B.Sc. (Hons) Physics Project

Research Proposal

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Characterisation of Nanostructured Thin Films

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1 Research Plan

1.1 Aim

This project aims to explore the electronic and optical properties of metallic nanostructures in thin films. The focus will be on creating structures which exhibit plasmonic effects, and the detection of these effects using various experimental techniques. The samples to be studied will be prepared under vacuum by evaporative deposition, and the effects of environmental conditions and post deposition treatment on the properties of the samples will be investigated. Samples of particular interest include so called "metal-black" films, and multilayered metal structures. Experimental techniques to be used include Ellipsometry, Optical Reflection and Transmission Spectroscopy, and Electron Spectroscopy.

1.2 Significance

An understanding of the properties of nano structures is essential for further progress in the miniaturisation of components of electronic devices and fabrication of functional materials. In particular, the coupling of photons to surface plasmon resonances in nanostructures may hold the key to developing photonic based computer devices [1]. The field enhancement caused by coupling of photons to surface plasmons has also been exploited for many applications including increasing the efficiency of thin film solar cells[2] and reception of light by nanoscale antenna's [3].

1.3 Methods

All work will be undertaken at the Centre for Atomic, Molecular and Surface Physics (CAMSP) in UWA.

1.3.1 Preparation of Samples

Thin films of metallic nanostructures can be produced by several techniques. This project will use evaporative deposition in a vacuum chamber.

The preparation of "metal-black" films requires a "bad" vacuum (10^{-2} mbar). This required pressure will be obtained by pumping the chamber to high vacuum (10^{-7} mbar) with a turbo-molecular pump, before flooding it with a chosen gas.

1.3.2 Ellipsometric Measurements

Ellipsometry is a versatile technique which can be used to determine not only the optical properties of materials, but also information about their composition and structure. Essentially, Ellipsometry measures the change in polarisation of light reflected from a sample. In the simplest case of a bulk substrate, this can be related directly to the optical constants of the material via the Fresnel equations. In more complex cases a multilayered model must be used, and various optical effects must be considered.[4], [5]

A Variable Angle Spectroscopic Ellipsometer (VASE) is capable of performing ellipsometric measurements across a large range of angles and wavelengths. The huge amount of data acquired is of enormous benefit in obtaining an accurate model for a sample. A VASE belonging to CAMSP will be used for Ellipsometric measurements, and specialised software provided with this Ellipsometer will be used for the modelling of experimental results.

1.3.3 Optical Reflection and Transmission Spectroscopic Measurements

The VASE at CAMSP is also capable of performing reflection and transmission measurements on prepared films for the p and s polarised components of incident light. An advanced spectrometer (OceanOptics) can also be used for performing reflection and transmission measurements.

1.3.4 Electron Spectroscopy

An electron gun will be setup in a vacuum chamber, to allow for the electron spectroscopy application for studying the films deposited in the same vacuum chamber.

To begin with, samples of “metal-black” films will be studied using Total Current Spectroscopy (TCS). In this technique, a beam of low energy electrons are directed at a sample, and the current through the sample as a function of accelerating voltage is measured. The resultant spectrum provides a great deal of information about the electronic states of the surface[6],[7].

If time permits, the system will be modified to allow for the optical spectrum produced by electron bombardment of a sample to be observed.

1.4 Status

The preparation of thin films of gold and silver nanostructures under different pressures has been investigated. In particular,“gold-black” and “silver-black” films were created using the methods described by Harris[8] and Pfund[9]. Initial measurements of the transmisitivity of “gold-black” films appear to aggree with the results of Harris[10].

Atomic Force Microscopy (AFM) and Scanning Electron Microscopy (SEM) images of gold and silver “black” films on silicon have been taken by the Centre for Microscopy Characterisation and Analysis (CMCA) at UWA. These images provide valuable information about the geometrical structure of “metal-black” films compared to nano-structured films of the same material prepared under high vacuum.

The use of the VASE for the acquisition of both ellipsometric and Reflection and Transmission data has been investigated. Currently, procedures for modelling experimental results from Transmission data of the “black” films are being explored.

2 Benefits

In the last 50 years the world has undergone a revolution in terms of electronic computing. In 1965, Gordon Moore predicted the continued exponential increase in the number of components that could be fit on an integrated circuit, and this law is still famous today[11]. However, at some point it is inevitable that the limit for speed and efficiency of electronic circuits is reached. Research performed for this honours project will explore effects on a nano scale which may be exploited for use in photon/plasmonic based circuitry as an alternative to electronic circuits, allowing further decreases in the size of computing components and increase in the speed of performance.

3 Publications

At CAMSP, Ellipsometry has been used for many years for the characterisation of thin films. In particular, the VASE has been used to investigate the Magneto-Optic Kerr Effect (MOKE) [12],[13]. Electron Spectroscopy, including Electron Energy Loss Spectroscopy (EELS) is also used widely at CAMSP for the characterisation of plasmonic effects.

After the initial description of so called “metal-blacks” by Pfund in the 1930s [9], [14], much research into optical properties was conducted by Harris and others at MIT[8], [10], [15]. This research includes accurate theoretical models for the conductivity and optical constants of “metal-blacks”[15], and experimental data was collected mostly using transmission spectroscopy. Most recently, “gold-black” coatings have been shown to lead to an increase in the efficiency of solar cells, with numerical modelling suggesting that plasmonic effects are responsible[2]. However direct experimental evidence for plasmonic behaviour in metal-black films has not yet been obtained.

Plasmons are electron density oscillations in a solid. The theory of plasmon oscillations was developed in the 1950s by Pines and Bohm[16],[17] to explain electron energy losses in scattering experiments. Recently, the use of Ellipsometry for characterising plasmonic effects has been reviewed by Oates[18].

Komolov [7] and Mller[6] have published extensive works on the setup and use of TCS for characterising surfaces.

4 Costs

Much of the equipment required, including the Ellipsometer, Optical Spectrometer, vacuum chamber (and pumps) and power supplies, is already available at CAMSP. The total estimated cost of the project is \$1000. This includes:

- 10 hours workshop time (\$40 $\times$ 10 = \$400)
- Electronic components (\$300)
- Deposition materials (\$300)

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