Influence of particle size of polymer nanoparticles on the static dielectric constant

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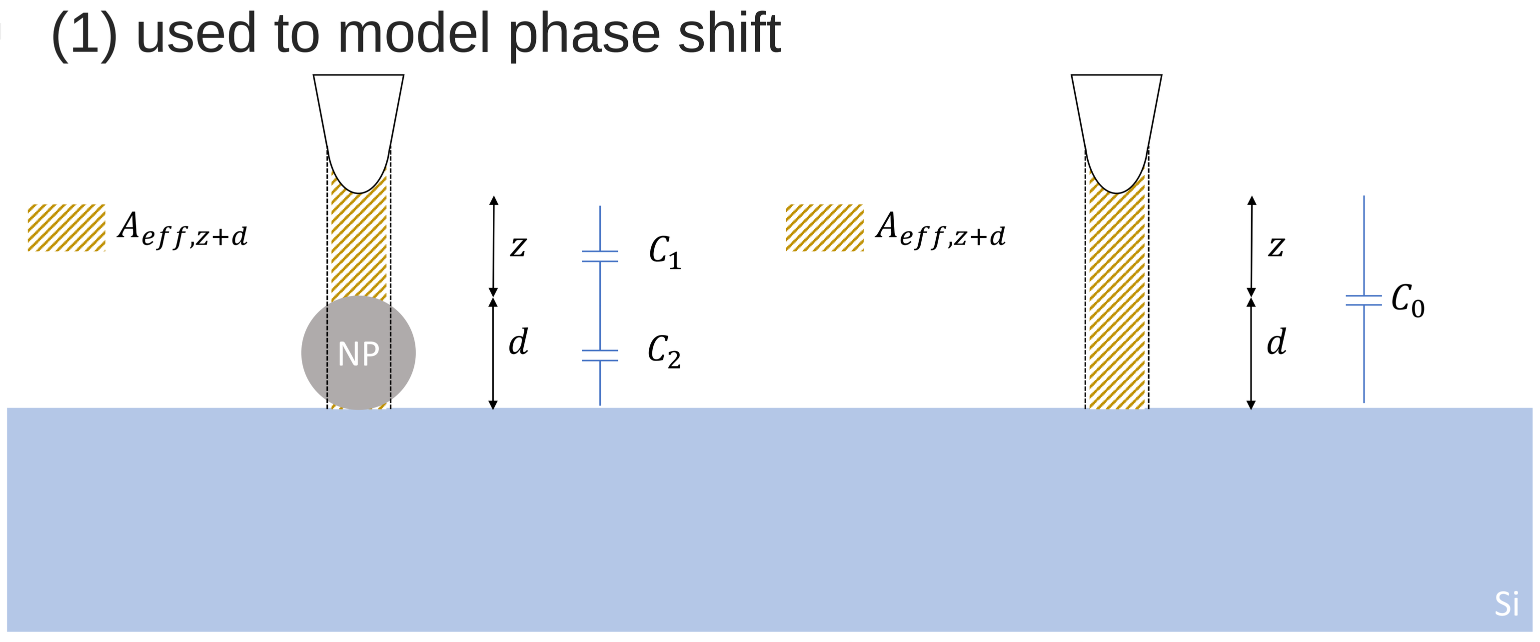
Abstract

- Current literature measurements of dielectric constants of nanoparticles reveal contradictory results for nanoparticles with a size smaller than 100 nm depending on the measurement method used [1-3].
- In [3] an increasing dielectric constant up to a factor of 3 for decreasing size of the nanoparticles is reported. In [2] the dielectric constant stays constant as a function of particles size.
- In this work a measurement method is developed eliminating the influence of the topography and of the effective area of the tip-sample capacitor.

Methods & Materials

- Probe is kept at a constant height (Linear Mode) to eliminate topographic crosstalk [1]
- Tip-surface capacitor is assumed to be a plate capacitor with an effective area depending on the FWHM of the topography scan across the particle
- Change of dielectric constant results in phase shift change
- (1) used to model phase shift



$$\Delta\varphi = -\frac{Q}{k}\varepsilon_0(V_{DC}-V_{CPD})^2\left(\frac{A_{eff,exp}}{\left(z+\frac{d}{\varepsilon_P}\right)^3}-\frac{A_{eff,exp}}{(z+d)^3}\right) \quad (1)$$

$$A_{eff,exp} = \pi\left(\frac{2}{3}w_h\right)^2$$

Figure1: Capacitor model using linear mode

Experiment Parameters

- Height above particle (z) is 20 nm to 40 nm
- CoCr coated AFM-Probes used:
  - *SSS-MFMR* from *Nanoworld* ($r_{Tip} = 15\ nm$)
  - *MFM_HC* from *NTM-DT* ($r_{Tip} = 40\ nm$)
- DC-Voltage applied to the tip (V_{DC}) is varied from -4 V to 4 V
- PS-NP provided by *Alpha Nanotech Inc.* and Fraunhofer IMM [4] ranging from 27 nm to 122 nm in diameter
- PMMA-NP provided by Fraunhofer IMM [4] ranging from 70 nm to 300 nm in diameter
- NPs diluted in water are drop casted onto p-Si dies
- Measurement data is fitted using MATLAB

Results

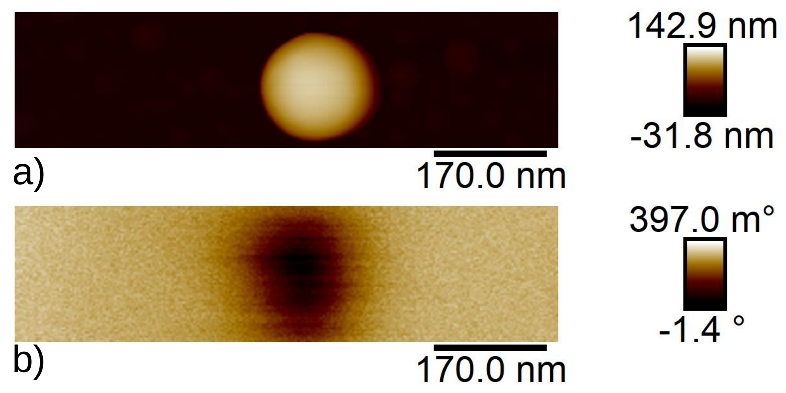


Figure 2: 116 nm PS-NP: a)Topography, b) Phase shift

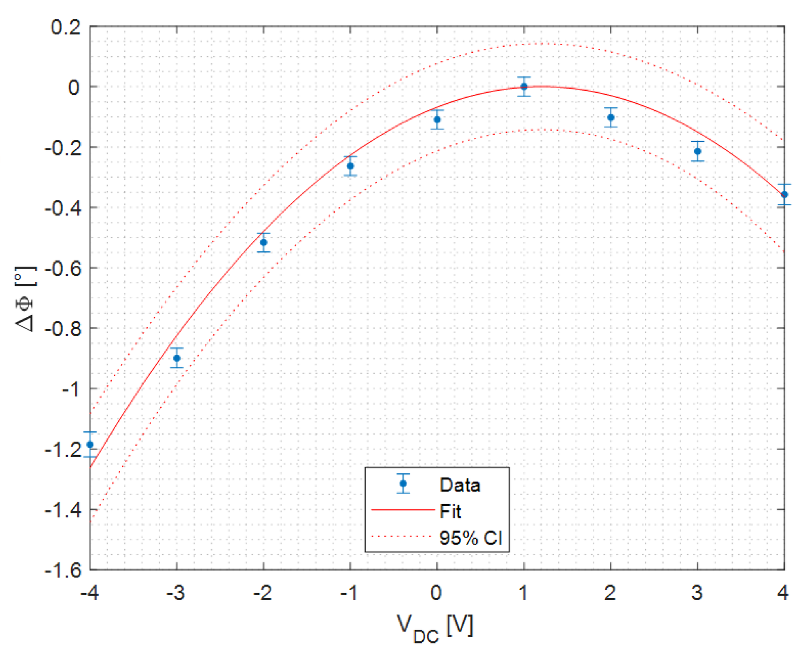


Figure 3: Phase shift as a function of DC-Tip-Voltage (blue) and fitted model (red)

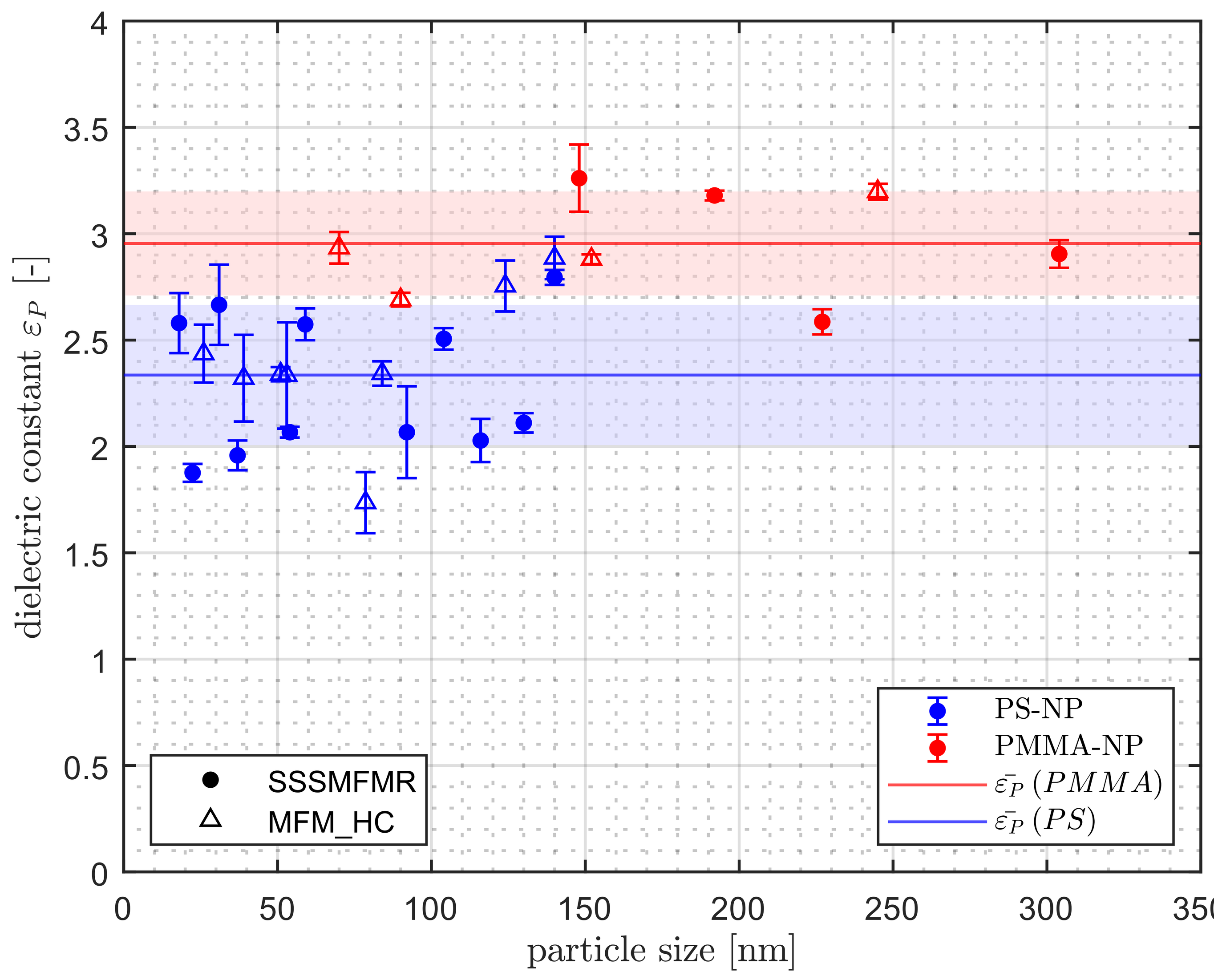


Figure 4: Dielectric constant as a function of particle size

Conclusion & Outlook

- A measurement method is developed which suppresses topographic crosstalk and which is independent of the effective area of the tip-sample capacitor.
- Dielectric constant of PS-NP and PMMA-NP is observed to be constant as a function particle size.
- With the knowledge of the dielectric constant of nanoparticles it is now possible to create and validate methods for data fusion of EFM and AFM to determine the dielectric constant in lift mode measurements as well.

Literature

[1]M. Fuhrmann, A. Musyanovych, R. Thoelen, and H. Moebius, "Determination of the dielectric constant of non-planar nanostructures and single nanoparticles by electrostatic force microscopy," Journal of Physics Communications, vol. 6, no. 12, 2022

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