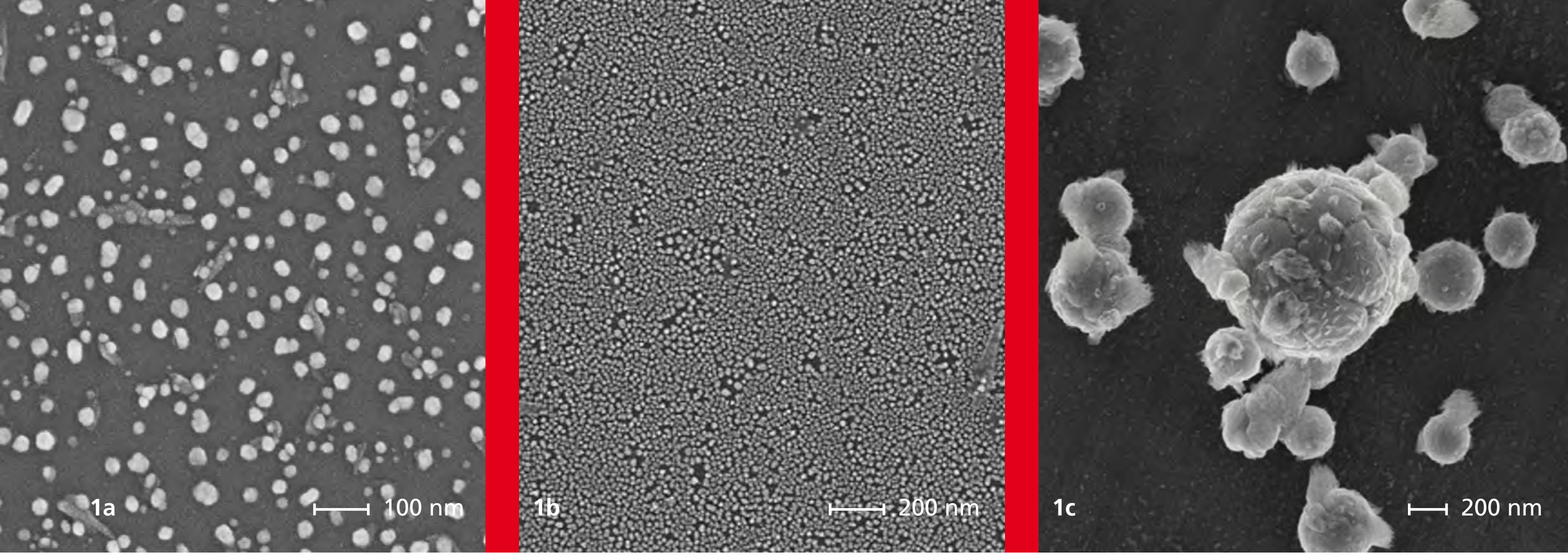
AP PLASMA OFFERS INNOVATIVE METHODS FOR APPLYING THIN NANOCOMPOSITE LAYERS

The Plasma Technology and Surfaces PLATO department at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM has developed a new, innovative method for the generation and functionalization of metallic nanoparticles and for the deposition of thin, functional nanocomposite layers using atmospheric pressure plasma (AP plasma). This work has been ongoing since mid 2011 in a close collaboration with Plasmatreat GmbH as part of a joint project funded by the Federal Ministry of Education and Research (BMBF).

Despite their small size, nanoparticles are currently playing an ever more important role in modern life. They are widely used, for example, in paints and polymer technology in the cosmetics and medical technology sectors. Besides the use of nanoparticles as additives, they can also be incorporated into polymer matrices and be deposited as nanocomposite layers. This allows a variety of surfaces to be given innovative functional features such as anti-bacterial or anti-fouling properties.

However, the manufacture, processing, and modification of nanoparticles are technologically challenging. Thus, wet chemical methods are often applied to produce metallic nanoparticles by chemical precipitation. These processes generally consist of several steps and involve a high consumption of hazardous media. Disposal of these media is as a rule complex and costly. Otherwise, metallic nanoparticles can also be produced using low pressure plasma processes. Here, the particles are generated by either a physical vapor deposition (PVD) or chemical vapor deposition (CVD) and can subsequently be deposited on substrates as thin layers. Since these processes operate at low pressures, there are relatively high costs for generating the vacuum in the process chamber. Also, the cycle times in production are relatively long. Furthermore, there are limitations regarding the size and geometry of the treated components, which restricts the industrial use of these processes significantly.

The collaborative APASI project "Development of atmospheric pressure plasma technology to deposit functional nanocomposite layers" was being carried out to address these shortcomings. It aimed to determine the suitability of pulsed, arc-like discharges at atmospheric pressure (Openair® plasma systems) for generating metallic nanoparticles, their simultaneous coating in the gas phase, and the possible deposition of thin metal-polymer nanocomposite layers. For this purpose, a special nozzle head system was designed and manufactured, which allows a controlled feeding of metallic wire electrodes (e.g. made of silver, gold, or copper) directly into the plasma volume. The pulsed arc-like discharge channels induced in the plasma are directly drawn at the electrode surface and initiate particle-forming sputter processes. The project team has succeeded in producing almost spherical metallic particles of nanoscale diameter (Fig. 1a + b). Furthermore, it was found that the size of the particles is highly dependent on the power density of the pulsed discharge channels on the metal electrodes. Hence, a customized variation of the process parame-



ters allows also submicron range particles to be produced (Fig. 1c).

Feeding a film-forming precursor into the plasma enables a direct functionalization of the nanoparticles after their generation. This was the basis for the development of a coating process in which the metal nanoparticles were incorporated into an organosilicon, plasma-polymer matrix and successfully deposited as nanocomposite layers.

The composition, morphology, and functional properties of the resulting layers were characterized in detail. For example, the inductive heating of the deposited nanocomposite layers was demonstrated. Here, the incorporated metal nanoparticles absorb the microwave energy leading to heating of the substrate surface.

The anti-bacterial properties of the nanocomposite layers were also evaluated. It was shown that the layers are effective not only against Escherichia coli bacteria, which are typically used for such tests, but also against much more resistant strains of bacteria such as Methylobacterium extorquens and Pseudomonas fluorescens. This makes the developed nanocomposite coatings highly promising for heat-exchangers and ventilation as well as air-conditioning systems.

Summary

The innovative method to produce metallic nanoparticles, developed and studied in the frame of the APASI project, is a favorable-cost and technologically simple alternative to existing wet chemical and vacuum based CVD/PVD techniques. The advantages of atmospheric pressure plasma technology, such as low space requirements, low process costs, easy integration into existing process chains, in-line capability, and localized as-needed coating, open up an array of opportunities for surface functionalization.

Acknowledgment

The aforementioned work was undertaken within the framework of the APASI project "Development of atmospheric pressure plasma technology to deposit functional nanocomposite layers". This was funded by the Federal Ministry of Education and Research (Funding program: KMU-innovativ: Nanotechnologie (NanoChance); Project term: April 1, 2011 to July 31, 2013).

Project partner

- Plasmatreat GmbH, Dr. Alexander Knospe

Industrial partners

- MAHLE Behr GmbH & Co. KG, Dr. Oliver Mamber
- Siemens AG, Dr. Florian Eder

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1a–c *Scanning electron micrographs of nanoparticles generated using atmospheric pressure plasma: (a) silver, (b) gold, (c) silver.*