Influence of diffusion of Fe atoms into the emissive layer of an organic light-emitting device on the luminescence properties

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This study investigated magnetic properties of multifilms, Fe/Al–O (Al-oxide), Fe/Al_{q3} (*tris*-(8-hydroxyquinolinato)-aluminum), and Fe/Al–O/Al_{q3}, using vibrating sample magnetometer and ferromagnetic resonance. In the case of Fe/Al_{q3}-films, the decrease of magnetization value of Fe was observed compared with the other two. It was explained with diffusion of Fe atoms from the underlayer into the Al_{q3} layer, and those diffused Fe atoms worked as quenching centers in the luminescence process of Al_{q3}. © *2005 American Institute of Physics*. [DOI: 10.1063/1.1845931]

I. INTRODUCTION

Since the discovery of electroluminescence using a stacking structure of organic materials,[1] study of organic light-emitting device (OLED) has attracted much attention for application to display devices. Recently, study of spin-injection from ferromagnetic electrode into the emissive layer of an OLED has been extremely focused.[2–4] Ferromagnetic metal (e.g., Fe, Co, or Ni) is a candidate material for spin-injection. Up to now, we have pointed out the validity of thin aluminum–oxide (Al–O) layer at the interface between cathode and the emissive layer of an OLED with ferromagnetic cathode for the effective spin-polarized electrons-injection.[5] In this article, we discuss the influence of the insertion of the Al–O layer on magnetism of ferromagnetic metal cathode and on luminescence from the emissive layer.

II. EXPERIMENTS

Three types of samples, Fe/Al_{q3} (*tris*-(8-hydroxyquinolinato)-aluminum), Fe/Al–O, and Fe/Al–O/Al_{q3} were prepared by vacuum (the base pressure $<4.0\times10^{-4}$ Pa) vapor deposition as follows. For the preparation of Fe/Al_{q3} film, Fe (thickness, 20 nm) was deposited on a glass substrate using electron beam (EB) evaporation. Subsequently and without breaking vacuum, Al_{q3} (50 nm) was deposited on the Fe film by a crucible. For the Fe/Al–O, an Fe film (20 nm) was deposited on glass substrates using an EB, and then Al (1.0 nm) was deposited on the Fe film by a crucible without breaking vacuum. After Al deposition, oxygen was introduced to the vacuum chamber for oxidization of Al surface. For the Fe/Al–O/Al_{q3}, Al_{q3} (50 nm) was evaporated by a crucible, after forming of Al–O film by the similar method mentioned above. During all depositions, the substrate temperature was kept at −2 °C.

Magnetic properties were measured at room temperature by using a vibrating sample magnetometer (VSM) for measurements of magnetization curves and electron spin-resonance equipment for measurements of ferromagnetic resonance (FMR) spectra. At each measurement, magnetic field was applied in plane. At FMR measurements, the resonance frequency and the power of microwave were 9.4 GHz and 2.5 mW, respectively.

III. RESULTS AND DISCUSSION

Figure 1 shows magnetization curves [(a)–(c)] and FMR spectra [(d)–(f)] for the films of Fe/Al–O [(a),(d)], Fe/Al_{q3} [(b),(e)], and Fe/Al–O/Al_{q3} [(c),(f)]. The value of M_{S1} is the saturation magnetization of Fe films by VSM measurements. M_{S2}, ΔH, and Hr are the total magnetic moment of Fe, the linewidth of absorbance, and the resonance magnetic field calculated by FMR measurements, respectively. In three magnetization curves, Fe/Al_{q3} film (b) has the smallest M_{S1} in the samples. Since the coercive forces were not so different from each other, M_{S1} might decrease essentially. Also, in the corresponding FMR spectra, Fe/Al_{q3}-film (e) has the smallest M_{S2} and the largest ΔH in the samples. Those results show the existence of an unusual magnetized state. We considered that the Fe atoms in the underlayer could diffuse into the Al_{q3} layer. The dotted line in Fig. 1(e) indicates an expected FMR spectrum of usual Fe film with the M_{S2} of 1300 emu/cc and with the ΔH of 50 Oe because, if pure Fe exists in the film, the value of M_{S1} should show about 1300 emu/cc. Therefore, the 900 emu/cc of M_{S1} suggests that the 14-nm-thick Fe layer ($900/1300\times20$ nm) has an usual saturation magnetization of Fe; on the other hand, the residual 6-nm-thick Fe might have diffused into the Al_{q3} layer. The disagreement in the resonance field between the experiment and the calculation could be due to the diffused Fe atoms. These could have certain degree of magnetic moment, although the interaction between them might be weak.

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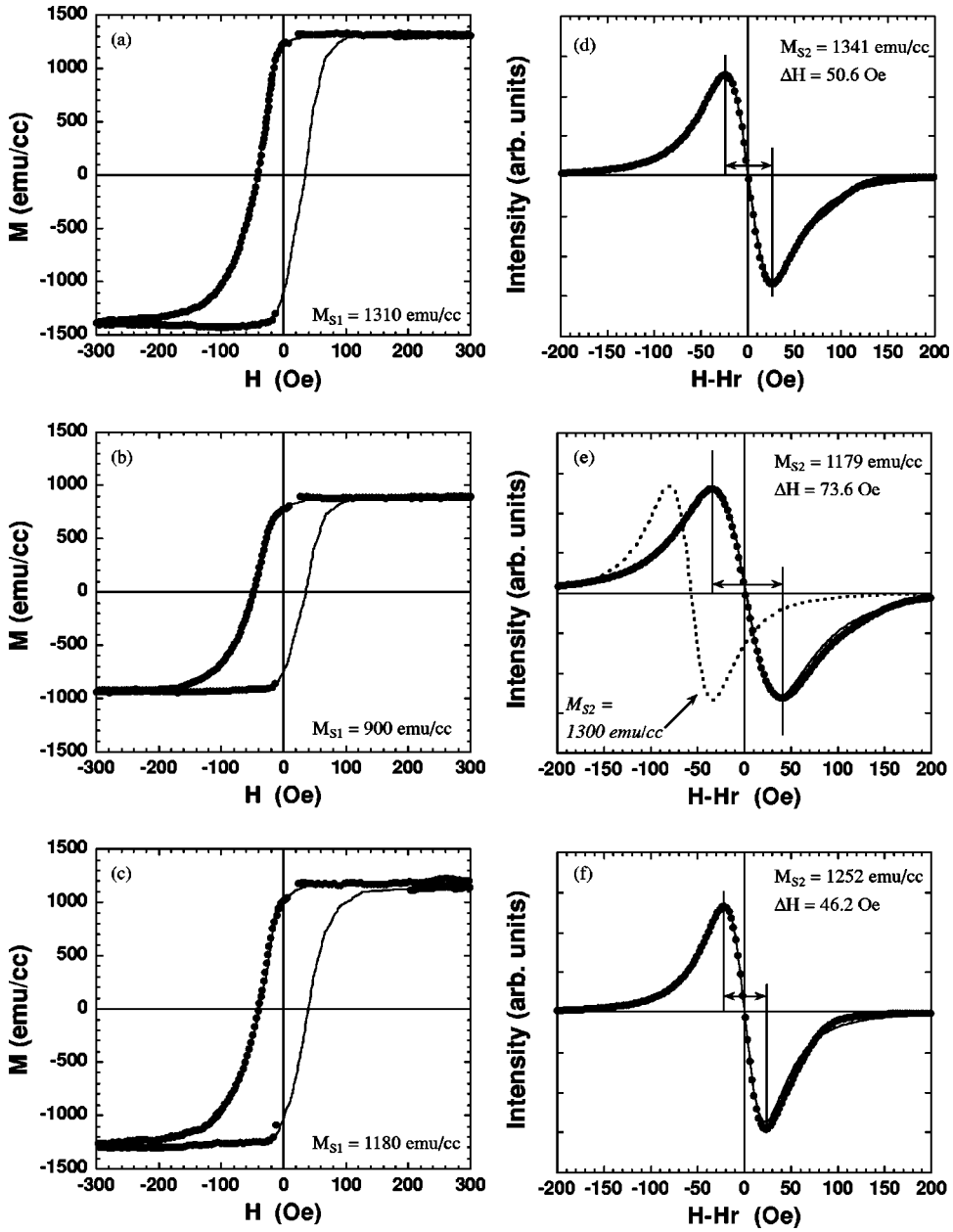

FIG. 1. Magnetization curves [(a)–(c)] and FMR spectra [(d)–(f)] of films. (a) and (d) Fe(thickness, 20 nm)/Al(1 nm); (b) and (e) Fe(20 nm)/Al_{q3}(50 nm); (c) and (f) Fe(20 nm)/Al(1 nm)–O/Al_{q3}(50 nm). A dotted line in (e) corresponds to the calculated spectrum of an Fe film.

Those diffused Fe atoms would work as quenching centers in the Al_{q3} layer, which could explain the decrease of luminescence intensity of the Fe/Al_{q3} films.[5]

For the effective spin-injection, large spin-polarization in the Fermi level of ferromagnetic metal cathode and flat interface are required. For this reason, the decrease of magnetization of the cathode surface should be eliminated. The insertion of Al–O layer between the ferromagnetic cathode and the emissive layer is effective for both the efficient spin-injection from ferromagnetic cathode and block of Fe atoms diffusing into the emissive layer.

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