



Original Research Paper

Preparation of nano-silver iodide powders and their efficiency as ice-nucleating agent in weather modification

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ABSTRACT

Nano-meter-sized silver iodide (n-AgI) powders were prepared by precipitation method at room temperature. The size, structure and specific surface area of the n-AgI powders were characterized by transmission electron microscopy, X-ray diffraction, X-ray photoelectron spectroscopy and Brunner–Emmett–Teller, respectively. The n-AgI powders obtained have an average particle size of ~90 nm, similar surface lattice structure with ice crystal (H₂O) and larger specific surface area than conventional micro-meter-sized silver iodide (m-AgI) powders. The cloud chamber experiment revealed that the n-AgI powders exhibit higher ice nucleation efficiency and higher threshold temperature value than conventional m-AgI powders.

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1. Introduction

Silver iodide (AgI) is a well-known ice-nucleating agent and has been used widely in the field of weather modification. The main reason of AgI as artificial ice nuclei is generally believed to be due to the high similarity of its lattice constants with those of ice crystal (H₂O) [1–3]. The investigation of Turnbull and Vonnegut pointed out that the high nucleation ability of AgI originates from the ability in the epitaxy of adsorbed water molecules on AgI besides the similarity in its crystalline structure with ice crystal [4]. The careful study of Zettlemoyer et al. on the adsorption of water on AgI revealed that AgI is primarily hydrophobic with about 25% hydrophilic sites [5]. These sites represent isolated patches of oxide, which offer a higher sticking coefficient for water molecules and are more conducive to ice nucleation. Hence, much effort has been made in the past to improve the ice-nucleating ability of AgI by different ways [6–9]. On the other hand, the surface structure and physical and chemical properties of AgI can be significantly altered when their particle size is reduced to nano-meter-scale (e.g., <100 nm). However, it is noted that all the previous investigations were carried out on conventional micro-meter-sized AgI (m-AgI) and there was no report about the application of nano-meter-sized AgI (n-AgI) in weather modification. In this paper, the n-AgI powders were prepared by a precipitation method. The size, structure and specific surface area of the n-AgI powders were char-

acterized and their efficiency as artificial ice nuclei was investigated.

2. Experimental

The n-AgI powders were prepared by using a precipitation method [10]. 0.1 mol/L AgNO₃ and 0.1 mol/L KI aqueous solutions containing different complexing agents and dispersants were prepared, respectively. The AgNO₃ solution was dropped into the KI solution through several thin syringe needles with stirring at room temperature. After placing for 1 h, the n-AgI precipitations formed in the solution were filtered and then washed repetitiously with deionized water to remove the remains of the chemical reactions such as KNO₃. Finally, the n-AgI precipitations were dried in the vacuum dry box at 135 °C. By this drying process, some small amount of the α-AgI type precipitations can be transferred completely to the β-AgI type ones.

The morphology and structure of the n-AgI powders were observed by using transmission electron microscopy (TEM, JEM-2100F), X-ray diffraction (XRD, D/MAX 2500PC) and X-ray photoelectron spectroscopy (XPS, ESCALAB Mk II). The specific surface area of the n-AgI powders was measured by Brunner–Emmett–Teller (BET, SSA-3600).

The ice nucleation efficiency of the n-AgI powders was examined in the cloud chamber at different temperatures. The air samples containing the n-AgI powders were obtained by exploding the 37-type cannonballs of 30 mm in outer diameter and 70 mm in body length in a room reinforced with thick steel plates of ~3 m

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in diameter and ~ 3 m height. The air samples were taken by an glass injector of 40 mm in diameter and 300 mm in length and then injected immediately into the cloud chamber of 0.2 m in diameter and 0.69 m in height with the given volume ratio of the air sample and the cloud chamber. The ice nuclei formed when the n-Agl powders in the air sample meet the cold cloud in the cloud chamber and fell down on the cold glass piece of 15 mm in width and 50 mm in length on the bottom of the cloud chamber. The nucleation rate (the number of ice nucleation per unit weight AgI) was calculated by counting the number of the ice nuclei formed on the cold glass pieces. The ice crystals or ice nuclei on the glass pieces were observed by using an optical microscope (Nikon, ECLIPSE-E200). The data of the ice nucleation rate were taken from 4 glass pieces and at least 10 fields of vision on each glass piece.

3. Results and discussion

3.1. Size and structure of n-Agl powders

Fig. 1 shows a typical TEM image of the n-Agl powders and the corresponding diffraction pattern is presented in the inset. It can be seen that the particle size of the n-Agl powders is uniform although they form aggregates due to their high adsorption ability. The statistical determination on the TEM images (more than 10 images) shows that the particle size of the n-Agl powders varies in a range of 20–150 nm and has an average value of ~ 90 nm.

Fig. 2(a) and (b) shows the X-ray diffraction patterns of the n-Agl and the conventional commercial m-Agl powders (~ 1 μm in the average particle size). It can be seen that the n-Agl powders have the typical β -AgI crystalline structure. Generally, the β -AgI exists in two types of crystalline structure, i.e. the hexagonal and cubical structures. According to the standard PDF card, the crystalline structure of the hexagonal β -AgI is closer to that of ice (H_2O), which is shown in Table 1. According to the X-ray diffraction data, the lattice constants a and c of the n-Agl and m-Agl powders were calculated and shown in Table 1. Obviously, the lattice constants a and c of the n-Agl powders are closer to the corresponding lattice constants of ice crystal than those of the m-Agl powders. This suggests that the nucleation barrier of ice crystal on the n-Agl powders would be lower than that on the m-Agl powders because of the smaller mismatch in the atomic arrangement between ice crystal and the n-Agl. Therefore, the n-Agl powders would be the better candidate as the ice-nucleating agent in weather modification in terms of the structural consistency.

Fig. 3(a–d) shows the XPS spectra of the Ag3d, I3d and C1s regions of the n-Agl and the C1s region of the m-Agl. From the spectra of the n-Agl, the typical peaks (core levels) associated with Ag3d, I3d and C1s are observed. For the n-Agl powders, the Ag3d re-

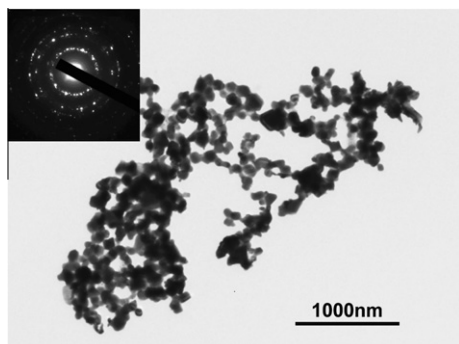


Fig. 1. TEM image of the n-Agl powders and the corresponding diffraction pattern in the inset.

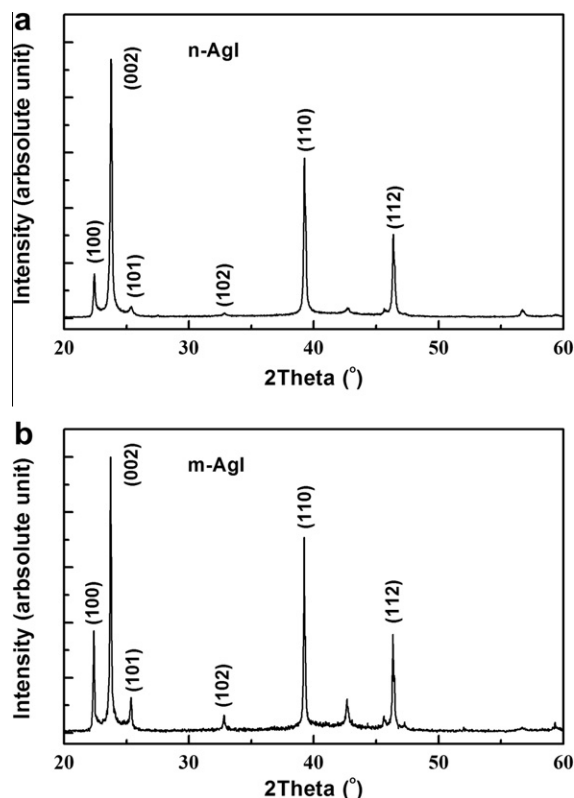


Fig. 2. X-ray diffraction patterns of the n-Agl powders (a) and the m-Agl powders (b).

gion shows two peaks located at 367.8 and 373.9 eV, respectively. The Ag3d_{5/2} peak at 367.8 eV is consistent with the formation of AgI [11]. The I3d spectrum also shows two peaks, one is peaked at 619.2 eV, another is peaked at 630.6 eV, which assign to I^+ of AgI [11]. Fig. 3(c) shows the C1s high-resolution spectrum obtained from the n-Agl particles. It can be resolved into three peaks located at 284.6, 285.1 and 288.5 eV, respectively. They are all attributed to the hydrocarbons (C–C and C–H) [12] and the C=O bonds [11]. These three peaks all come from the substance adsorbed on the surface of the n-Agl particles because the n-Agl powders have high adsorption ability. In order to compare the adsorption ability of the n-Agl and m-Agl powders, the C1s region of the m-Agl powders was also shown in Fig. 3(d). From the spectra, it can be seen that only one peak was detected from the m-Agl powder seated at 284.6 eV which attributes to the hydrocarbons. It can be concluded that as compared with the m-Agl powders, the n-Agl powders have higher adsorption ability. During the operation of artificial rainfall, this high absorption ability allows the n-Agl powders to adsorb more water molecules in wet atmosphere and thus improves their efficiency as the ice-nucleating agent.

3.2. Specific surface area of the n-Agl powders

The values of the specific surface area of the n-Agl powders are given in Table 2. In the case of the same quality, the specific surface area of the n-Agl powders is ~ 5.7 times of that of the m-Agl powders. The significant increase in the specific surface area of the n-Agl powders as compared with that of the m-Agl powders would be an indication that the n-Agl powders have better adsorption ability to water and higher surface chemical activation. Therefore, in the same experimental condition, the n-Agl powders would exhibit higher ice nucleation efficiency than the m-Agl powders.

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