Chemical and Physical Analysis of Acetate-Oxide Sol-Gel Processing Routes for the Y-Ba-Cu-O System

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Abstract. The formation of three sols by fluorine-free aqueous and non-aqueous processes were analyzed and modified to vary the chemical properties of the sols (inks) to suit a variety of deposition processes such as dip-coating and ink-jet coating/printing. Ink-jet printing requires high wetting angles; choosing the right complexing agents to modify the ink allows the formation of droplets with high wetting angles on the surface. Dip-coating and ink-jet coating require low wetting angles; additives added to the sols reduce wetting angles to $10^\circ$ and allow complete coverage of the substrate surface. The deposition theories and requirements are briefly discussed, as are some initial tests with the printing and converting of the developed superconducting inks.

Keywords: YBCO, Sol-Gel Synthesis, Non-fluorine, Superconductor, Ink-Jet Printing, Ink-Jet, Ink-Jet Coating, Ceramic Coatings

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Introduction

Over the past few years YBa$_2$Cu$_3$O$_7$-δ (YBCO) thin film formation for the development of coated conductors has proven to be costly. High vacuum deposition processes create films with high critical current densities but come with high processing costs as well as restricted scalability [1].

There has been an increasing shift towards chemical solution deposition (CSD) processes, where deposition occurs in ambient conditions and therefore costs are considerably less than for vacuum processes. Of the main deposition processes of sol-gel technology, spin coating [2] and dip-coating [3] are the front runners. With the former process restricted to small areas, more groups worldwide are moving towards the dip-coating process as it opens up the possibility for a reel to reel system and therefore long length coated conductors.

In this paper we report results of Y-Ba-Cu-O sol development and formation for the dip-coating process as well as the newly devised ink-jet deposition processes. The ink-jet deposition processes offer added advantages to dip-coating. The first deposition process, that of ink-jet coating, mimics the dip-coating procedure. Here, ink droplets are deposited side by side to coat the entire surface of the substrate. The advantages of this process are that the thickness of the coating can be controlled by the degree of droplet overlap, and the substrate is coated on just one side therefore facilitating the conversion to the final oxide compound.

The second deposition process, ink-jet printing, offers the ability to deposit complex shapes and lines for the rapid prototyping of devices and structures by inkjet printing. One of the greatest advantages this offers is the ability to rapidly create and test three-dimensional structures designed for low alternating current (a.c.) losses [4]. However, in order to understand what is required from the Y-Ba-Cu-O sols to be formulated, we must take a look at the basic theory behind each deposition process.

In the dip-coating process, rheological properties of the sols have a large effect on the thickness, $h$, of the coating developed. Equation (1) shows the balance between the viscous drag ($\propto \eta U / h$) and gravitational ($\rho gh$) forces on unit area of sol during deposition by dip coating. It summarizes the parameters involved during the deposition of sols on surfaces during dip coating, where $c_1$ is a constant and $h$ is governed by the viscosity of the sol, $\eta$, the speed of withdrawal of the substrate from the ink, $U$, the density of the sol, $\rho$ and the acceleration due to gravity, $g$ [5]. Other than varying the withdrawal speed, little can be done with the deposition parameters to vary the thickness of the coating: it becomes sol specific.

$$h = c_1 \sqrt{((\eta U) / (\rho g))}$$ (1)

With deposition processes, such as dip-coating and ink-jet printing, ink properties not only influence the thickness of coating but also the coverage and connectivity of the droplets deposited on the surface, and the resolution of the printed pattern. An understanding of the wetting of the ink on the surface is necessary as it defines these parameters.

The adhesion energy, $E_{Ad}$, of a droplet deposited on the surface indicates that surface tension of the inks, $\gamma_{LA}$, plays a major role in the wetting or contact angle, $\Omega_c$, created between the liquid and the surface. The solid-liquid interface of a drop on the surface of a substrate can be quantified by the contact angle, $\Omega_c$, created between the surface and the droplet where $\gamma_{LA}$ is the surface tension of the droplet at the liquid-air interface, $\gamma_{SL}$ is the surface tension at the solid-liquid interface and $F_{SA}$ is the force exerted onto the substrate by the droplet during spreading, Fig. 1. The relevant variables for this process are summarized in Eq. (2) [6].

$$E_{Ad} = \gamma_{LA}(1 + \cos(\Omega_c))$$ (2)

The wetting angle is the key factor that needs to be adjusted to suit different deposition methods. For dip-coating and ink-jet coating, it is necessary to have high wetting on the surface of the substrate (in an ideal situation $\Omega_c = 0^\circ$) therefore surface tension must be as low as possible. For ink-jet printing, the optimum resolution would be obtained for minimum surface wetting, and hence the surface tension should be maximized.

Figure 2 illustrates the droplet profiles as deposited by ink-jet printing. The wetting angles created between the substrate and the ink have a large effect on the profiles. With angles close to zero, the velocity a droplet attains before interaction with the surface may cause...