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学位論文紹介
Doctoral Thesis Introduction

Study on Hollow Silica Nanoparticle Composite Materials and Their Dielectric Properties

中空シリカナノ粒子複合材料の誘電特性に関する研究

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1. Introduction

This study explored the factors that affect the dielectric properties of nano-sized hollow fillers. It discussed the effects of the shell structure of Hollow Silica NanoParticles (HSNPs) and their water adsorption characteristics on the dielectric properties of composite materials.

2. Main research results

2.1 Effect of the shell structure of hollow silica nanoparticles on the dielectric constant

HNSPs were synthesized by the $CaCO_3$ templates method, which can be shown in **Fig. 1**(a). Ultrasonic irradiation during hydrolysis and polycondensation of Tetraethyl orthosilicate (TEOS) can change the shell density. The amount of TEOS used controlled the shell thickness. These hollow particle fillers combined with polyimide (PI) to prepare thin films for dielectric constant measurements. It confirmed that HSNPs with a thinner and lower density of shell can reduce the dielectric constant of composite. The same results could be obtained even if the particle size of the hollow particles was changed, as shown in Fig. 1(b) and Fig. 1(c).

2.2 Effect of adsorbed water of hollow silica nanoparticles on dielectric properties

HSNPs with different hygroscopic properties were prepared by the polyacrylic acid (PAA) emulsion template method (**Fig. 2**(a)), and the dielectric properties of these particles were evaluated. The results showed that the higher cover area of PAA in HSNPs will significantly improve its hygroscopic properties (Fig. 2(b)), and the increase in the water content of the particles will significantly increase the dielectric loss (Fig. 2(c)).

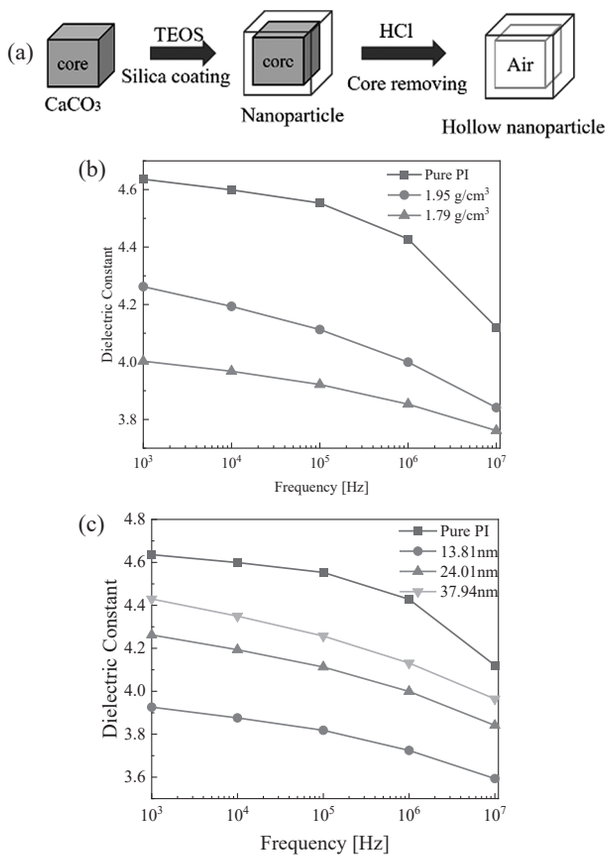

Fig. 1 (a) Synthesis of hollow nanoparticles. (b) Effect of particle shell density on the dielectric constant of PI composites. (c) Effect of particle shell thickness on the dielectric constant of PI composites

3. Future research directions

This study explored the factors that affect the dielectric properties of nano hollow particles and pointed out the direction for preparing high-performance, low dielectric constant nano hollow fillers. These results can provide a theoretical basis and technical support for the design and optimization of new low-dielectric materials, especially in the fields of high-frequency electronic components, integrated circuit (IC) packaging, and 6 G communications.

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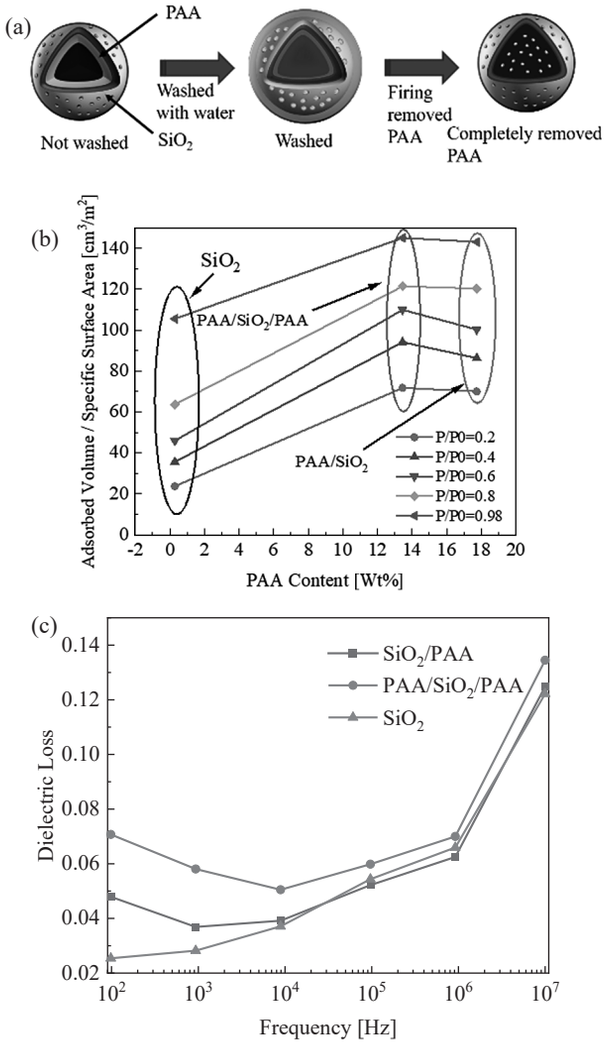

Fig. 2 (a) Shell structure change of composite HSNPs. (b) Water vapor adsorption capacity of different shell structures. (c) Influence of different shell structures on dielectric loss at 40% relative humidity

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List of Publications

[1] Q. Wen, I. Tanahashi, K. Ishii, M. Fuji. Hollow silica particles synthesized by calcite nanoparticle template method, J. Soc. Powder Technol., Japan 61 (2024) 672-679.

[2] Q. Wen, K. Ishii, M. Fuji. Preparation of hollow silica nanoparticles with polyacrylic acid and their moisture sorption properties, Coatings 14 (2024) 829.

[3] Q.Wen, F. Tanahashi, M. Fuji. Evaluating surface smoothness of composite film of well-dispersed silica particles, Surf. Eng. 38 (2022) 786-796.

[4] Q. Wen, K. Ishii, F. Tanahashi, M. Fuji. The effect of hollow silica nanoparticle shell structure on the dielectric properties of hollow silica nanoparticle/polyimide composite films, Adv. Powder Technol. 36 (2025) 104854.

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