# BIREFRINGENCE AND PHASE RETARDANCE IN MOSCOVITE MICA

**N. N. Nagib and S. A. Khodier**

*National Institute for Standards, Cairo, Egypt.*

## ABSTRACT

*A muscovite mica plate of thickness 0.0329 ± 0.0002 mm is calibrated by ellipsometry in the spectral region 425 - 650 nm. The phase retardance produced by the plate falls from 117.52 ° for λ = 425 nm to 76.05 ° for λ = 650nm. The plate is a quarter - wave phase retarder at λ = 560 nm. The dispersion of birefringence in the studied region is non- monotonic with a mean value of* $(n_e - n_o) = -0.00422 \pm 0.00004$.

## INTRODUCTION

Muscovite mica is a negative biaxial crystal with the chemical formula $K\ Al_2\ (O\ H)_2\ (Al\ Si_3\ O_{10})$. Thin sheets of the crystal have high transmittance from the ultraviolet to the near infrared. Birefringence in mica (defined as $n_e - n_o$, or the difference between the refractive indices of the extra - ordinary e and the ordinary o rays) is much smaller than in calcite and quartz which makes it advantageous in constructing phase retarders (usually called phase plates) as the required thicknesses for such plates need not to be very thin[1-3] . The most common type of phase plates is the quarter-wave (λ/4) which constitute an important optical element in ellipsometric measurements. Other uses of λ/4 plates are cited in[4]. The fast axis of the plate is the direction in which the faster-moving ray vibrates (sometimes referred to as the reference axis) and the direction perpendicular to it is the slow axis.

In ellipsometry, the phase plate need not to be exactly λ/4, but it is essential that the phase retardance it introduces between the resolved components of the light beam be known at different wavelengths. The required thickness for a λ/4 plate at λ =

= 589 nm is between 0.032 and 0.036 mm depending upon the value of birefringence for the used sample[5].

The path difference N λ between the 0 and e rays is

$$N\lambda = -d(n_e - n_o) \quad (1)$$

Where d is the thickness of the plate. The phase retardance δ is given by[5].

$$\delta = 2\pi N = -2\pi d(n_e - n_o)/\lambda \quad (2)$$

In this work a mica plate is calibrated by ellipsometry between λ = 425 and 650nm to find the dispersions of its retardance and birefringence.

## EXPERIMENTAL

A carefully selected Ural muscovite mica plate, freshly cleaved of a high quality sample, was used in the experiment. The plate is of average thickness d = 0.0329 ± 0.0002 mm and of surface dimensions about 10mm x 10mm. Visual inspection showed that the plate is free from inclusions and scratches. The plate was then mounted in its holder, introduced between crossed polarizers and slowly rotated. The uniformity of the field of view ensured the homogeneity of the layer structure. The thickness was measured by an opto-mechanical comparator with accuracy ± 0.0002 mm. With this thickness, the plate is expected to be of λ/4 retardance ($90^o$) at some value of λ close to the centre of the visible spectrum. the plate was cemented between glass plates of thicknesses D>> d. The two solutions of the cementing material (optical araldite) were mixed at a ratio of 3 : 1 by volume to provide a cement of refractive index value intermediate between the refractive indices of mica and glass. This is necessary to minimize interference effects in the plate which produce oscillations in the value of the retardance. The fast and the slow axes were identified by Tutton's test [5].

An ellipsometer with the same arrangement as that used by Alfano - Woodruff[6] is used to calibrate the plate, Fig. 1. Light from a halogine lamp falls on the entrance slit of a monochromator. The emerging quasi-monochromatic light beam passes successively through the polarizer P, the plate C, and falls at an angle of incidence 70° on a metallic reflector (evaporated silver mirror). The reflected beam passes through the analyser A and the detector T (telescope). The polarizer and the analyser are Nicol-type calcite prisms mounted in rotatable graduated circles which can be read to 1'. The calibrated plate was set in two different positions with its fast axis making ± 45° with the plane of incidence and measurements were carried out in the four ellipsometric zones at each value of λ[7]. Extinction of the reflected beam was obtained by adjusting the polarizer and the analyzer.

## RESULTS AND DISCUSSION

The retardance of the plate is given by [6].

$$\delta = \cos^{-1} [- \sin (a_p - a_s) / \sin (a_p + a_s) \cos 2p] \qquad (3)$$

where $a_p$ is the angle between the analyser plane of transmission and the plane of incidence when p is the angle between the polarizer plane of transmission and the plane of incidence, while $a_s$ is the angle between the analyser plane of transmission and the plane of incidence when p is the angle between the polarizer plane of transmission and the plane of the metallic reflector respectively. The measured angles were reproducible to within ± 5'. As the value of the plate thickness d is not involved in Eq.(3), the retardance of the plate δ is not affected by the accuracy of measuring d. However, high accuracy in measuring d is required to calculate the birefringence of the plate $(n_e - n_o)$. It follows from Eq.(3) that the plate retardance is exactly 90° when $a_p = a_s$.

Figure 2 shows variations of $a_p$, $a_s$ and $(a_p - a_s)$ with λ. Obviously, the plate is of retardance 90° at λ = 560nm. The dispersion of δ in the studied spectral region, as calculated from equation (3), is shown in Fig. 3, curve (a) where δ varies from 117.52° at λ = 425 nm to 76.05° at λ = 650nm. As measurements were carried out in the four ellipsometric zones, the mean values of p, $a_p$ and $a_s$ were used in our calculations. The maximum error in the value of δ is ± 0.4°. The calibration curve of the plate retardance (Fig. 3, curve a) represents the tested plate and to a large extent plates cleaved from

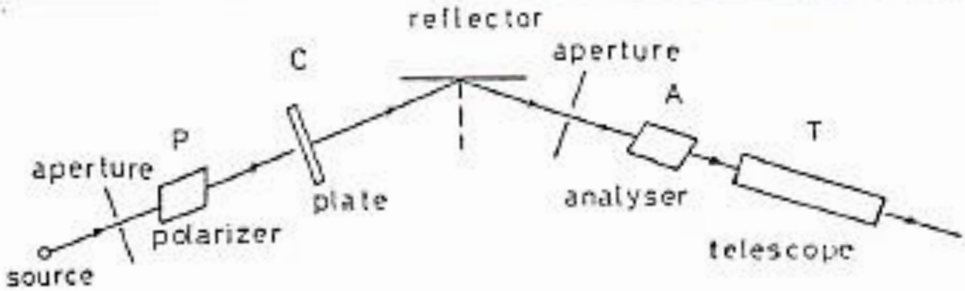


Fig. 1.: Schematic diagram of the ellipsometer.

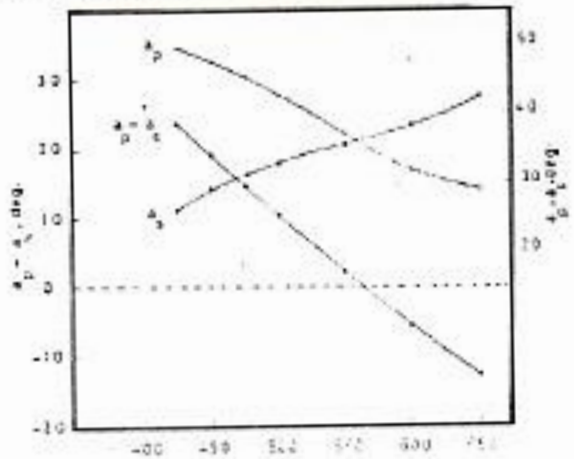

Fig. 2.: Variations of $a_p$, $a_s$ and $a_p - a_s$ with wavelength λ.

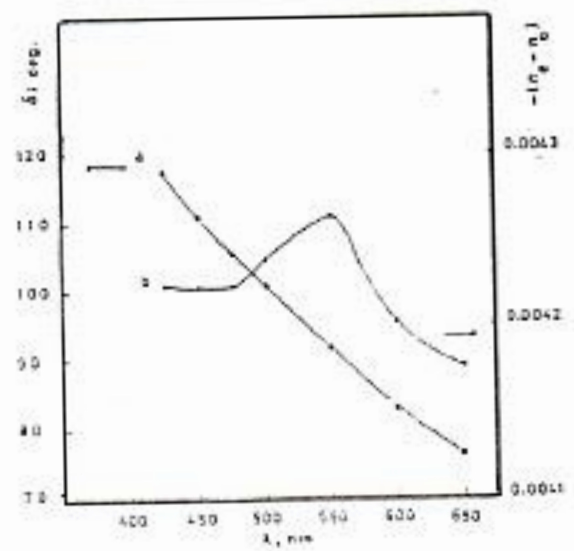


Fig. 2.: Dispersion relations of the retardance (δ) and the birefringence ($n_e - n_o$).

the same crystal. The results highly conform with the published data for mica[5,8]. The dispersion of birefringence as calculated from Eq. (2) by substituting the values of $\delta$ and d for different values of $\lambda$ is shown in Fig. 3, curve (b), where the relation is non-monotonic in the studied spectral region with a mean value of $(n_e - n_s) = -0.00422 \pm 0.00004$ which is very close to the known representative value of - 0.0041 at 589 nm[3], while reported value of - 0.00492 was given for another sample at 546 nm[8]. The non-monotonic behaviour of birefringence was observed before in two samples of muscovite mica[5] while, for another sample, the absolute value of birefringence increased monotonically with $\lambda$ from 500 nm to 650 nm[9].

## REFERENCES

1 - S. Ruthberg, M. W. Barnes and R. H. Noyce, J. Res. NBS-A, 67A, 309 (1963).
2 - Encyclopaedic Dictionary of Physics, Vol. 4, P. 632, Pergamon Press (1961).
3 - F. A. Jenkins and H. E. White, Fundamentals of Optics, p. 545, McGraw - Hill, New York (1957).
4 - M. S. El-Bahrawi, N. N. Nagib, S. E. Demian and S. Khodier, J. Eng. and Appl. Sci., 41, 241 (1994).
5 - Handbook of Optics, W. G. Driscoll ed., Sec. 10, pp. 102-134, McGraw - Hill, New York (1978).
6 - R. R. Alfano and W. H. Woodruff, Appl. Opt. 5, 352 (1966).
7 - R. M. Azzam and N. M. Bashara, Ellipsometry and Polarized Light, Chap. 3, North - Holland Publ. (1977).
8 - P. H. Smith, Surf. Sci. 16, 34 (1969).
9 - I. N. Shklyarevskii, T. I. Korneeva and A. N. Ryazanov, J. Appl. Spectrosc., 4, 65 (1966).