Electric current during electrophoretic deposition of conjugated polymer: A test with various electrode distances

Kazuya Tada *, Mitsuyoshi Onoda
Division of Electrical Engineering, University of Hyogo, 2167 Shosha, Himeji, Hyogo 671-2280, Japan

Abstract

The transient current during electrophoretic deposition of conjugated polymer is a promising tool for exploring the basic process of the deposition. In this paper, it has been shown that the transit times obtained from various electrode distances give almost identical electrophoretic mobility. The result shown here seems to support our interpretation of the transient current profile during electrophoretic deposition that it reflects the drift motion of colloidal particles in suspension driven by the electric field.

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Keywords: conjugated polymer; film deposition; electrophoretic deposition; electric current; mobility

1. Introduction

Conjugated polymers have attracted much attention of researchers as a class of printable semiconductors for large-area electronic devices such as light-emitting devices, field-effect transistors and photocells. A number of coating methods including spin-coating, ink-jet printing and screen printing have been studied to realize large-scale production of printed electronic devices using conjugated polymers and their composites. [1] Although the electrophoretic deposition is a traditional coating technology, [2,3] it was proposed as a method to obtain nanostructured conjugated polymer films relatively recently. [4-6] One of the most important advantages of this method is that material efficiency, i.e. the recovery rate of conjugated polymer dispersed in the suspension onto the substrate, is relatively high, especially in contrast to spin-coating technique. [7]

Understanding the basic processes of electrophoretic deposition including the properties of colloidal particles must be a key to improve the deposition technology. We are trying to explore the basic process of electrophoretic deposition by measuring the transient electric current during deposition. It has been reported that the electric current profiles during the electrophoretic deposition in thin slab vessels show clear break corresponding to the drift transport of colloidal particles, when the polymer concentration is sufficiently high. [8] Recently, it has been
clarified that the transient current profiles for different applied voltages show a scaling behavior. [9, 10] That is, the dimensionless plots of current profiles for different voltages overlap one another. This behavior is similar to that frequently observed in the transient photocurrent of amorphous photoconductors, although the mechanisms of current for the two cases are quite different each other. [11-13]

However, series of studies mentioned above have been conducted by using single electrode distance and it is obviously needed to check how current profile changes when the electrode distance changes. Here, we show that the transit times obtained from various electrode distances give almost identical electrophoretic mobility.

2. Experimental

The molecular structure of the conjugated polymer used in this study, Poly[(9,9-dioctyl-2,7-divinylenefluorenylene)-alt-{2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylene}] (PDOF-MEHPV) is shown in Fig. 1(a). PDOF-MEHPV used in this study was purchased from American Dye Source (Canada) and used as received. A 1.0 g/l suspension of PDOF-MEHPV was made by mixing the equivalent volumes of the toluene solution of the polymer (2.0 g/l) and acetonitrile.

The electrophoretic deposition was carried out in thin slab vessels consisting of two ITO-coated glass plates with silicone rubber spacer. [8] The scheme of the thin slab vessels is shown in Fig. 1(b). The thickness of the silicone rubber spacer, or the electrode distance, was changed from 0.5 to 5 mm. The deposition area was approximately 1.0 cm × 1.5 cm. All experiments were carried out in air at room temperature. The electrophoretic deposition of PDOF-MEHPV occurs on the positively biased electrode, indicating that the colloidal particles of PDOF-MEHPV are negatively charged in the suspension.

The electric current measured by using a Keithley 6517A electrometer was recorded by a PC at a rate of approximately 10 readings per second. The voltage between the deposition and counter electrodes was supplied by the internal high voltage power source of the electrometer. The values of electric field mentioned in this paper are the nominal values, i.e. the applied voltage \( V \) divided by the electrode distance \( d \). All experiments were carried out in air at room temperature.

3. Results and Discussion

Figure 2(a) shows the transient currents during the electrophoretic deposition in thin slab vessels with various electrode distances at a constant electric field 600 V/cm. Double logarithmic plot is employed to emphasize the
plateaus and breaks. Relatively distinct plateau and break can be observed in each current profile except for \( d = 0.5 \) mm. Since the nominal electric field is constant, the applied voltage itself is lower for shorter electrode distance, making the voltage drops nearby the electrodes, which may have considerable temporal variation, nonnegligible. This presumably make the current profile for \( d = 0.5 \) mm featureless.

![Figure 2](image.png)

**Figure 2** Current profiles during electrophoretic deposition with various electrode distances at (a) 600, (b) 300 and (c) 200 V/cm. (d) shows the relationship between applied electric field and the current at plateau for \( d = 5 \) mm.

As previously reported, the current significantly increases with increased polymer concentration in suspensions. [8] The current at the plateau is almost identical. Judging from these observations, it can be concluded that the current reflects the motion of colloidal particles of the polymer in the suspension driven by the electric field, and the break corresponds to the arrival of the particles which initially located near the negative electrode at the positive electrode, or the transit time \( \tau \). Obviously, shorter electrode distance gives the shorter transit time. Similar features can be found in Fig. 2(b) and (c), which show the current profiles recorded at 300 and 200 V/cm, respectively. It is also confirmed that Ohm’s law holds for the current at plateau, as shown in Fig. 2(d).

As shown in Fig. 3(a), the transit time is proportional to the electrode distance regardless of the applied electric field. The transit time-reciprocal electric field characteristics also show the proportional relationship, as shown in Fig. 3(b). These features suggest that all of the current profiles give almost single electrophoretic mobility, as is most strikingly illustrated by the velocity \( (d/\tau) \) – electric field plot indicated in Fig. 3(c), in which all lines overlap one another. The slope of the proportional fitting was obtained to calculate the electrophoretic mobility \( \mu \) by using the equation \( \mu = d^2/(V \cdot \tau) \). \( \mu \) was found to be approximately \( 8 \times 10^{-5} \) cm\(^2\)/(V·s), which is almost identical to that mentioned in our preceding reports. [8-10]
Figure 3 (a) Transit time – electrode distance, (b) transit time – reciprocal electric field, and (c) velocity – electric field characteristics extracted from the data shown in Fig. 2.

4. Conclusion

The transient current during electrophoretic deposition of conjugated polymer is a promising tool for exploring the basic process of the deposition. In this paper, it has been shown that the transit times obtained from various electrode distances give almost identical electrophoretic mobility. The result shown here seems to support our interpretation of the transient current profile during electrophoretic deposition that it reflects the drift motion of colloidal particles in suspension driven by the electric field.

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