# A Nano-particle Deposition System for Ceramic and Metal Coating at Room Temperature and Low Vacuum Conditions

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*A new nano-particle deposition system (NPDS) was developed for a ceramic and metal coating process. Nano- and micro-sized powders were sprayed through a supersonic nozzle at room temperature and low vacuum conditions to create ceramic and metal thin films on metal and polymer substrates without thermal damage. Ceramic titanium dioxide ($TiO_2$) powder was deposited on polyethylene terephthalate substrates and metal tin (Sn) powder was deposited on SUS substrates. Deposition images were obtained and the resulting chemical composition was measured using X-ray photoelectron spectroscopy. The test results demonstrated that the new NPDS provides a noble coating method for ceramic and metal materials.*

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## 1. Introduction

Ceramic and metal coatings have been used for different applications in mechanical, electric, electronic, and biomedical devices. There are many conventional ceramic or metal coating processes. These include sol-gel, thermal chemical vapor deposition (CVD), plasma-enhanced CVD, reactive and RF magnetron sputtering technologies, two-photon stereolithography, and aerosol deposition for ceramic coatings,[1,4] and physical vapor deposition (PVD), electrochemical deposition, and thermal and cold sprays for metal coatings.[5,7] However, the high temperature conditions required for many processes cause thermal damage and limit the range of substrates, while the wet process conditions required for sol-gel and electrochemical deposition processes limit the range of application. Among these processes, aerosol deposition and cold spray are low temperature deposition processes with similar working mechanisms. Both coating processes accelerate powders and impact them against the substrates. However, these coating processes can only be used for either ceramic or metal coatings, not both.

Low temperature coating processes are necessary for organic devices. It is also desirable to reduce the process time and simplify the fabrication process. Therefore, we analyzed aerosol deposition and cold spray processes, and combined their strengths to develop a new deposition process. Ceramic titanium dioxide ($TiO_2$) and metal tin (Sn) coatings were then deposited using the new process.

## 2. Nano-particle deposition system

### 2.1 Aerosol deposition and cold spray

Aerosol deposition was developed in Japan by Dr. Jun Akedo in the mid 1990s. Ceramic powders sprayed by a converging rectangular nozzle were deposited on a substrate in a vacuum chamber by fracturing the particles. The ceramic powders were supplied by an aerosol generator.[8]

Cold spray was developed in Russia in the early 1980s. Deposition by cold spray does not involve melting materials. Instead, the metal powders sprayed by a supersonic gas jet are deposited on a substrate by plastic deformation. The low process temperature can minimize thermal stresses and reduce substrate deformation.[9]

Both processes use micro- or nano-sized powders for deposition and nozzles for acceleration. The main differences between the two processes are the nozzle types, vacuum conditions, and methods of powder supply. New processes for metal and ceramic coatings have selected supersonic nozzles due to the velocity limitations of subsonic nozzles. Vacuum conditions make a better environment for deposition by increasing the pressure ratio between the nozzle inlet and outlet for high-speed flow, and the reduced aerodynamic drag and chemical reactions. A powder supplier and a cyclone for filtering large particles have been used. Compressed air has also been used to reduce fabrication costs.

### 2.2 System configuration

Our nano-particle deposition system (NPDS) consists of an air compressor, powder supplier, vacuum chamber, vacuum pump, and controllers as shown in Fig. 1. The vacuum chamber is equipped with a supersonic nozzle, two-axis stage, and substrate holder. A compressor supplies 0.6 MPa of air flow, which carries the particles from the powder supplier to the nozzle. The supersonic nozzle accelerates the particles, which impact against the substrate. The tilting part can be used to change the deposition angle while the two-axis stage moves the substrate to generate patterns such as rectangular

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and crossing lines. Vacuum conditions were used for the deposition environment to increase the flow speed and reduce chemical reactions. Detailed experimental parameters are listed in Table 1.

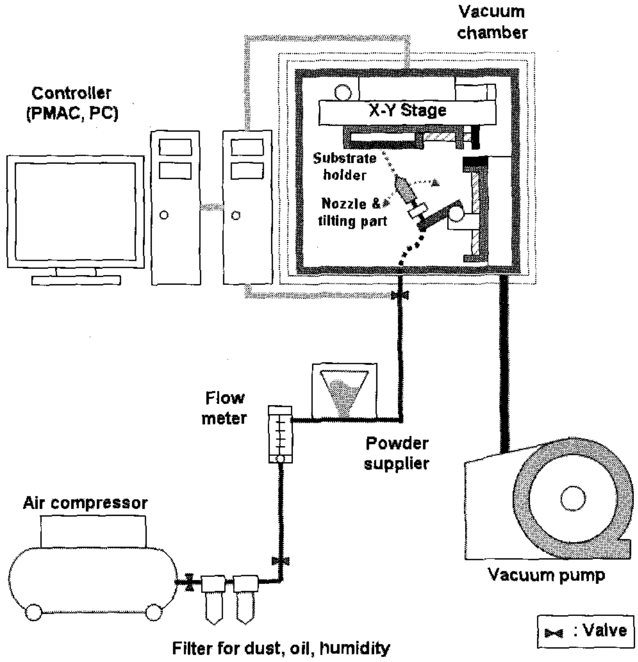


Fig. 1 System configuration of the NPDS

Table 1 Experimental parameters for the NPDS

| Parameters | Values |
|---|---|
| Stage speed (mm/sec) | 0.05 |
| Nozzle neck size (mm) | 0.9 |
| Distance between a substrate and a nozzle (mm) | 1.5 |
| Compressor pressure (MPa) | 0.7 |
| Chamber pressure (MPa) | 0.02 ~ 0.03 |
| Flow rate (liter/min) | 8 ~ 9 |
| Deposited shape | 5 mm × 5 mm |
| Deposition particles | $TiO_2$, Sn |
| Substrate materials | PET, SUS |

## 3. Experimental Results

Ceramic and metal particles were deposited using the developed NPDS. Ceramic $TiO_2$ particles were selected because they are widely used for various applications, such as corrosion protection, solar cells, self-cleaning surfaces, photocatalysis, and capacitors.[3] Metal Sn particles were selected because they are easy to deposit; they are used on SUS for wear protection.[10] For each film, deposition images were obtained and the resulting chemical composition was measured.

### 3.1 Ceramic deposition results - $TiO_2$

Thin films were fabricated on polymer substrates using $TiO_2$ powder manufactured by Sigma-Aldrich. The diameter of the $TiO_2$ powder was less than 5 μm. The polymer substrate was polyethylene terephthalate (PET). The particles were deposited on a 5 × 5 $mm^2$ rectangular area, as shown in Fig. 2.

The chemical components were detected using an energy dispersive X-ray (EDX) analysis and X-ray photoelectron spectroscopy (XPS).

The results are shown in Fig. 3. The $TiO_2$ peaks in the figure confirmed that successful $TiO_2$ deposition occurred.

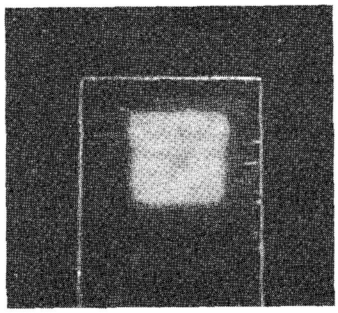

Fig. 2 $TiO_2$ deposition on a 5 × 5 $mm^2$ PET surface

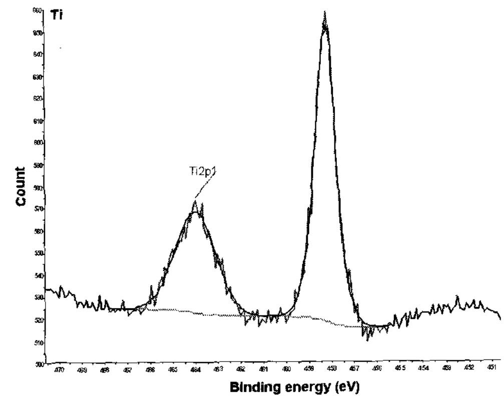


Fig. 3 $TiO_2$ peaks in the XPS results for the PET substrate after deposition

### 3.2 Metal deposition results - Sn

The Sn powder was manufactured by Sigma-Aldrich. It was filtered with 100 meshes and then deposited on a SUS plate. Optical microscope images of the SUS plate and the area with Sn deposits are shown in Fig. 4 to indicate the difference between non-deposited areas and deposited areas. The Sn component was detected by an XPS analysis, as shown in Fig. 5.

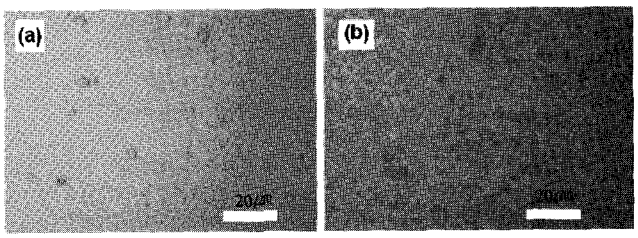


Fig. 4 Optical microscope images of a SUS plate (a) without deposits and (b) with Sn deposits

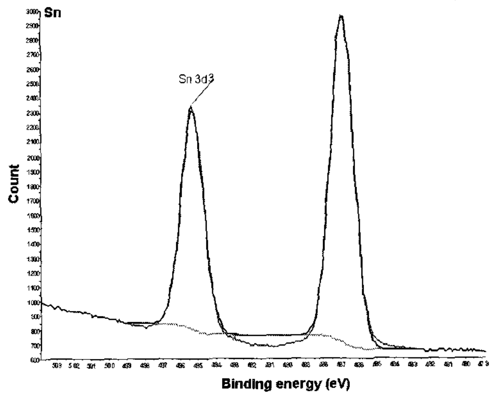


Fig. 5 Sn peaks in the XPS results for the SUS plate after deposition

## 4. Conclusions

We analyzed conventional aerosol deposition and cold spray coating processes and developed a new process for low-temperature conditions. Ceramic titanium dioxide ($TiO_2$) thin films on PET substrates and metal tin (Sn) thin films on SUS substrates were successfully deposited using our new nano-particle deposition system. There was no thermal damage because the processes were performed at room temperature, which makes it possible to use this technique to fabricate organic devices. The ability to create ceramic and metal deposits with one process can be used to simplify manufacturing processes in industry and shorten the process time.

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