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Control of Stepper Motor Rotary Stages applied to optical sensing technique using LabView

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ABSTRACT

This work describes the design of an optomechatronics system controlled with LabVIEW via RS232 serial port. The system, that uses polarized light from a He-Ne laser, is applied in an optical sensing technique by Surface Plasmon Resonance (SPR) in the prism-based Kretschmann configuration, for optical characterization of thin film and biosensing applications. Since the measurements must be of high accuracy and insulated from mechanical noise, optomechatronics system improvements are realized by integrating control of Stepper Motor Rotary Stages that accomplish the required system features. The results showed that the system can yield reliable measurement data and greater precision.

1. Introduction

The techniques and applications of mechatronics systems are widely used both in industry and in research. This technology has evolved to the technology fusion as “Optomechatronics”, which is an integration of optical and mechatronic technologies. The latter may be due to the fact that integrated optical technology provides solutions to complex problems by achieving a desirable function or performance that mechatronic technology alone cannot solve. As a result, mechatronic or optical products, machines, and systems have further evolved toward a state of precision, reduced size, and greater intelligence and autonomy [1]. Within these systems, optical sensors are especially preferable in noncontact measurements because light transmission and reflection can be used without contacting the object surface, additionally, this kind of sensors are the fastest in response due to their propagation velocity, although the response time is limited by the mechatronics system. The inclusion of a programmable controller in an optomechatronics system improves its performance by providing higher accuracy measurements. LabVIEW is a fully-featured graphical programming language which has been used successfully in research [2].

This paper present an optical sensing system with two motorized rotation stages of 0.00025° of angular resolution to scan the reflected light from the sample by using LabVIEW software platform which enables monitoring the data acquisition and system control.

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Exist different techniques to measure the optical properties of a thin film, the most commonly used are reflectance and transmittance [3], ellipsometry [4], and SPR methods, for metallic [5] and dielectric [6] thin film. Each one of these techniques has their own advantages and can complement each other.

The system is based on SPR method, which stand out for their simplicity and rather high sensitivity. Through them is possible to obtain the optical parameters (refractive index and thickness) of dielectric (organic and inorganic) and metallic thin films that produce surface plasmon wave [6] as well as in biosensing applications in recognition of antigen/antibody reactions.

The SPR technique is considered one of the most sensitive and straightforward techniques to measure the refractive index of gaseous, liquid, or solid samples. Due to its high specificity and selectivity, SPR is a well-known use among researchers for label-free in biomedical and chemical detection in real time. The well-known intrinsic capabilities of the technique, the versatility and adaptability of the setup to the customer's needs, and the possibility to carry out multi-parameter sensing, have contributed to the success of the technique.

The SPR, the Abelès-Brewster method, critic angle and scattering measurement are important and easy techniques in the optical characterization of thin films and optical sensors that by using the p polarization illumination is possible to implement in a same opto-mechanical system θ-2θ efficiently controlled by LabVIEW software [7].

There are many commercial SPR instruments [8], but are expensive and very specific, mostly for biosensing applications.

2. Theoretical simulation using the Fresnel equations and the matrix method

We establish a theory model using the Fresnel equations and the matrix formalism
to describe the post-selected SPR Sensing system as a multilayer thin film assembly [9].

The theoretical reflectance of multilayer thin film was expressed by $R = \rho\rho^*$, where ρ is the amplitude reflectance calculated by the expression:

$$r = \frac{\eta_0 - Y}{\eta_0 + Y} \tag{1}$$

Here η_0 is the admittance of the interface of the incident medium, and Y is the admittance of the multilayer system and given by the characteristic matrix,

$$Y = \frac{H}{E} \tag{2}$$

where H and E represents the amplitude of the magnetic and electric field tangential component, respectively. These components are expressed, in matrix representation, by

$$\begin{bmatrix} E \\ H \end{bmatrix} = \prod_{j=1}^{k} \begin{bmatrix} \cos\delta_j & \dfrac{i\sin\delta_j}{\eta_j} \\ i\eta_j \sin\delta_j & \cos\delta_j \end{bmatrix} \begin{bmatrix} 1 \\ \eta_s \end{bmatrix} \tag{3}$$

where optical admittance of the jth layer film is $\eta_j = n_j / \cos\left(\theta_j\right)$ for TM (transversal magnetic) polarization and $\eta_j = n_j \cos\left(\theta_j\right)$ for TE(transversal electric) polarization. δ_j is the phase thickness (given for, $\delta_j = 2\pi n_j d_j (\cos\theta_j)/\lambda$), d is the physical thickness, n is the refractive index of the thin film, λ is the wavelength, η_S is the relative admittance of the substrate or sample medium, and θ is the angle for the incident medium. Refractive index is an important optical parameter of samples which can be defined in terms of real and imaginary parts.

The electric and magnetic fields are expressed as column vectors, and each film as a transfer matrix, thus the calculus involves successive multiplications of the column vectors by the transfer matrix. The problem is then reduced to finding the reflectance of the simple ideal interface between an incident medium n_0 and a medium of admittance Y.

3. System design

The optomechatronics system mainly consists of two precision rotation stages with an integrated stepper motor/controller, one of which moves a base containing the mount where a prism-based Kretschmann configuration [10] is placed as shown in Fig. 1, and the other moves the base of a photodetector to capture the reflected signal through the prism or sample for the sensing tests. They must realize a simultaneous movement in which one rotates the double of degrees that the other at a speed also to the double, because it is a system θ–2θ. As a source of illumination, it is possible to use a polarized He-Ne laser or a diode laser with polarizer. The advantage of using a laser diode is that they are compact, very inexpensive and there is a wide range of wavelengths.

As a first step in this work, mechanical structure required for the SPR system is analyzed, specifically in the rotary plates. According to the manufacturer, a motor controls a stage and for this system, two of them are necessary in order to achieve the total scan of the sample, so it was necessary to design a mechanical system that contains both stages as well as all necessary pieces to the correct operation of the measuring system. Each piece was designed in different files of a design software (Fig. 2a), to create finally an assembly where all the pieces are joined (Fig. 2b).