



Role of TiO₂ nanoparticles in the dry deposition of NiO micro-sized particles at room temperature

Hyungsub Kim^a, Seungkyu Yang^a, Rajendra C. Pawar^a, Sung-Hoon Ahn^b, Caroline Sunyong Lee^{a,*}

^aDepartment of Materials Engineering, Hanyang University, Gyeonggi-do 426-791, Republic of Korea

^bDepartment of Mechanical & Aerospace Engineering, Seoul National University, Seoul 151-742, Republic of Korea

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Abstract

A room-temperature dry-deposition method with TiO₂ powder was used to deposit NiO particles onto a fluorine-doped tin oxide (FTO) substrate. Initially, in the absence of TiO₂ powder, we observed that the NiO particles did not adhere to the substrate; however, the addition of TiO₂ particles facilitated NiO deposition. The volume percentage (vol%) deposition of NiO particles increased with the TiO₂ particle concentration. The inability of the NiO particles to adhere to the FTO substrate was attributed to the absence of deformation and fragmentation in the substrate. This is related to the lower hardness of the FTO substrate, compared with that of the NiO particles. However, the addition of the TiO₂ particles at different vol% during NiO deposition induced deposition, possibly due to the lower hardness of the TiO₂ particles compared with the FTO substrate. The minimum TiO₂ fraction that enabled NiO powder deposition was ~4.8 vol%. Microstructural analysis revealed that TiO₂ powder agglomerates tended to break up as the NiO particles impacted the substrate surface, creating a “deposition complement” from the excess kinetic energy. The deposition mechanism was investigated using microstructural analysis, electron probe microanalysis, and Brunauer–Emmett–Teller (BET) measurements; the results confirmed the influence of the TiO₂ powders on NiO powder deposition, specifically, an improvement in the adhesion and density of the NiO powder and a decrease in the surface roughness of the coating. Therefore, we demonstrated NiO deposition with TiO₂ particles at room temperature, providing potential applications to the supercapacitor and battery industries.

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1. Introduction

Dry deposition processes, including nanoparticle deposition system (NPDS), cold spray deposition, and aerosol deposition method (ADM), are well known to be low energy consumption processes contrary to conventional deposition processes such as sputtering and ion beam deposition, which are expensive and high energy consuming process due to high vacuum condition and relatively low deposition rate [1].

Cold spray deposition accelerates micro-sized particles using a high-pressure gas, without particle melting before impact. This process uses mainly metallic powders that are accelerated to speeds in excess of supersonic speeds prior to

being deposited on a substrate, and has been used to deposit cermets and metal matrix composites through a converging/diverging nozzle [2]. The aerosol deposition method is a room-temperature process, which uses an aerosol mixture of mainly nano-sized ceramic particles and a carrier gas. The aerosol with particles is accelerated by the carrier gas through a converging nozzle, and the kinetic energy of the particles is used for bonding during impact [3]. The main advantage of the ADM and NPDS methods is that they can be carried out at low temperature, minimizing the thermal damage to the substrate.

The NPDS is a recently developed dry deposition system, capable of depositing both nano- and sub-micron-sized metal and ceramic particles at room temperature. Using the NPDS, particles are accelerated at supersonic velocities through a converging/diverging nozzle, using compressed air as the carrier gas. The major difference between NPDS and the

*Corresponding author. Tel.: +82 31 400 5221; fax: +82 31 436 8146.

E-mail address: sunyonglee@hanyang.ac.kr (C.S. Lee).

traditional ADM is the high velocity of the powders with the NPDS process. Furthermore, the powder deposition occurs at room temperature, which is considerably lower than the temperatures required for cold-spray deposition [1,4]. Additionally, NPDS requires low vacuum and pressurized gas.

Chun et al. compared the amount of energy consumption among cold-spray, ADM, and NPD processes, based on the gas pressure and level of vacuum for the deposition chamber (i.e., the major energy consumption sources) [1]. They explained that the cold spray uses a high-pressure gas, while ADM uses a low-pressure gas and medium vacuum. In contrast, the NPDS uses low vacuum for the deposition chamber and a low-pressure gas. Thus, it was found that the cold-spray consumed the most amount of energy, while the NPDS consumed the least amount of energy among the three processes. Therefore, the total energy consumption using NPDS, given the chamber pressure and the carrier gas pressure, was roughly 1/6 of ADM and 1/2 of cold spray deposition, [1]. Hence, under similar experimental conditions (nozzle throat size, gas, and temperature), NPDS appears to be the most energy-efficient dry deposition method.

Based on the aforementioned advantages, various metal and ceramic materials, such as Cu, Ni, TiO₂, and Al₂O₃, have been used to coat metals, ceramics, and polymer substrates using the NPDS [4–8]. In the literature, the NPDS for single-component material deposition has been studied experimentally and numerically. These studies indicated that particle fragmentation occurs upon impact with the substrate during NPDS;

Table 1
Composition of different volume mixtures of NiO and TiO₂ powders.

NiO vol%:TiO ₂ vol%
TiO ₂ 100%
33.3%:66.7%
66.7%:33.3%
80.0%:20.0%
90.9%:9.1%
95.2%:4.8%
96.2%:3.8%
98.0%:2.0%
NiO 100%

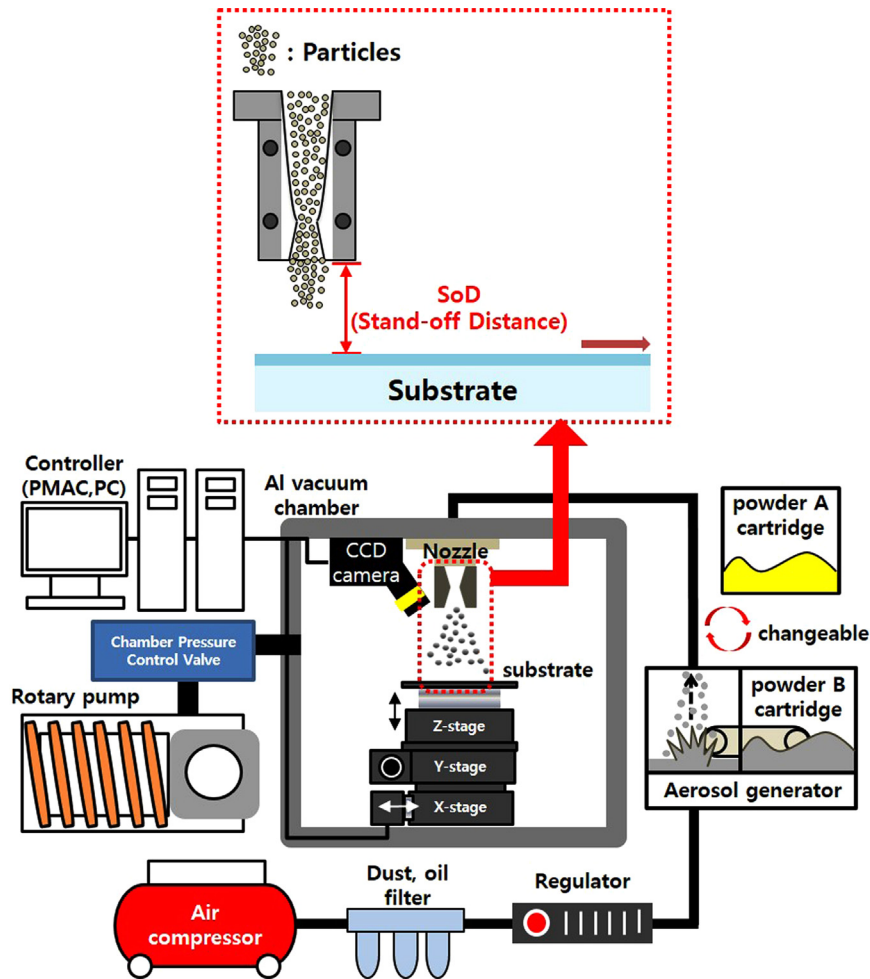


Fig. 1. Schematic diagram of the nanoparticle deposition system (NPDS).

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