Diffraction-Based Tracking of Surface Plasmon Resonance Enhanced Transmission Through a Gold-Coated Grating

Wei-Hsun Yeh, Joseph W. Petefish, and Andrew C. Hillier*
Department of Chemical and Biological Engineering,
Iowa State University, Ames, Iowa 50011.

SUPPORTING INFORMATION

Grating Construction. Two different gratings were used in this work. The first was a commercial holographic transmission grating with a 1000 nm pitch (Edmund Optics). The second was a metal-coated grating prepared from a commercial DVD-R. Grating preparation involved manually splitting the DVD-R into two pieces (Fig.S.1) at the center-plane using a razor blade. The dye layer was removed by rinsing in ethanol, while the silver layer was removed by soaking in concentrated nitric acid. The grating was then thoroughly rinsed with deionized water, dried under nitrogen, and placed in a vacuum chamber for film coating (Denton Vacuum Turbo III, Morrestown, NJ). Gold films of ~40 nm thickness were deposited onto the gratings at a rate of 1–2 Å s^{-1} and a pressure of 7×10^{-5} Torr under nitrogen atmosphere. The thickness was monitored using a quartz crystal thickness gauge. SiO films were also formed via vacuum evaporation under conditions similar to gold coating. Film thicknesses and compositions were confirmed using atomic force microscopy (AFM) imaging, ellipsometry, and infrared reflectance absoption spectroscopy (IRRAS).

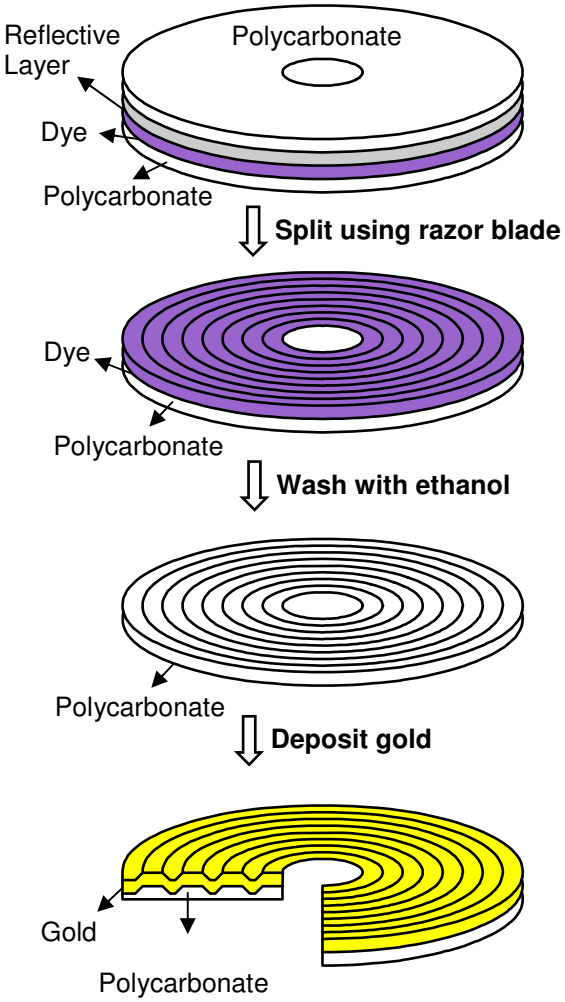

Figure S.1. Schematic showing construction of gold gratings from commercial DVD-R

Atomic Force Microscope (AFM) Imaging. AFM imaging of the sample surfaces was performed with a Dimension 3100 scanning probe microscope and a Nanoscope IV controller (Veeco Metrology, LLC, Santa Barbara, CA). Imaging was performed in tapping mode using silicon TESP7 AFM tips (Veeco Metrology, LLC, Santa Barbara, CA) with a spring constant of ~70 N m^{-1} and a resonance frequency of ~280 kHz.

Ellipsometry. Film thicknesses were confirmed using ellipsometry. A motorized variable-angle null ellipsometer (Multiskop, Optrel GbR) operating as a rotating analyzer ellipsometer (RAE) in the polarizer-sample-analyzer (PSA) configuration utilizing a broadband light source at 70° angle of incidence was used to measure the ellipsometric parameters Δ and Ψ. The values of Δ and Ψ were converted into equivalent optical thicknesses using a n-layer model. The optical constants of the gold substrate (refractive index n and the absorption coefficient k) were first determined using a two-phase model (air/substrate). The thickness of the adsorbed films were then found using a three-phase model (air/film/substrate).

Infrared Reflection Absorption Spectroscopy (IRRAS). A Fourier transform infrared spectrometer (Nicolet Magna 750, Thermo Scientific) using a liquid nitrogen-cooled MCT detector was used to obtain infrared spectra. Reflectance spectra were collected using a specular reflectance accessory (VeeMax, Pike Technologies) and a ZnSe polarizer using p-polarized light incident at 80º with respect to the surface normal. These spectra are presented as log(1/R), where R is the sample reflectance divided by a reference surface. Each spectrum represents an average of 512 individual sample and reference scans acquired at 2 cm^{-1} resolution. A freshly prepared, gold coated, glass slide served as the reference sample.

Optical Modeling. The optical response of the film-coated grating was modeled using the rigorously coupled wave analysis (RCWA) method. Details of the method and the form of its

implementation used here can be found in several publications.[14] Briefly, diffraction efficiencies were calculated for both transverse magnetic (TM) and transverse electric (TE) incident light as a function of wavelength. Calculations were performed using a custom-built code written in Matlab.

The RCWA method involves approximating the grating geometry in terms of a series of thin layers. In each layer, the effective refractive index is described by a Fourier expansion of the refractive index and geometry of the component materials. The reflection and transmission coefficients are then solved by matching the transverse and longitudinal components of the electric and magnetic fields at the interface of each layer. Results include reflected and transmitted diffraction efficiencies for all retained orders. In order to achieve adequate convergence in the calculations, the Fourier expansion for the refractive index values within the grating layers were described by 42 terms for TE polarization (+/- 21 diffracted orders) and 122 terms for TM polarization (+/- 61 diffracted orders).

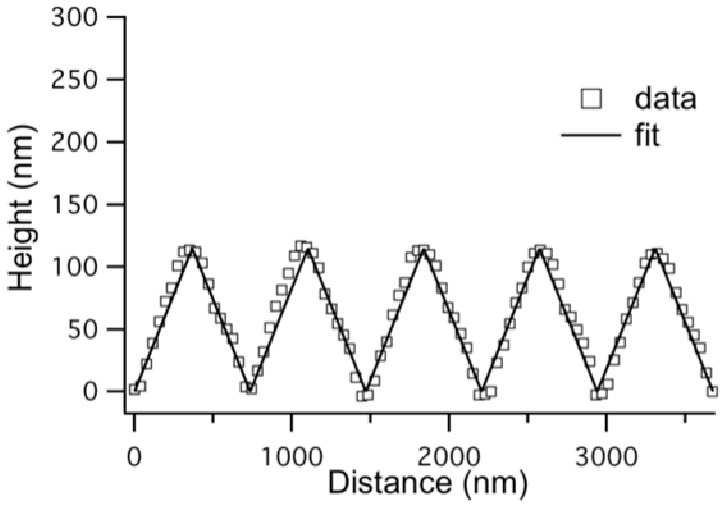

Figure S2. Atomic force micrograph line scan (open squares) and geometric fit (line) of DVD profile. Fit is a sawtooth profile with height of 120 nm and pitch of 670 nm.

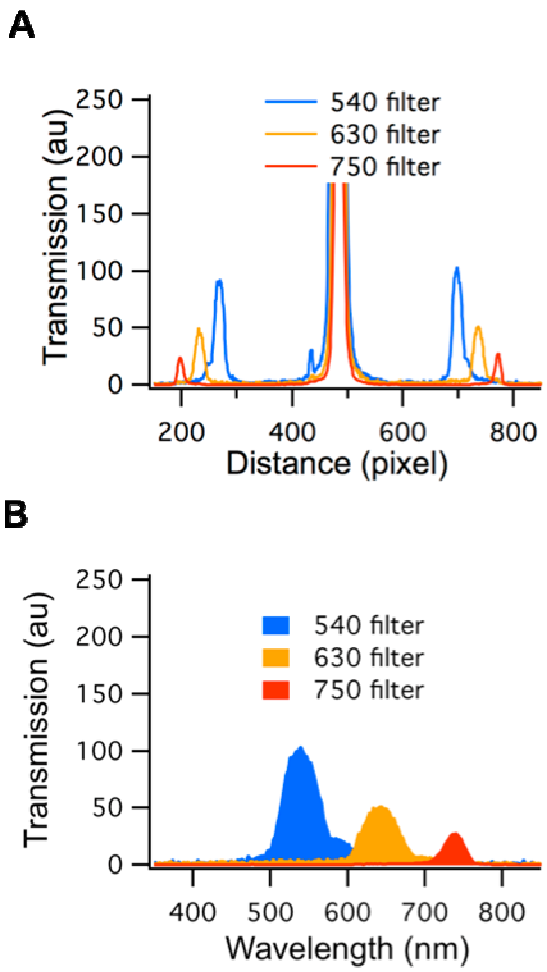

Figure S3. (A) Raw transmission intensity of diffracted peaks from uncoated grating in units of pixels. (B) Transmitted intensity of +1 diffracted peak after converting pixel location to units of wavelength. Both figures show transmission response of light using 540, 630 and 750 nm interference filters.

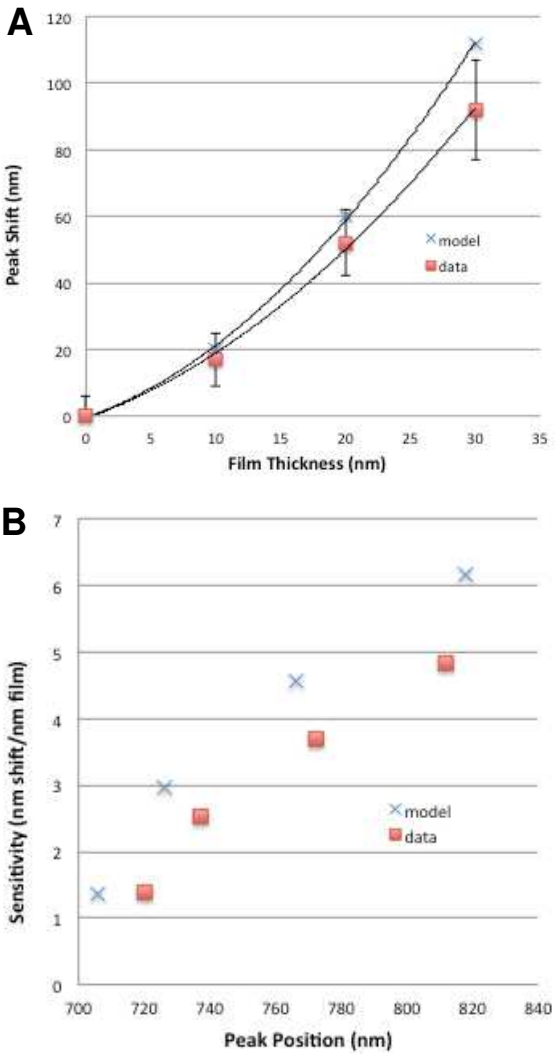

Figure S4. Comparison between experimental data and results from RCWA model. (A) Peak shift versus film thickness as measured (data) and calculated (model). (B) Sensitivity of peak shift (in nm shift/nm film) for measured (data) and calculated (model) results.