QNANO Research Infrastructure

## Karlsruhe Microwave Plasma Process (KMPP)

**Category:**
**A. Particle Synthesis**

**Institute:**
**KIT**

**Location:**
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**Short technology description/Overview** *(approx 300 words)*:

The Karlsruhe Microwave Plasma Process is a non-thermal, low-pressure process. This method is highly applicable for the synthesis of nanoparticles with particle size <10 nm and very narrow particle size distribution. Beside the low intrinsic temperature in the plasma, one central feature of this process is the short residence time of the reactants in the plasma of only a few milliseconds. Due to the combination of short residence time in the reaction zone, low temperature, and equally charged particles, growth and formation of hard agglomerates is reduced. Another advantage of this process is, that synthesis of ceramic/ceramic, and inorganic/organic hybrid core/shell nanoparticles with sizes below 10 nm is possible. In such a case each nanoparticle is covered either with a ceramic or an organic layer, adding functionality to each particle. The temperature in a microwave plasma is significantly lower than in an AC or DC plasma because the energy *E*, transferred to a charged particle of a mass *m* in an oscillating electrical field is inversely proportional to its mass and the squared frequency. As the mass of the electrons is small compared to that of ions, at high frequencies a substantially larger amount of energy is transferred to the electrons, as compared to the energy transferred to the ions.

**Main Features (Equipment Capabilities):**

- Microwave frequency: 2,45 GHz
- Microwave cavity: $TE_{11}$-mode
- Precursors: Volatile (b.p. < 350°C @ 10mbar) and water-free (chlorides, carbonyls, metal-alkoxides, metal-alkyl)
- Synthesis of bare nanoparticles with primary particle sizes < 10 nm
- Synthesis of ceramic core/shell nanoparticles
- Synthesis of hybrid core/shell/nanoparticles (ceramic core/ organic coating)
- Synthesis of multi-layer nanoparticles (core/shell1/shell2)
- Powder collection by
  - Thermophoresis (10mg -500mg)
  - Deposition on substrates ($10mm^2$)
  - In situ dispersion in resins, diethylenglycole, high

- Core and/or shell materials:
  - $Fe_2O_3$ (superparamagnetic)
  - $TiO_2$ (optical properties; solar cell)
  - $SnO_2$ (semiconducting; gas sensing properties; anode material for Li-ion battery)
  - $ZrO_2$, $Ta_2O_5$, $HfO_2$ (optical properties)
  - $WO_x$, $MoO_3$ (electrochromic material)
  - ZnO (semiconducting)
  - MgO, $Al_2O_3$, $SiO_2$
  - Others on request
- Organic coating
  - Methacrylate, methylmethacrylate, . . .
  - Organic dyes (anthracene, pyrene, perylene, coumarines, . . .)
  - Surfactants
- Decoration of nanoparticles with noble metals (Pt, Pd,

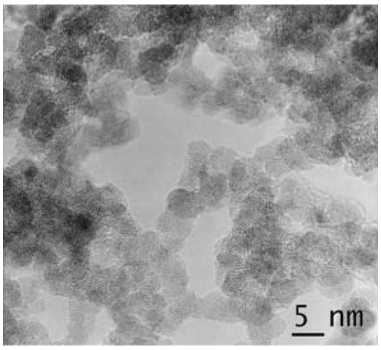
boiling liquids

- Potential for up-scaling

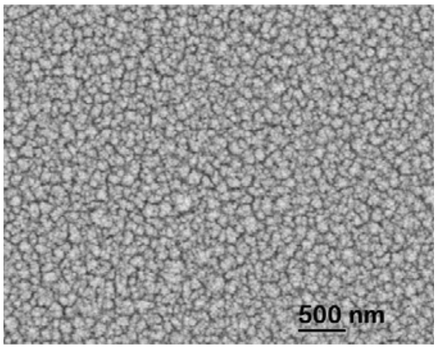
Au) possible

- Bi-functional nanoparticles (e.g. $Fe_2O_3$ superparamagnetic core coated with organic dye)

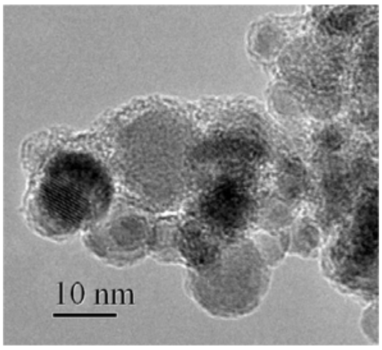
**Typical structures**



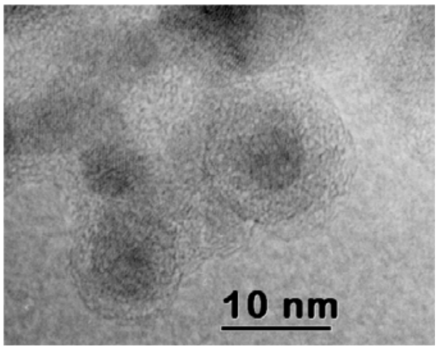

Bare $SnO_2$ nanoparticles with narrow size distribution and crystallite size of around 4 nm



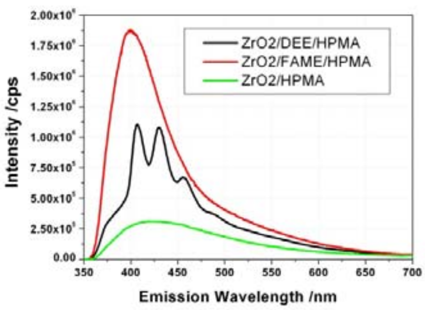

$SnO_2$ nanoparticles deposited as porous layer on a substrate



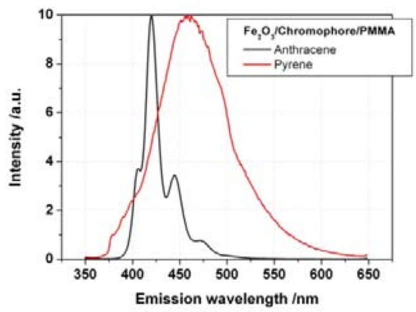

Ceramic core/shell nanoparticle (core $ZrO_2$, shell $Fe_2O_3$)




Hybrid core/shell nanoparticle (core $Fe_2O_3$, shell polymethacrylate)




Fluorescence properties of $ZrO_2$ nanoparticles coated with different organic molecules (DEE=diethylether, FAME=formic acid methyl ester, HPMA=Hydroxypolymethylmethacrylate)




Example of bi-functional nanoparticles: superparamagnetic $Fe_2O_3$ with specific fluorescence properties, depending on the dye used, and additionally coated with PMMA.

*Any further Information*: