Plasma Deposition of Functional Nanocomposites

F. Faupel[1*], T. Strunskus[1], O. Polonskyi[1], M. Elbahri[2,3]

[1]*Chair for Multicomponent Materials, Institute for Materials Science, Christian-Albrechts University at Kiel, Kaiserstr. 2, 24143 Kiel, Germany,*
[2]*Nanochemistry and Nanoengineering, Institute for Materials Science, CAU Kiel,*
[3]*Helmholtz-Zentrum Geesthacht, Center for Materials and Coastal Research, Institute for Polymer Research, Max-Planck-Str. 1, 21502 Geesthacht, Germany*
**ff@tf.uni-kiel*

Nanocomposite films consisting of metal nanoparticles in a dielectric organic or ceramic matrix have unique functional properties with hosts of applications. The present review demonstrates how plasma and other vapor phase deposition techniques can be employed for tailoring the nanostructure and the resulting properties. Various examples of functional nanocomposites are given, ranging from magnetic and plasmonic devices to biocompatible antibacterial coatings.

1. Introduction

Composite materials benefit from the combination of favorable matrix and filler properties. New functionalities can be obtained, in particular, if the filler size is on the nanoscale. Those materials are generally denoted as nanocomposites. Among the functional nanomaterials, nanocomposites consisting of metal nanoparticles dispersed in a dielectric matrix are of particular interest due to their novel properties offering hosts of new applications [1]. The present review focusses on work performed at the Institute for Materials Science in Kiel. For other work we refer, e.g., to [2,3] and references therein and in [1].

Most functional applications explore electronic, magnetic or dipolar interactions between nanoparticles and hence require high nanoparticle filling factors close to the percolation threshold. Sometimes even alloy nanoparticles are needed to adjust the physical properties. These requirements are difficult to fulfil with most wet chemical techniques. Therefore, vapor phase deposition was used for the fabrication of the functional nanocomposites.

2. Vapor phase deposition

Vapor phase deposition, inter alia, allows excellent control of the metallic filling factor and its depth profile as well as the incorporation of alloy nanoparticles with well-defined composition. The metallic nanoparticles typically form via self-organization during co-deposition of the metallic and matrix components due to the high cohesive energy of the metals and the low metal-matrix interaction energy. Various methods such as sputtering, plasma polymerization, and evaporation have been applied for the deposition of the matrix component, while the metallic component has mostly been sputter-deposited or evaporated. Moreover, gas aggregation cluster sources were utilized to obtain independent control of filling factor and size of the embedded nanoparticles [5]. In particular, high filling factors with resulting narrow gaps between the nanoparticles in the nm range, which give rise to strong nanoparticle-nanoparticle interaction, can be obtained at very small particle sizes.

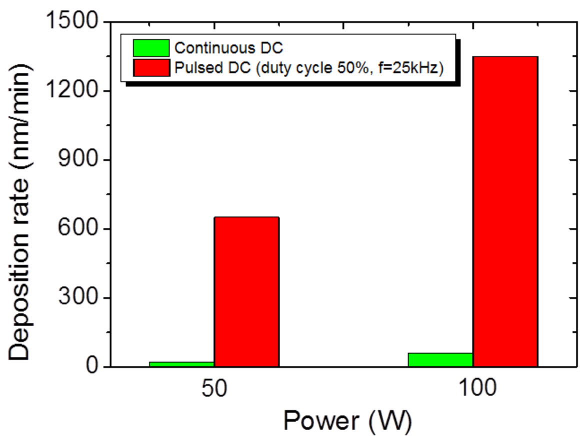

Figure 1. Deposition rate of TiO_x nanoparticles generated by a gas aggregation cluster source in combination with continuous DC magnetron sputtering (green) and pulsed DC magnetron sputtering (red) systems. Measurements were performed for different powers (50W and 100W), argon aggregation pressure 200 Pa, and optimal low amount of oxygen admixture (see [5] for details).

Nucleation of the nanoparticles in the gas aggregation cluster source, at least for reactive metals like Ti, Al, and Co, always require traces of oxygen or other reactive gases. Recently, we showed that very high deposition rates can be obtained by combining the addition of trace amounts of oxygen with pulsed

DC operation of the magnetron in a Haberland-type cluster source [5]. Fig. 1 gives an example.

3. Properties and applications

The novel properties originating from the nanoscale dimensions of particles have various applications. Recently, optical nanocomposites with tuned particle surface plasmon resonances received much attention in the new field of plasmonics. Here the freedom of design provided by plasmonic nanocomposites covers the whole range from transparent metallic conductors with excellent conductivity (see Fig. 2 and [6]) to perfect plasmonic absorbers [7].

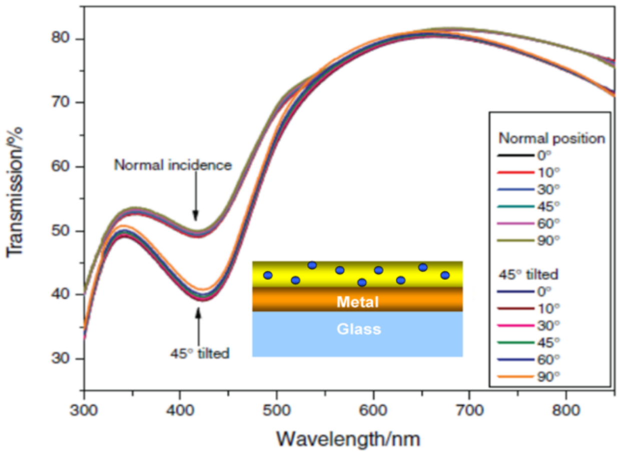

Figure 2. An omnidirectional transparent conducting-metal-based plasmonic nano-composite (see [6] for details).

Magnetic nanocomposites, where a magnetic alloy component with nanoscale dimensions is embedded in an insulating polymer or ceramic matrix, can be used as magnetic core materials for very high frequencies with eddy current cut-off frequencies well above 1 GHz [8]. Highly filled nanocomposites can be used in sensors that are based on the huge change in the electronic properties near the percolation threshold. In particular, two dimensional composites made up of 2D arrays of metallic nanoparticles embedded just below the surface of a polymer, give rise to very fast response times for volatile organic compounds [9]. Nanocomposites are also used in medical applications, e.g., in antibacterial coatings that rely on the release of Ag^+ ions. Ag^+ ions exhibit broadband antibacterial function without the problem of the development of bacterial resistance. Biocompatibility requires antibacterial coatings with a large therapeutic window in which bacteria are killed while human cells can grow [10]. This window is particularly large at surfaces. A tailored release rate can be achieved by adjusting the Ag nanoparticle filling factor and the use of barriers, e.g., deposited via plasma polymers [11].

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