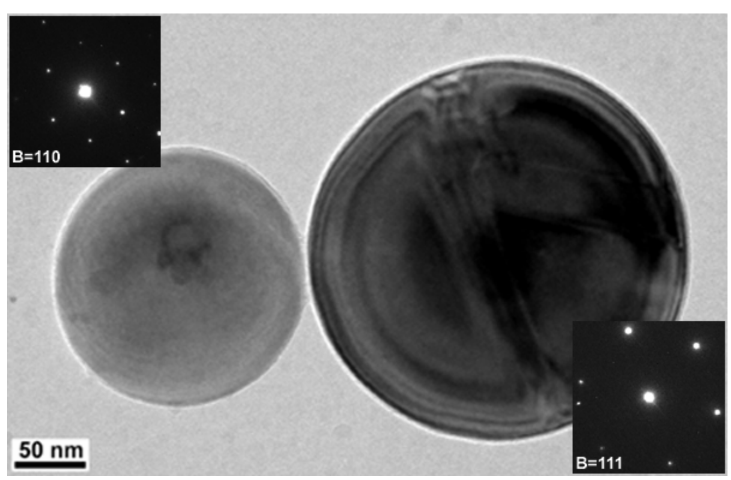


Fig. 5 (right) Orientation relationship of the particles. Here the larger particle is on the 111 zone. When tilted 2°α and 3°β the smaller particle is on the 110 zone.

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