OPTICAL AND MECHANICAL PROPERTIES OF BULK NANO- AND MESOSIZED PARTICLE ASSEMBLIES

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We show how macroscopic properties of materials can be influenced in a predictable way by self-assembly of nano-particles with well defined – and tunable- interactions. Light and neutron scattering is used to characterize the structural properties in-situ. A quantitative discussion relating micro- and macro behavior will be given with special emphasis on mechanical and optical properties. We show that the processes and phenomena studied here can be useful in such different areas as consumer products, optics, food science, dispersion technology and materials (for example ceramics).

Tailoring nanoparticle structures with an appropriate degree of order gives rise to new material properties. We study the self-assembly of spherical as well as of non-spherical particles to larger arrays using colloidal methods. More specifically the aim of our research is to understand the mechanism and kinetics of self-assembly of nanoparticles during the increase in the concentration and for modified interparticle interactions. In-situ optical methods SAXS, SANS, light scattering and photon correlation spectroscopy are used to investigate the assembling processes.
Here we will focus on two examples of how macroscopic properties of nano-particle assemblies can be controlled by tailoring local order. The first example deals with mechanical properties of nano-particle gels. In the second example we show that liquid order in nano- and mesoparticle assemblies leads to photonic properties that can be used tune the optical transmission.

MECHNICAL PROPERTIES OF NANOPARTICLE GELS

Gels are formed by chemical or physical reactions of small sub-units such as molecules, polymers or colloids. The macroscopic features that tie together such different materials are based on the microstructural properties of all gels, which can be described as random networks built up by aggregation of individual sub-units.

FIGURE 1 Left: Nanoparticle suspension (particle size 20nm) before and after gelation. Right: Diffusing Wave Spectroscopy intensity autocorrelation function before (open symbols) and after gelation (solid symbols). Inset: Gel elastic modulus derived from light scattering.

Here we focus on the fascinating problem of the liquid to solid transition in destabilized nanoparticle suspensions. The destabilisation rapidly leads to aggregation, cluster formation and gelation. At the gel point a liquid-solid transition is observed which can be characterized by the appearance of an elastic modulus in mechanical measurements (and also in a much increased scattering of visible light for the

nanoparticle case, Fig 1). We have studied the sol gel-transition for dense particle suspensions. From a detailed analysis of microscopic dynamic properties of these materials we extract information about the macroscopic viscoelastic behavior. Subsequent comparison to classical oscillatory shear measurements yields excellent agreement over the range accessible to both techniques. The many inherent advantages of a light scattering characterization are discussed in detail: non-invasive sample access, extremely fast data acquisition time and an extended range of accessible frequencies. This enables us to study extremely slow gelation processes but also the critical power law scaling of the elastic moduli of weak physical gels formed within minutes [1,2].

PHOTONIC LIQUIDS –TUNING THE OPTICAL TRANSMISSON BY LOCAL ORDER

When mesoscopic variations of the dielectric constant can be neatly controlled over macroscopic distances, totally new, so called photonic properties may appear. At the core of the design of new photonic materials lies the intelligent way structures are assembled on length scales comparable to the wavelength of light. There are two main promising concepts to achieve lossless guidance and manipulation of light based on seemingly opposite principles: order or disorder. Photonic bandgap materials (PBG) are based on periodic structures predicted to inhibit light propagation completely. In the case of disorder, light cannot propagate in the material due to recurrent interference called strong Anderson localization (SAL).

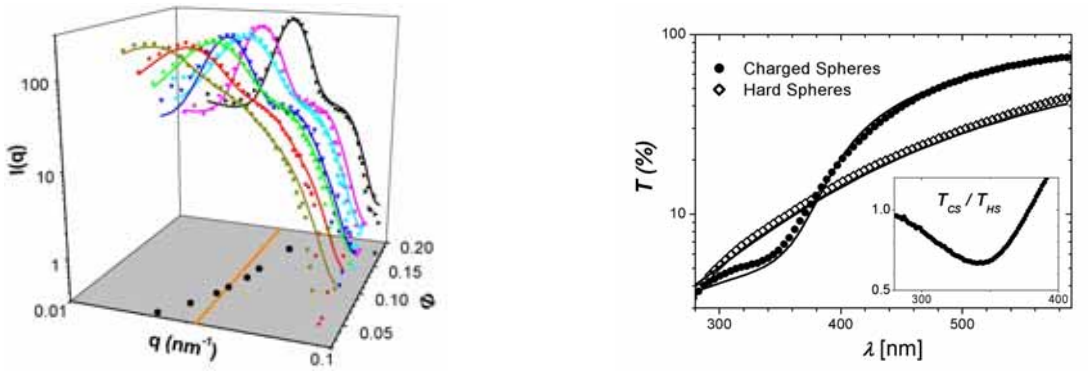

Figure 2 Left: Neutron scattering intensity for different particle densities. Right: Transmission wavelength dependence for a suspension of 240nm polystyrene particles. Experimental values for charged spheres (solid symbols) and hard spheres (open symbols), $\Phi = 9.8\%$. Cell thickness L=2mm.

Tailoring microstructures with an appropriate degree of order and disorder should result in new class of materials with unusual transport properties for light. We have recently demonstrated that short-range-order induced Bragg backscattering resonances can lead to a strong wavelength dependence of the optical transmission of colloidal liquids [3] as shown in Fig. 2. By tuning the interaction potential between the particles we are able to control the degree of order or disorder and thus explore photonic properties in a completely new regime. The unusual properties of photonic liquids could lead to interesting applications. Titanium dioxide nanoparticle based sunscreen lotions for example require efficient blocking of UV light while retaining a high transparency for visible wavelengths. As we shown in Fig. 2 photonic liquids fulfill this requirement significantly better than random particle assemblies. Photonic liquids could also be used as tuneable optical filters and switches, for example in windows that change from opaque to clear, provided particle interactions can be controlled externally. As an example for a tunable model system we will discuss preliminary results from a nanoparticle system with a temperature sensitive coating (PNIPAM).

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