Characterisation of nanostructured thin films

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1 Research Plan

1.1 Aim

This project aims to explore the electronic and magnetic 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 on the properties of the samples will be investigated. Samples of particular interest include so called "metal-black" films, and multilayered ferromagnetic metal structures. Experimental techniques to be used include Ellipsometry, R & T Spectroscopy, and Electron Energy Loss Spectroscopy (EELS).

1.2 Significance

An understanding of the properties of nano structures is essential for further progress in the miniaturisation of computer technological components. In particular, the coupling of photons to surface plasmon resonances may hold the key to developing photonic based computer devices [7]. 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[9] and reception of light by nanoscale antenna's [4].

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 evaporative deposition under a vacuum. A small piece of metal is placed on a tungsten filament, through which a current is passed. The current is increased until the filament is near the melting point of the particular metal. At a high enough temperature, the metal will evaporate isotropically from the filament. A substrate is placed a small distance from the filament, and becomes coated in a film comprised of nano-scale evaporated particles. The thickness of the film can be controlled by the temperature of the filament (through the current), and the time of evaporation.

The preparation of "metal-black" films requires a "bad" vacuum (10^{-2} mbar). An air like atmosphere of such pressure is relatively simple to create using a conventional rotary pump. Alternately, the chamber can be pumped to a high vacuum, and then flooded with an inert gas to the desired pressure through a leak valve.

1.3.2 Ellipsometric Measurements

Ellipsometry is an extremely 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.[14], [12]

A Variable Angle Spectroscopic Ellipsometer (VASE) is capable of performing ellipsometric measurements accross a large range of angles and wavelengths simultaneously. The huge amount of data aquired is of enormous benefit in obtaining an accurate model for a sample. A VASE belonging to CAMSP will be used for Ellipsometric measurements, and a special program can be used for the modelling of experimental results.

1.3.3 Spectroscopic Measurements

The VASE at CAMSP is also capable of performing reflection and transmission measurements 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 Energy Loss Spectroscopy

Electron Energy Loss Spectroscopy measures the energies of electrons scattered inelastically from a sample. If a sample exhibits plasmonic behaviour, it is possible for an electron to couple to a plasmon.

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[6] and Pfund[10]. Initial measurements of the transmisitivity of "gold-black" films appear to aggree with the results of Harris[1].

Atomic Force Microscopy (AFM) and Transmission Electron Microscopy (TEM) images of gold and silver "black" films have been prepared by the Centre for Microscopy Characterisation and Analysis (CMCA) at UWA. These images provide valuable information about the physical structure of "metal-black" films compared to nano-structured films prepared under high vacuum.

The use of the VASE for the aquisition of both ellipsometric and R & T data has been investigated. Currently, procedures for modelling experimental results from R & T data of the "black" films are being explored.

A small data analysis program has been written to enable easy conversion of an electron Time of Flight spectrum into an Energy spectrum. This program may prove useful for analysing the results of EELS experiments, which measure Time of Flight rather than energy directly.

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[8]. 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.

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) [5],[3]. EELS is also used widely at CAMSP for the characterisation of plasmonic effects. One of the project supervisors has conducted EELS experiments in the past.

After the initial description of so called "metal-blacks" by Pfund in the 1930s [10], [11], much research into optical properties was conducted by Louis Harris and others at MIT[6], [1], [2]. This research includes accurate theoretical models for the conductivity and optical constants of "metal-blacks"[2]. However, the majority of the data used for this research was aquired from transmission measurements at fixed angles. Since the 1950s advances in computer technologies have made ellipsometry a more attractive technique for characterisation of optical properties.

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[9]. However direct experimental evidence for plasmonic behaviour in metal-black films has not yet been obtained.

A recent review of the use of Ellipsometry in surface science[13] may also prove a useful reference for this project.

4 Costs

The Ellipsometer, Vaccuum chamber and pump, and most other equipment required is already available at CAMSP.

References

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