Oxide Nanoparticle Uptake in Human Lung Fibroblasts: Effect of Particle Size, Agglomeration and Diffusion at Low Concentration

Ludwig K. Limbach[1], Yuchun Li[2], Robert N. Grass[1], Tobias J. Brunner[1], Marcel A. Hintermann[1], Martin Muller[3], Detlef Gunther[2], Wendelin J. Stark[1,]*

[1] Institute for Chemical and Bioengineering, Department of Chemistry and Applied Biosciences, ETH Zurich, CH-8093 Zurich, Switzerland

[2] Laboratory of Inorganic Chemistry, Department of Chemistry and Applied Biosciences, ETH Zurich, CH-8093 Zurich, Switzerland

[3] Electron Microscopy Facility, Department of Physics, ETH Zurich, CH-8093 Zurich, Switzerland

Supplementary Information

[*]Correspondence should be addressed to

Wendelin J. Stark
Institute for Chemical and Bioengineering, HCI E 107
ETH Hoenggerberg
Wolfgang-Pauli-Str. 10
CH-0893 Zurich
Switzerland

e-mail: wendelin.stark@chem.ethz.ch
phone: +41 44 632 09 80
fax: +41 44 633 10 83.

Electronic supplementary Information

Crystallinity of nanoparticles. The predominant phase of the investigated ceria nanoparticles was determined by X-ray diffraction of the solids of all size fractions I to IV. Samples were heated at 110 °C for 12 hours and the resulting powder was analyzed as detailed by (*1*).

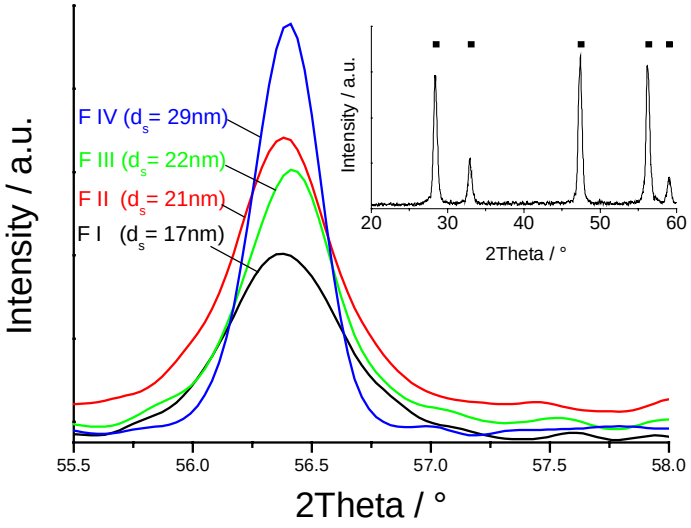

Figure S1. X-ray diffraction pattern of ceria size fractions I to IV. The mass mean crystallite size diameter of size fraction 1 is around 17 nm while higher size fractions are build from crystallites of 20 to 30 nm in size. The insert shows a full diffraction pattern with the calculated pattern (squares) of ceria CeO_2 oxide.

Comparison of the hydrodynamic diameter as measured by X-ray diffraction, the crystallite diameter as determined using the Scherrer formula and the particle size by transmission electron microscopy (Figure 1) proofs that the particles are polycrystalline hard aggregates of ceria (*2*). Since size fractions II and III are made from the same type of sintering treatment, the crystallites that build the material are similar, 21 and 22 nm, respectively. A stronger sintering treatment (1000 °C) was used to prepare the hard aggregates for size fraction IV, consequently, the crystallites of this fraction are larger (29 nm).

Infrared spectroscopy and surface properties. The high surface area of nanoparticles may provoke significant amounts of organic substances to adsorb on their oxide surface. Such coatings result in a different zeta-potential and, as a consequence, an altered behavior in biological fluids. Some substances could themselves induce a toxic response on the fibroblast cells. Infrared spectroscopy was therefore used as a sensitive probe to exclude the presence of such organic surface coatings. Figure S2 shows an IR spectrum measured as a diffuse reflectance spectrum as detailed by (*3*). The absence of absorption signals in the indicated regions around 2900 to 3000 cm^{-1} corroborates the presence of an oxidic surface without significant organic absorbates.

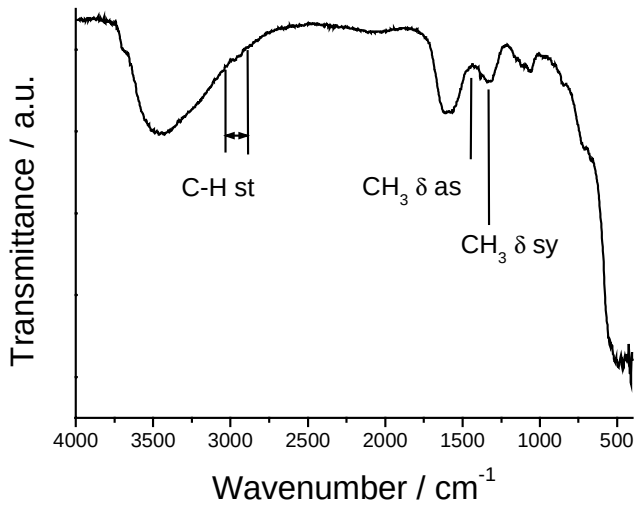

Figure S2. Infrared diffuse reflectance spectrum of ceria nanoparticles. The spectrum shows a prominent broad signal around 3500 cm^{-1} attributed to OH groups and hydrates and lattice vibrations around 1600, 1300 and 1000 cm^{-1}. No evidence is found for C-H stretching bonds in the area of 2900 to 3000 cm^{-1} confirming the absence of an organic coating on the particles.

Solubility and chemical reactivity. Ceria is a Mosh Hardness 9 oxide of considerable mechanical and chemical resistance and has been reported as insoluble in water. No chemical activity has been reported in biological media (*4*).

References

(1) Madler, L.; Stark, W. J.; Pratsinis, S. E. Flame-made ceria nanoparticles. *J. Mater. Res.* **2002**, *17*, 1356-1362.

(2) Borchert, H.; Shevehenko, E. V.; Robert, A.; Mekis, I.; Kornowski, A.; Grubel, G.; Weller, H. Determination of nanocrystal sizes: A comparison of TEM, SAXS, and XRD studies of highly monodisperse COPt3 particles. *Langmuir* **2005**, *21*, 1931-1936.

(3) Stark, W. J.; Pratsinis, S. E.; Baiker, A. Flame made titania/silica epoxidation catalysts. *J. Catal.* **2001**, *203*, 516-524.

(4) Greenwood, N. N., Earnshaw, A. *Chemistry of the Elements*; 2nd edition ed.; Butterworth, UK, 1997.