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Submitted herewith is the final report on Contract NAS8-30813 with Athens College. "Optical Grating Analyzer Studies". Principal Investigator, Dr. Joseph K. McDonald.

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FINAL REPORT

Contract NAS8-30813

In the study of reflection grating spectra, anomalous variations in the intensity are often found to occur at certain critical wavelengths under p-polarization that appear, for example as sharp peaks or dips in the otherwise smooth spectrum of a continuum source. This resonance type behavior is due to the excitation, at the highly reflecting metal surface, of surface waves (surface plasmons) which exhibit a dispersive behavior from the infrared and visible to the surface plasma frequency, $W_p / \sqrt{2}$, for which a typical coating metal like aluminum lies in the vacuum ultraviolet. For a given incidence angle, the characteristic resonances appear throughout the spectrum, but they shift to different wavelengths for different incidence angles.[1] By taking many measurements at different incidence angles, not only can a complete dispersion relation be constructed, but band-gap spacing in the dispersion curve can be measured.[1,2]

A proper study of reflection grating characteristics as related to plasma resonance behavior really requires a spectral scanning device that can operate at not only one, but a variety of incidence or source-detector angles over a wide spectral range, a versatility the usual spectrometer does not have. We were thus led to construct a new type of spectrometer that was specifically designed to observe grating spectra over a range of incidence angles from normal to almost grazing incidence and that utlizes a unique scanning and focusing mechanism to keep the exit slit on the Rowland circle. Figure 1 shows generally how this is accomplished. Two motions of an Ortek triple positioner vacuum feedthrough mechanism are utilized. The grating on a kinematic mount and its rotation table are centered on one of these and a sliding track that holds the phototube on ball-bearing mounts and which is also within the vacuum chamber is centered on the other one. The exit slit which is attached to the phototube, thus is always facing the grating and can move towards or away from it. Focusing is provided by a linkage mechanism consisting of two arms, each of a length equal to half the grating radius of curvature, i.e. the Rowland circle radius (in this case 25 cm, since the gratings under study have R=50 cm). One arm is rigidly attached to the grating and extends out in a direction perpendicular to it while the other connects this arm to the phototube just below the exit slit. Thus the exit slit and phototube are constrained to move along the Rowland circle for any given incidence angle. The entrance slit, which is outside the chamber, can be moved toward or away from the grating at one of two entrance ports at just the proper distance to also place it on the Rowland circle for a given angle of incidence. A grating spectrum is obtained by fixing the angle of incidence, positioning the entrance port at the proper distance, and scanning the exit slit by slowly moving the track by a motor drive outside the chamber.

Polarization effects can be investigated in the vacuum region by a triple-reflection polarizer consisting of three gold-coated mirrors (or at longer wavelengths by a Polaroid sheet) attached between the exit slit and phototube. The polarizer is rotated by a vacuum compatible motor attached to the sliding track, but controlled from outside the chamber. Electrical leads to the motor and phototube are provided by vacuum feedthrough connections. The chamber itself is pumped by two 6 inch diffusion pumps and operates at 10^{-6} Torr.

For efficiency measurements, there is a separate entrance port that can accomodate the exit slit assembly of an external monochromator. A separate phototube within the chamber can swing either into the monochromator beam (to measure I_0) or away from it such that the angle between the port and phototube with the vertex at the grating is the Seya-Namioka Angle (70.1^o) (to measure I). The efficiency is thus the ratio I/I_0. This mechanism is shown in Figure 2. A separate polarizer can also be positioned between this port and the monochromator for polarization-dependent efficiency measurements. Spectral scans and efficiency measurements can both be made almost simultaneously, the only requirement being that the grating under study be swung around to face the proper entrance port.

Results of measurements made with the chamber are given in the following figures. Figure 3 shows scans in the visible region for a 600 line/mm Al-coated grating for incidence angles ranging from 14^o to 26^o, and Figure 4, for an Al 1200 line/mm grating at incidence angles from 4° to 10° , under p-polarized light. For both of these, there is a gradual shift of the resonances throughout the spectrum. Similiar curves for the vacuum region are not included because neither of these gratings showed anomalous behavior in this region. A typical efficiency curve is shown in Figure 5, and is for the 1st order on-blaze spectrum of a 600 line/mm grating where the incident light is unpolarized.

If a metal coated grating is coated with a thin layer of dielectric, the resonances are shifted to longer wavelengths and the resulting different dispersion relation is now characteristic of both the metal and the overcoating layer.[3] A study of plasma resonance behavior should be useful in determining some of the properties of dielectric materials. This has found value recently in the space program in the study of contamination on optical surfaces, and in particular, of the reflection gratings used in space-borne spectrometers.[2] The thickness of contamination on grating surfaces could be estimated from the plasma resonance wavelength shifts. A grating was coated with various layers of contaminant in the form of vacuum evaporated diffusion pump oil (20 to 250 Å) and the wavelength shifts of the plasma resonances were correlated with the calculated thicknesses based on the dispersion curve and with changes in grating efficiences in the vacuum ultraviolet.[2] This was done at only a single source-detector angle (70.1°). The present grating analyzer is constructed so that various source-detector angles can be used to monitor contaminate layers. This may well allow one to obtain correlations useful for identification of contaminants.

There appears to be only one resonance peak in the vacuum ultraviolet. Although other peaks may occur when the incidence angles are changed, it is our opinion that the best region for studying contaminant effects on resonance behavior is in the visible and near ultraviolet regions of the spectrum. There are more resonance peaks to study in this region (some gratings that show anomalous peaks in the visible do not in the vacuum ultraviolet), more efficient detectors, polarizers, continium lamps, etc. are available, and absorption of spectrum light is less. There is, of course, no necessity to work in vacuum using near ultraviolet and visible light, except to reduce chances of uncontrolled contamination of the grating being studied.

We recommend that one of the diffusion pumps on the grating analyzer be replaced with an ion pump. The remaining diffusion pump could be used to obtain vacuum conditions. It could then be turned off and the ion pump would maintain the vacuum. This system would reduce contamination with diffusion pump oil which could arise from continuous operation of the diffusion pump.

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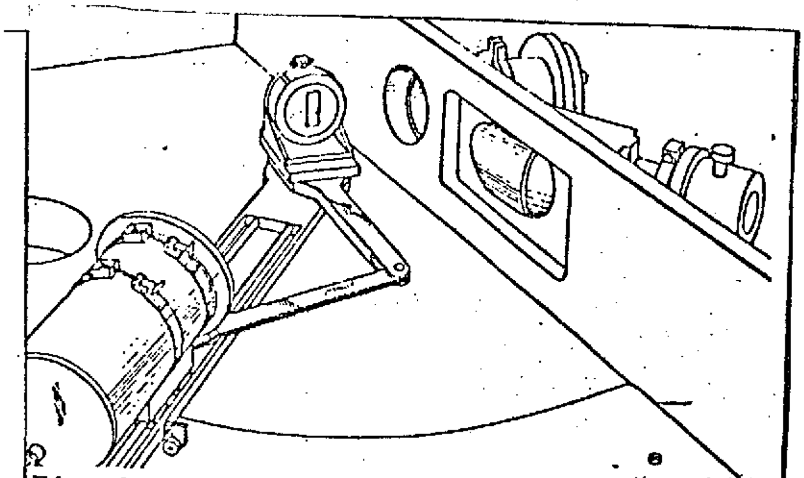

Fig. 1. Chamber and scanning mechanism

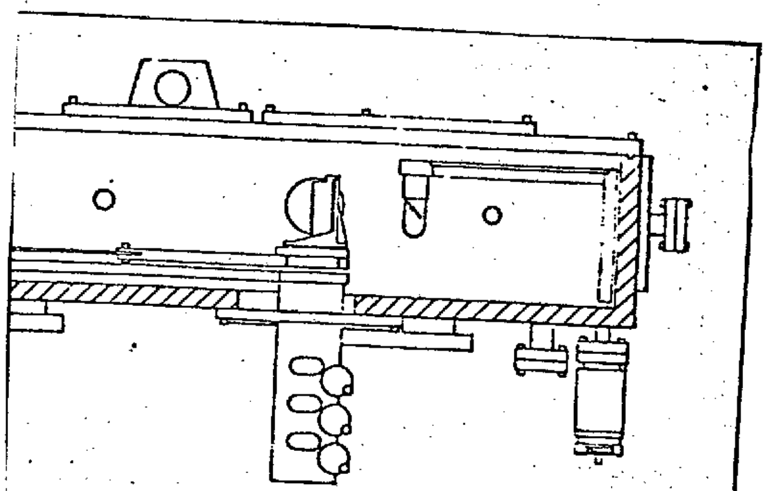

Fig. 2. Efficiency study mechanism

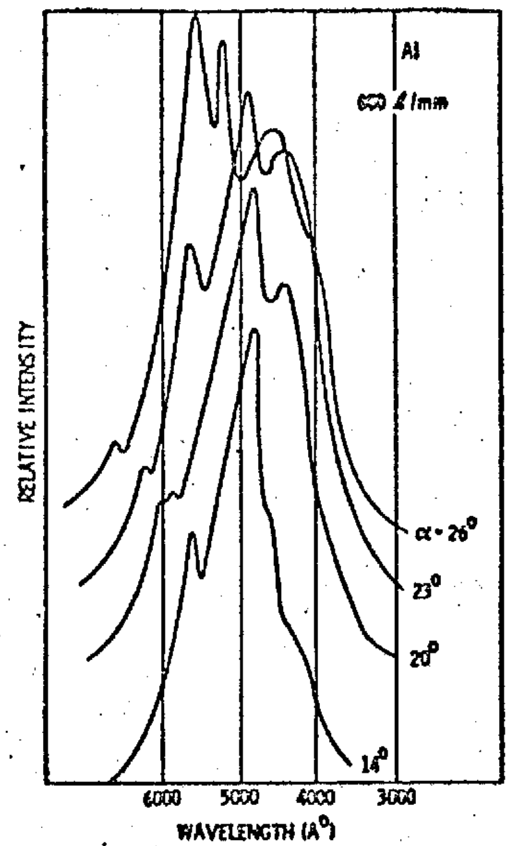

Fig. 3. Spectral scans, 1st order on-blaze Al 600 line/mm grating

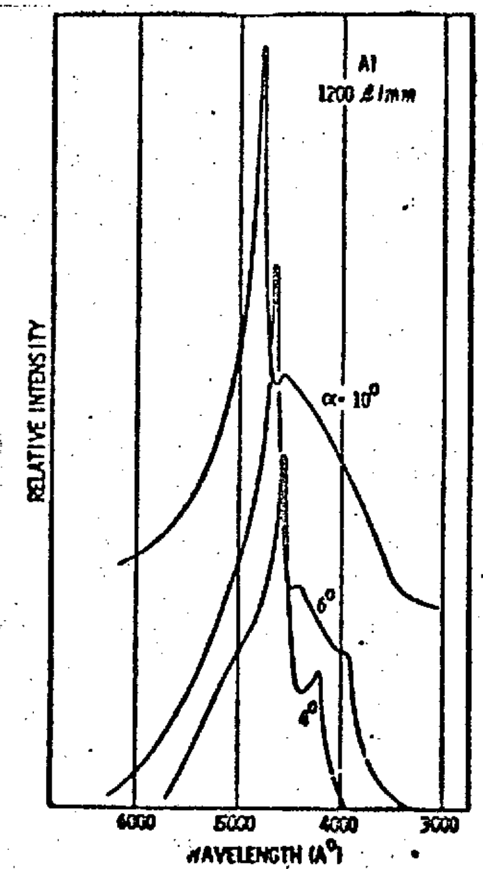

Fig. 4. Spectral scans, 1st order on-blaze Al 1200 line/mm grating

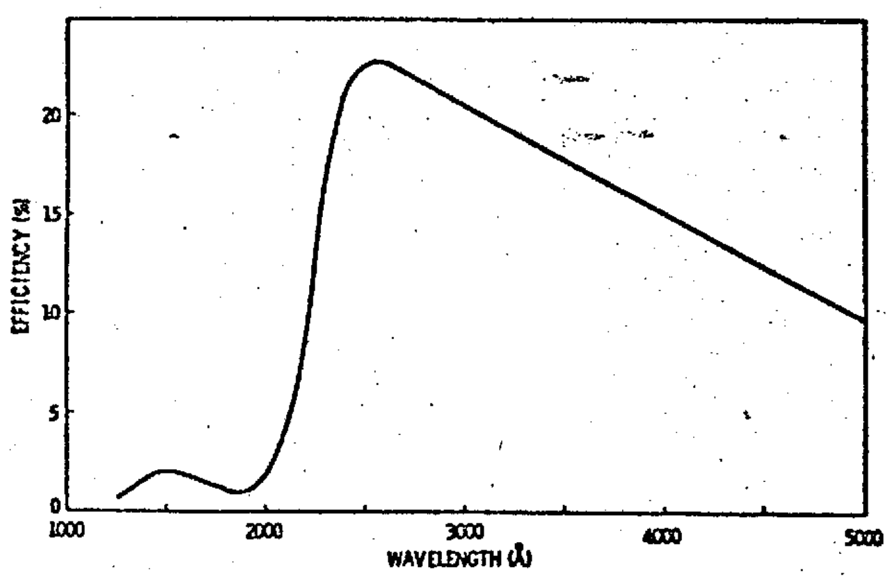

Fig. 5. Efficiency in 1st order on-blaze, Al 600 line/mm grating

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3. J.J. Cowan and E.T. Arakawa, Z. Physik 235 (1970) 97; Phys. Stat. Sol., 1A (1970) 695.