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Rheology of Plasticized Screen Printing Pastes Based on $BaTiO_3$ Nanopowder

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Abstract:
This paper represents the rheology of screen printing pastes based on $BaTiO_3$ nanopowder. It is found that the pastes are shear thickened fluids with subsequent shear thinning under high shear rates. Different concentrations of plasticizer in organic binder lead to various conformations of ethyl cellulose molecules that influence the type of adsorption between polymer molecules and nanoparticles. The flow loop shows intervals of shear rate corresponding to rheopexy, pseudoplasticity and thixotropy. The appearance of rheopexy indicates that the added amount of plasticizer may be insufficient to bind the majority of free functional groups of the polymer and the remaining groups are bound with $BaTiO_3$ nanoparticles forming a strong structural network. But in the case of pseudoplastic structures, the polymer molecule exists in the conformation where almost all free functional groups are bound with the nanoparticle surfaces. The pseudoplastic properties of the system are caused by the structural polymer-polymer links. SEM and optical profilometry of the obtained films shows that plasticization lead to the formation of thin (less than 1 μm) smooth (Ra is equal to the size of individual $BaTiO_3$ nanoparticle) prints.

Key words:
Paste, rheology, rheopexy, pseudoplasticity, thixotropy.

1 INTRODUCTION

Pastes based on oxide particles are used in various fields of industry, particularly in formation of printed electronic products such as MLCC [1–3], SOFC [4–8], and DSSC [9]. One of the widely used methods of the particulate film's formation is the screen printing because of its low cost, rapidity and the possibility to obtain smooth uniform high dense, structured layers in one step. During the printing process the paste passes through the mesh and forms the film on a substrate. The viscosity of pastes and their responses on shear stresses influence the films quality. Thorough understanding of the rheology of screen printing pastes is important to get minimal thickness and roughness of printed films. Traditional screen printing pastes are generally required to be shear thinned, thixotropic over a definite time scale and shear rate, stable for screen/shelf-life and low solvent evaporation [7, 10, 11]. Therefore, terpineol [12–19] and its derivatives [15, 18, 20–23] are used as a solvent, ethyl cellulose (EthCell) as an polymeric binder [12, 13–19, 24–30] because of their ability to form thixotropic systems with suspensions of particles of various origin [31]. Such requirements can be met by optimizing the formulation of pastes. For correct design of a paste, the stable and well dispersed colloidal suspension must be prepared [6, 32, 33].

Screen printing pastes based on $BaTiO_3$ powder are the initial materials for dielectric layers in multilayered ceramic capacitors. Barium titanate is used extensively as the dielectric in ceramic capacitors, particularly due to its high dielectric constant and low loss characteristics [1, 34, 35]. Because of MLCC miniaturization trend, the compositions of pastes based on $BaTiO_3$ nanopowder with mean particles size about of 20–25 nm were optimized [36–38]. It is known that EthCell is a kind of water-insoluble cellulose ether with favorable mechanical properties, relatively low cost and good film-forming performance [39, 40]. However, due to the rigid inter-chain hydrogen bonds of EthCell and the bulkiness of glucose units, EthCell films have relatively high glass transition temperature and brittle nature, thus their application in formation of thin layers is limited. To improve the flexibility, thermal stability and processability of EthCell films, plasticizers are necessary additives [39, 41]. Long chain esters, such as phtha-

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