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Application of imaging ellipsometry to the detection of latent fingermarks

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ABSTRACT

Imaging ellipsometry (IE) is applied to visualize latent fingermarks on specular surfaces. Instead of a real image, IE provides images related to the polarization states, which are changed by the imprinted layer on a surface. Fingermarks formed on the surfaces of various materials are investigated, including a shiny metal and a black-colored plastic. Relatively clear IE images are obtained from most surfaces on which the optical properties are distinguishable from those of the fingermarks. Also, it is shown that discernible IE images can be obtained even after a fingermark is vigorously rubbed with lab tissues.

1. Introduction

Latent fingermarks may provide critical evidence in criminal investigations. However, the visualization of fingermarks is sometimes challenging when the marks are faint or the surface conditions are not suitable for imaging. The surfaces on which the fingermarks are formed may have various physical constraints for detection. Therefore, a variety of detection methods have been developed, such as powder dusting [1], vacuum vapor deposition [2–4], fuming [5,6], luminescence [7,8], and other techniques [9,10]. In most techniques, various foreign materials are introduced onto the marks in order to enhance the visibility. However, chemical or physical processes involved in the use of such materials can potentially degrade or damage the marks. Furthermore, the use of such materials may prevent further forensic testing of the same sample. The success of deposition techniques depends upon the proper choice of materials, as well as the deposition conditions. Without a priori knowledge of the optimum conditions, the use of this technique can irreversibly degrade the quality of the evidence.

Therefore, non-destructive fingermark visualization techniques are preferable if applicable. Optical techniques are possible non-invasive candidates. The laser-induced luminescence technique can be used, but the natural fluorescence signal from a fingermark is generally very weak unless prior treatment is performed with strongly fluorescent chemicals or powders [7]. Also, the background noise can be problematic when luminescence is produced by the underlying surface. Recently, specular reflection of polarized light was used to image fingermarks [11]. This optical method utilizes the fact that the reflected light is partially polarized with the plane of polarization perpendicular to the plane of incidence. The difference in polarization-dependent reflection between the fingermark and the background allows the visualization of the image of the latent fingermark. This method works well for dielectric surfaces but is not suitable for metallic surfaces, because the underlying metal reflects more light than the upper fingermark.

In the present work, we introduce a novel optical method called imaging ellipsometry (IE). This technique utilizes fully polarized light for the visualization of latent fingermarks. Instead of a real reflection image based on a difference in reflected intensity, IE provides images of the change in polarization state induced by the fingermark layer on the surface. In this paper, many example applications of this technique are demonstrated.

2. Imaging ellipsometry

2.1. Ellipsometry

Ellipsometry is a powerful technique for characterizing the optical properties and microstructures of thin films through analysis of changes in the polarization states upon reflection. In

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general, the values measured by ellipsometry are expressed as Δ and Ψ. These values are related to the complex reflection coefficients for p- and s-polarized light (r_p and r_s). Here, p(s)-polarization indicates the component of an electric field of light that is parallel (perpendicular) to the plane of incidence.

$$r_p = |r_p|e^{i\delta_p},\ r_s = |r_s|e^{i\delta_s}, \tag{1}$$

where $\delta_{p(s)}$ is the change in phase of p(s)-polarized light after reflection. The two ellipsometry parameters, Δ and Ψ, are defined as follows:

$$\Delta = \delta_P - \delta_S,\ \Psi = \arctan\left(\frac{|r_P|}{|r_S|}\right) \tag{2}$$

That is, Δ measures the phase difference between p- and s-polarized light upon reflection. Meanwhile, Ψ measures the magnitude ratio of reflection between these two waves. Physical information about the sample, such as the thickness of the film or the refractive indexes of the materials, can be deduced through optical analysis of the Δ and Ψ values. When Δ and Ψ are obtained as a function of wavelength, this represents spectroscopic ellipsometry (SE). Meanwhile, IE is based on single-wavelength ellipsometry.

Ellipsometry shows monolayer sensitivity in the measurement of ultrathin films. However, its lateral resolution is limited by its beam spot size (typically a few mm or less). As most deposition techniques produce uniform films over a wide area, the lateral resolution of ellipsometry is not a concern in most thin film studies.

2.2. Imaging ellipsometry

IE has been developed and drawn much attention because it shows the merits of both ellipsometry and optical microscopy [12,13]. In IE, a microscope and an image sensor such as a charge-coupled device (CCD) or a complementary metal oxide semiconductor array detector are integrated into an ellipsometer to acquire ellipsometric images over a microscopic area of a surface. In other words, IE provides Δ and Ψ images rather than an optical image like that obtained with a conventional microscope.

Fig. 1 shows the IE system used in this study. Its operating principle is based on rotating compensator ellipsometry [14]. The system consists of: (1) a light-emitting diode, (2) a diffuser, (3) a focusing lens, (4) a band-pass filter (520 nm), (5) a polarizer, (6) a rotating waveplate, (7) a sample stage, (8) an analyzer, (9) zoom optics, and (10) a CCD camera. The zoom lens provides variable primary magnifications of 0.7–4.5×. With the current optical elements, only partial images of a fingermark can be observed. If one is interested in viewing the full fingermark, macroimaging optics can be adopted. In this study, the angle of incidence is fixed at 70°, and the wavelength is fixed at 520 nm. One can change these parameters for different samples in order to enhance the sensitivity of the system. The intensity images collected at different angular positions of the waveplate are processed in order to acquire Δ and Ψ images.

2.3. Optical properties of a fingermark

A fingermark usually consists of ridges of skin residue composed of inorganic (salt and water) and organic (amino acids, lipids, etc.) materials [15]. The mixture of these substances is rather transparent and can be assumed as a dielectric material in optical analysis. When a finger touches an object, a dielectric-like thin film bearing a fingermark pattern is imprinted on the surface. Thus, IE can detect the image of a thin film as long as the optical properties of the thin film are different from those of the underlying surface.

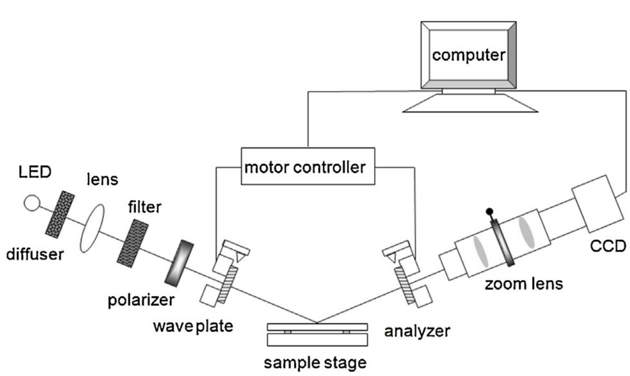
For investigation of its optical properties, a fingermark was imprinted on a silicon wafer. This mark was rubbed to form a uniformly thin film, and SE measurement was performed. Fig. 2 shows SE spectra collected over this sample (circles). Lines are fit to the data assuming dielectric-like optical properties of the fingermark (see inset). The overall fit quality is acceptable considering the poor quality of the fingermark film, which supports the assumption. This also suggests that the image of a fingermark formed on dielectric material such as glass will be less distinct compared to that on semiconductor or metal due to the similar optical properties of the fingermark and the underlying surface.

3. Results and discussion

3.1. Fingermarks on various surfaces

For IE studies, fingermarks are imprinted on various surfaces in order to investigate the sensitivity of the technique and the guidelines are followed which are provided by the International Fingerprint Research Group (IFRG) [16]. Four donors are employed and six different substrates are used overall. All marks are natural and most are aged at least a day.

First, fingermarks on a slide glass, a silicon wafer, and a chromium-coated surface are studied. These are representatives of the three branches of optical materials, i.e., dielectrics, semiconductors, and conductors. Fig. 3 shows the Δ and Ψ images of the fingermarks on each surface. Both Δ and Ψ provide discernible



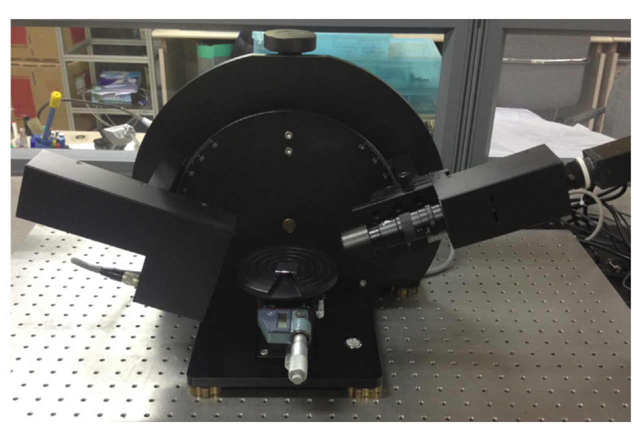


Fig. 1. Schematic and photograph of the imaging ellipsometer used in this study.