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Study of mechanical properties of light-emitting polymer films by nano-indentation technique

Kaiyang Zeng*, Zhi-Kuan Chen, Lu Shen, Bin Liu

Institute of Materials Research and Engineering, 3 Research Link, Singapore 117602, Singapore

Abstract

This paper presents our recent study on characterizing mechanical properties of a series of light-emitting conjugated polymer films designed for Polymer Light Emitting Diode (PLED) applications. The nano-indentation technique is used for such characterization. The elastic modulus and hardness of the conjugated polymers are found to be significantly higher than other polymeric materials. The mechanical properties of the conjugated polymer films are correlated with their chemical structures. The structures of side chains in the polymers show significant effects on the measured mechanical properties.

Keywords: Nano-indentation; Conjugated polymer; Light-emitting polymer; Elastic modulus; Hardness

1. Introduction

In recent years, great efforts have been denoted to the design and synthesis of light-emitting polymers (LEPs) for fabrication of Polymer Light Emitting Diodes (PLEDs). A number of conjugated polymers have been demonstrated to be great values in realizing different emissive colours [1–11]. Recently, polyfluorene and its derivatives (PFs) have been of great interest due to their blue emission and high efficiencies both in photoluminescence (PL) and in electroluminescence (EL) [12–16]. Almost all of the research activities so far are focused on the materials synthesis and their opto-electronic properties characterization. However, the applications of the LEPs are closely related to device manufacture, in which the LEP is one of many layers in the structures and will be subject to the electronic and mechanical force. Therefore, the mechanical properties of the LEP films, the properties of the interfaces between the LEPs and adjunct layers, and the stability of the LEPs under the mechanical stress will have important roles during the fabrication and the applications of the devices. In general, high values of elastic moduli and tensile strength are needed to help the polymers "to survive" under the harsh conditions prevailing during device manufacture and operation.

It has been realized now that it is possible to make polymers with the conductivity of copper and the strength of steel [7] from the conjugated polymers. The electrical conductivity of these polymers results from the existence of charge carriers and the ability of those carriers to move. In principle, the intra-chain π bonding and the relatively strong inter-chain electron-transfer interaction lead to the mechanical properties (Young's modulus and tensile strength) of conjugated polymers are potentially superior to those saturated polymers [1,17]. Thus, those polymer materials might offer the promise of truly high performance, high conductivity plus superior mechanical properties. The experimental studies have demonstrated that for conducting polymers, the electrical properties and the mechanical properties improved together, in a correlated manner, as the degree of chain extension and chain alignment are improved [1]. It has been shown that Young's modulus of 50 GPa and the tensile strength approaching 1 GPa are possible [1,18]. More importantly, there seems to exist a linear relationship between the electrical conductiv-

* Corresponding author. Current address: Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117576, Singapore. Tel.: +65 6874 6627; fax: +65 6779 1459.

E-mail address: mpezK@nus.edu.sg (K. Zeng).

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ity and the mechanical properties. The correlation can be understood as a general feature of conducting polymers [19].

As these conjugated polymers are always in the form of thin films, it is therefore of important to characterize the mechanical properties of these conjugated polymer films to determine the mechanical properties such as Young's modulus and hardness. In this paper, we will therefore present some of our recent studies on the characterization of mechanical properties of several PF-derivative LEPs films by using nano-indentation technique.

2. Materials and experiments

Several PF-derivative LEPs were studied in this work. The material synthesis and the characterization of the optical and electrochemical properties of these polymers have been described in detail previously [12–16,20,21]. The chemical structures of these polymers were shown in Fig. 1. Their molecular weights (M_w), the number of repeat units, glass-transition temperatures (T_g) were listed in Table 1 [20,21]. These polymers were spin-coated onto glass substrates to form thin films with the thickness of approximately 100 nm depending on the materials and the conditions of spin-coating. Since this was our first study on the characterization of the mechanical properties of the conjugated polymer films, we therefore selected this simplified polymer-film-on-glass-substrate configuration to simplify the analysis.

The nano-indentation experiments were performed by using Nano Indenter® XP (MTS Cooperation, Nano Instruments Innovation Center, TN, USA) with a Dynamic Contact Module (DCM) attachment and Continuous Stiffness Measurement (CSM) technique at a constant strain rate condition [22–27]. In the CSM technique, an alternating force is superimposed to the nominal applied force. This oscillated force with known phase and

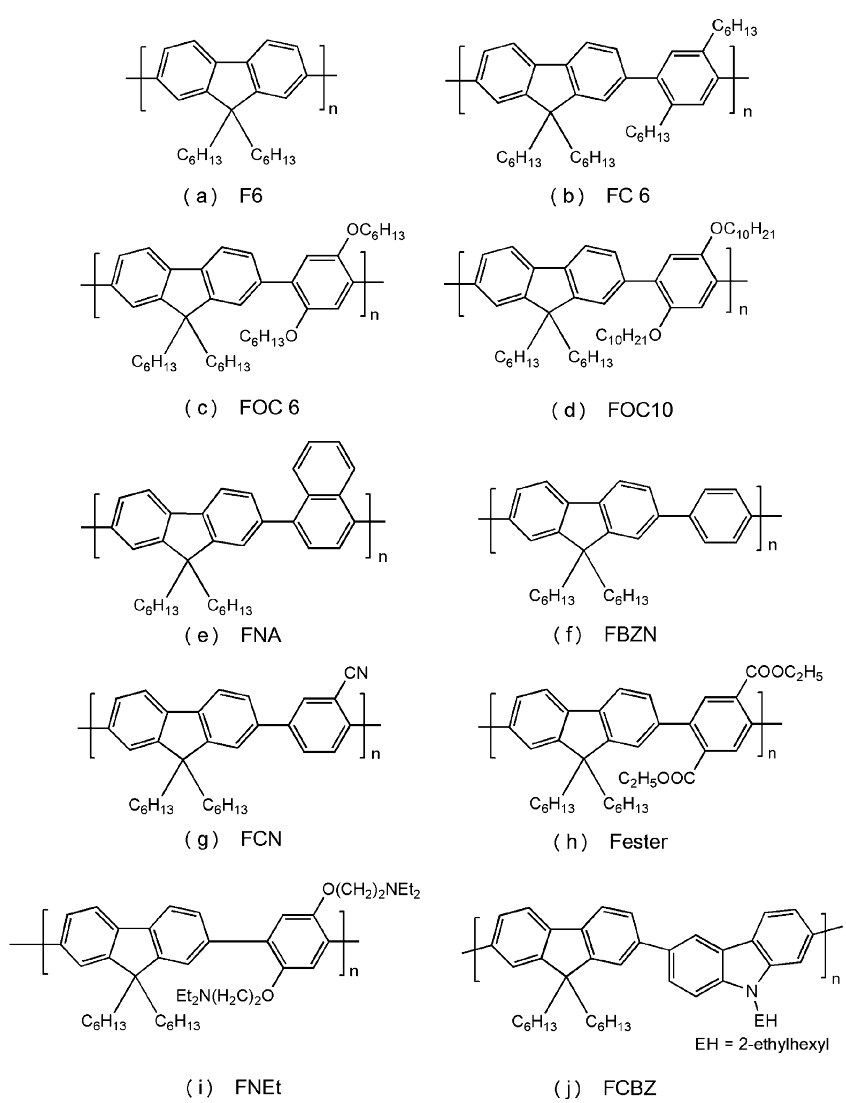

Fig. 1. Chemical structures of the light-emitting polymers.