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Title: Reflectance measurements and optical constants in the Extreme Ultraviolet for thin films of ion-beam-deposited SiC, Mo, Mg_2Si, and InSb, and evaporated Cr

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When the research was performed, J. I. Larruquert was on leave from the Instituto de Física Aplicada, Consejo Superior de Investigaciones Científicas.

Abstract

Reflectance measurements and optical constants of thin films of ion-beam-deposited SiC, Mo, Mg_2Si, and InSb, and evaporated Cr have been measured in the extreme ultraviolet (EUV) spectral region from 49.0 to 200.0 nm. In this spectral region no optical constant data were available for materials deposited by ion-beam-deposition. We compared our data with those for bulk samples or for thin films prepared by different techniques. The goal of this work is to study candidate materials for multilayer coatings in the EUV.

OCIS Codes: 120.4530 (Optical constants), 120.5700 (Reflection), 240.0310 (Thin films), 260.7210 (Ultraviolet, far), 260.7200 (Ultraviolet, extreme), 310.1620 (Coatings)

1. Introduction

The optical constants of materials in the spectral region below 200 nm, that will be referred to as extreme ultraviolet (EUV), are scarce, do not often agree among different authors, or are even non-existent for some materials. The high radiation absorption of all materials in this spectral region makes it difficult to characterize material properties that may be affected by the presence of a thin oxide layer or a contaminant layer. Changes in properties such as crystallinity, density, thickness, homogeneity, etc. may have a strong effect on optical constants in the EUV.

The characterization of the optical constants of materials is interesting for both theoretical and practical reasons. In our case we were interested in the search of materials for the development of both single layer and multilayer coatings with an enhanced reflectance over standard single layer coatings[1] in the spectral region between about 50 and 125 nm. In this paper we present reflectance and optical constants obtained for thin films of ion-beam-deposited (IBD) SiC, Mo, Mg_2Si, and InSb, and evaporated Cr. These were considered candidate materials for multilayer coatings for EUV astronomy applications. Optical constants are obtained from reflectance measurements on thin films at several angles of incidence ranging from near normal to near grazing. Section 2 gives information on the experimental techniques used. In Section 3 we describe the procedure used to generate the optical constants. In Section 4, specific information on deposition conditions of the materials is given, as well as reflectance measurements and optical constants.

2. Experimental techniques

Two deposition chambers pumped with cryopumps were used in this work. One of them was equipped with a 3-cm Kauffman ion gun that focused a 40 mA, 1 KeV Ar^+ beam onto a water-cooled target placed at about 45º to the ion beam. Discharge voltage was set to 40 V to avoid multiply-ionized ions. An Ar flow of 7.0 sccm was maintained. The ions sputtered target atoms that impinged perpendicularly onto a water-cooled float glass substrate placed 10 cm away from the target. 3 in diameter sputtering targets were used. The other chamber was used to deposit thin films of Cr by evaporation. Cr was evaporated from Mo boats and deposited onto non-cooled float glass substrates placed about 54 cm above the boat. Both chambers were equipped with residual gas analyzers. Base pressure in the sputtering chamber and evaporation chamber were $4x10^{-6}$ Pa and 10^{-6} Pa, respectively. Typical total pressures during deposition were $4x10^{-2}$ Pa in the sputtering chamber, and 10^{-5} Pa in the evaporation chamber. All films investigated in this paper were deposited and their reflectance measured at room temperature.

A McPherson model 247 grazing-incidence monochromator and a model 225 normal-incidence monochromator were used to make reflectance measurements on the deposited coatings in the 49.0 to 121.6 and 121.6 to 200 nm spectral regions, respectively, and are described elsewhere[2]. Accuracy of reflectance measurements is estimated to be ±0.01. Samples were transferred in air from the deposition chambers to the grazing incidence reflectometer and were exposed to atmosphere for 5 minutes or less, except for the Cr sample, which was stored in a desiccator for ~2 hours. For SiC samples, once their reflectance was measured with the grazing incidence monochromator, they were transferred as quickly as possible to the normal incidence monochromator for reflectance measurements at longer wavelengths, being exposed to atmosphere for ~3 minutes. Film thickness was obtained *in situ* with quartz crystal monitors.

Thickness of one or two samples of every material ranging ~20-40 nm was also measured with a Topo-3D non-contact interferometric surface profiler. Thickness accuracy is estimated to be within ±5%. Roughness measurements on IBD SiC and IBD Mo samples were obtained with the same instrument. Roughness of other materials was not determined.

3. Optical constant calculation

The method of sample preparation affects optical constants in the EUV. Even if we limit ourselves to optical constants of thin films, many parameters in the deposition may change the physical characteristics of the film: the deposition method (for instance, deposition by evaporation or sputtering, or even among different sputtering methods), film thickness, substrate temperature, partial pressures in the chamber, etc. We paid particular attention to the effect of thickness. Optical constant determination of a material has to keep in mind the application planned for the film. We deposited thin films of candidate materials for multilayer coatings in the EUV, where radiation is absorbed in a few tens of nanometers. For that reason, we measured optical constants on thin films. When the film is not completely opaque to radiation, the film/ substrate interface gives a small but not negligible contribution to the reflectance that has to be taken into account. In the optical constant calculation of thin films we took into account the interface thin film/ glass substrate. In the calculation we used optical constants of glass substrates that had been previously obtained.

The amplitude reflectance of the multilayer vacuum/ thin film/ glass substrate is given by:

$$r^{s,p} = \frac{r_{12}{}^{s,p} + r_{23}{}^{s,p}\exp(-2i\beta)}{1 + r_{12}{}^{s,p} r_{23}{}^{s,p}\exp(-2i\beta)} \qquad (1)$$

where $r_{ij}^{s,p}$ are the Fresnel reflection coefficients at the interface ij for both parallel (p) or perpendicular (s) electric vector. 1 stands for vacuum, 2 for the thin film and 3 for the substrate. β can be expressed as:

$$\beta = k_0 x\left(n_2{}^2 - n_1{}^2 sin^2\theta\right)^{1/2} \qquad (2)$$

where θ is the angle of incidence of the incident beam, x is the film thickness, n_1 is the refractive index of vacuum, n_2 is the complex refractive index of the thin film, and k_0 is the free space wavevector.

Radiation emerging from the monochromator onto the sample is partially polarized. The influence of polarization on reflectance can be described by a single parameter that will be referred to as the degree of polarization p:

$$p = \frac{I_p - I_s}{I_p + I_s} \qquad (3)$$

where I_p and I_s indicate the fraction of the incident intensity with the electric vector parallel and perpendicular, respectively, to the plane of incidence. With this notation, the reflectance (ratio of reflected to incident intensity) of the multilayer vacuum/ thin film/substrate for a certain degree of polarization is given by:

$$R = \frac{1+p}{2} R_p + \frac{1-p}{2} R_s \qquad (4)$$

where R_p and R_s are the intensity reflectance for p and s polarization, i.e. they equal the square modulus of the amplitude reflectance for parallel and perpendicular incidence, respectively, as they are given in Eq. 1.

When roughness data were available (IBD SiC and IBD Mo films) we incorporated its effect on the reflectance through the Debye-Waller factors:

$$\left(r^*\right)_{12}^{s,p} = r_{12}^{s,p} \exp\left[-2\left(\frac{2\pi\sigma\cos\theta}{\lambda}\right)^2\right] \qquad (5)$$

For materials whose roughness was measured, surface roughness was described through the rms roughness parameter σ of the vacuum/ film interface by replacing $r_{12}^{s,\,p}$ in Eq. 1 with $(r^*)_{12}^{s,\,p}$. The thin film/ substrate interface was assumed smooth, because reflection at the film/ substrate interface gives a small correction to the main reflectance component at the vacuum/ film interface, and the roughness correction is therefore negligible. The roughness correction even at the vacuum/ film interface was small. For instance, the measured rms roughness for SiC films was 0.7 nm. This roughness results in a calculated decrease in reflectance at normal incidence of 0.003 at 54.3 nm, and roughness effect is even less important at longer wavelengths and incidence angles farther away from the normal. Therefore, although roughness was taken into account for optical constant calculation on some materials, the error in the calculated reflectance when ignoring roughness is smaller than the reflectance measurement accuracy.

The search for the optical constants of films was made by minimization of the following merit function:

$$s_j^{\,2} = \sum_{i=1,\dots,m} \left\{ R^{\exp}{}_{\theta(i)} - R\left[\theta(i), n_j, k_j, p\right] \right\}^2 \qquad (6)$$

where $R^{\exp}{}_{\theta(i)}$ is the reflectance measured at the angle of incidence θ(i), and $R[\theta(i),n_j,k_j,p]$ is the calculated reflectance for the trial set (n_j,k_j) of optical constants in the iteration j, and for the partial polarization of the beam p as defined in Eq. 3. The number of angles of incidence was m=6. They were 15º, 30º, 45º, 60º, 75º, and 83º, all of them in the horizontal plane of incidence of the reflectometer. The degree of polarization p of the monochromators was previously obtained from reflectance measurements versus the angle of incidence in two perpendicular planes of incidence: a horizontal and a vertical plane. Measurements were made on float glass samples, the same as those used for substrates. Those measurements allowed us to obtain both the degree of polarization of the beam and the optical constants of glass, which were used in the calculation of the optical constants of the different materials.

Films were thick enough as to be able to neglect thickness errors in the optical constant calculation, since, as stated above, the reflection at the film/ substrate interface gives a small correction to the main reflectance component at the vacuum/ film interface. Thickness inaccuracies only affected the optical constant calculation for the thin and less absorbing IBD InSb films; therefore, in this case optical constant error bars were calculated. For other materials, estimated thickness errors of ±5% would result in calculated reflectance errors, at normal incidence, lower than or equal to 0.005 for current materials other than IBD InSb, and this is smaller than the reflectance measurement accuracy. Reflectance dependence on thickness errors decreases at angles farther away from the normal. Therefore, thickness errors on films other that IBD InSb can be neglected.

4. Reflectance measurements and optical constants of 5 materials

4.1 IBD SiC

The EUV reflectance and optical constants of SiC prepared with different techniques have been measured by a few authors. Choyke *et al.*[3] measured the high reflectance of chemical vapor deposited (CVD) SiC. Palik[4] compiled the available EUV optical constants of 6H SiC crystals. Reflectance at 45° on CVD, hot pressed, and reaction bonded SiC was measured by Kelly *et al.*[5]. Near normal reflectance of polished CVD SiC was measured by Keski-Kuha *et al.*[6]. Near normal reflectance of high density cast SiC was measured by Keski-Kuha *et al.*[7]. Regarding to thin films of SiC, Kortright and Windt[8] reported reflectance measurements and optical constants of SiC films deposited by magnetron sputtering. Keski-Kuha *et al.*[6] measured the near normal reflectance of IBD SiC. Schwarcz and Keski-Kuha[9, 10] measured the near normal reflectance of SiC prepared by IBD and by ion-assisted deposition and studied the degradation of the films.

EUV optical constants of IBD SiC have not been measured previously. For this study, thin films of SiC were prepared by IBD from a 99.999% purity, CVD SiC target. Deposition rate was 0.1 nm/s. Rms roughness of IBD SiC films was determined to be 0.7±0.2 nm. Fig. 1 shows the near normal reflectance (15°) of a 34-nm thick, SiC film exposed to atmosphere for about 2 minutes. Straight lines in this and the following figures are drawn to connect data points. Reflectance at other angles of incidence was measured immediately thereafter.

Thin films of IBD SiC are known to degrade after exposure to atmosphere by surface oxidation, the degradation rate slowing down with time and being almost completed after about 3 months[9]. A near normal reflectance drop of about 1-2% is expected for the film with respect to the reflectance of the sample kept in vacuum. Our reflectance is compared in Fig. 1 with that of magnetron sputtered films by Kortright and Windt [8] and that of CVD SiC [6]. As previously reported[6] IBD SiC has a lower reflectance than CVD SiC. IBD SiC near normal reflectance is close to that of magnetron sputtered SiC; the difference might be attributed to different age of the samples. Fig. 2 shows the optical constants n and k of IBD SiC calculated from reflectance measurements as a function of the angle of incidence. These data are also shown in Table 1. Fig. 2 compares also current optical constants with those in the literature. There is a good agreement with those of Kortright and Windt[8] for the magnetron sputtered films. Reflectance and optical constants of 6H SiC crystals[4] are somewhat different in the whole spectral region, but differ significantly at longer wavelengths, mainly at 200 nm. Differences in reflectance and optical constants may be attributed to the amorphous structure of the thin films compared to the bulk 6H SiC crystalline samples and to the possible incorporation of impurities in the different types of samples. No explanation was found for the large difference at 200 nm.

4.2 IBD Mo

Different authors have measured the EUV optical properties of Mo prepared with different techniques. Data on bulk Mo[11-15] as well as on films deposited by evaporation [16-19] are available in the literature.

We present our reflectance measurements and optical constants of IBD Mo. To our knowledge these are the first data in the present spectral region on Mo films prepared not only by IBD, but even by any sputtering technique. A 99.95% purity Mo sputtering target was used. Deposition rate was 0.16 nm/s. Rms roughness of IBD Mo films was determined to be 0.6±0.2 nm. Near normal reflectance measurements (15°) made on a fresh 25-nm thick film are shown in Fig. 3. Other data in the literature are also shown in Fig. 3 for comparison. IBD Mo normal incidence reflectance is considerably higher than for films prepared by evaporation. This may be related to the higher mobility of the sputtered atoms on the growing film, due to their higher kinetic energy, giving rise to denser and more perfect films. On the other hand, reflectance of bulk samples is slightly higher than our data for some studies[12], similar for others [11], and lower for the rest[13, 14].

The sample whose reflectance is shown in Fig. 3 was exposed to atmosphere for about 3 minutes during the transfer to the reflectometer. Reflectance loss in the EUV on IBD Mo films was observed to be very low for short time exposures; however, degradation did not slow down after long exposures to atmosphere and large reflectance losses were measured for samples stored in a desiccator for several months. Therefore we believe that reflectance shown in Fig. 3 should be very close to the reflectance of a sample unexposed to atmosphere. Fig. 4 shows Mo optical constants, n and k, calculated from reflectance measurements as a function of the angle of incidence. The data are also shown in Table 2. Current optical constants are compared to those of Weaver *et al.* [13] obtained on Mo crystals in Fig. 5. There is a reasonable qualitative agreement between both optical constant sets. The highest difference is at 49.0 nm, mainly for k. The IBD film is more absorbing at this wavelength, which is observable by a higher near normal reflectance. The differences may rise from the different crystalline state, which is a single crystallite for Weaver *et al.* [13], and a polycrystalline film for IBD film, and also from the different treatments undergone by the bulk sample, and maybe from a different exposure to atmosphere.

4.3 IBD Mg_2Si

Mg_2Si is a candidate spacer material for multilayer coatings in the soft x-ray and short EUV spectral regions [20-22]. In the EUV it is expected to work as a good spacer material in the spectral region from about 25 to 60 nm [23]. It is more stable than other low absorbing materials, like Mg[23]. To our knowledge there are no optical constant data available for this material in the spectral region above 40 nm.

A 30-nm thick Mg_2Si film was prepared by IBD at a rate of 0.16 nm/s. A Mg_2Si sputtering target of 99.5% purity was used. The sample was transferred to the reflectometer as quickly as possible, being exposed to atmosphere for about 3 minutes. The near normal reflectance (15º) is shown in Fig. 5. Reflectance measurements as a function of the angle of incidence were used to obtain the optical constants of Mg_2Si. The optical constants are shown in Fig. 6 and Table 3. The imaginary part of the refractive index increases almost monotonically with wavelength, except for a peak at 83.5 nm. The real part stays constant in the whole spectral region from 49 to 121.6 nm. Reflectance data shown in Fig. 5 correspond to thin films of a low absorbing material, mainly at short wavelengths, and interference between vacuum/ film interface and film/ substrate interface is important. As was stated above, the optical constant calculation took into account the reflectance of the multilayer vacuum/ film/ substrate. The sample might have reacted with atmosphere to some extent by the time that reflectance measurements were made. In fact some reflectance decrease was observed during the reflectance measurements, while the sample was in the reflectometer vacuum. The reflectance of the sample stored in a desiccator was observed to degrade over time. Aging data is shown in Table 4. Significant reflectance decrease was observed after a storage time of 10 days. After 10 days reflectance keeps decreasing, although at a smaller rate than for the first 10 days.

In summary, to our knowledge these are the first of Mg_2Si reflectance and optical constant measurements in the EUV above 49 nm. Since this material seems to react with atmosphere, new data on ultra high vacuum (UHV) deposited films with in situ reflectance measurements would be desirable in order to get conclusive data.

4.4 IBD InSb

Two sets of EUV optical constant data are available on InSb, which were reviewed by Palik [4]. Cardona *et al.* [24] made transmission measurements on evaporated thin films, either freely suspended on copper mesh or on transparent substrates of carbon. The films had a native oxide, since some of the preparation was done outside of vacuum. The other work was made by Philipp and Ehrenreich [25]. They measured reflectance on probably bulk samples that were polished and etched to remove distorted layers and oxides. After etching, the samples were shortly exposed to atmosphere.

We deposited 20-nm thick InSb films by IBD at a rate of 0.25-0.30 nm/s. An InSb sputtering target of 99.99% purity was used. The samples were transferred into the reflectometer as quickly as possible. They were exposed to atmosphere for about 5 minutes. The near normal reflectance (15°) of InSb is shown in Fig. 7. Reflectance measurements as a function of the angle of incidence were used to obtain the optical constants of InSb. The optical constants so obtained are shown in Fig. 8, and in Table 5. As in the case of Mg_2Si, the sample might have reacted with atmosphere to some extent by the time that reflectance measurements were made, and in particular some native oxide may have grown.

Our reflectance measurements are compared in Fig. 7 to those of Philipp and Ehrenreich. The big difference is due to interference between vacuum/ film and film/ substrate interfaces within our thin films, which are unusually low absorbing (see k values in Fig. 8). In fact InSb, as well as Mg_2Si, were investigated for their potential as spacer materials for multilayer coatings. In the same figure we plot the calculated reflectance of a film thick enough to avoid interference; the optical constants shown in Fig. 8 were used in the calculation. The agreement with Philipp's and Ehrenreich's data is now much better, with the exception at 83.5 nm, where our calculated reflectance is higher, and at 58.0 nm and below, where our calculated reflectance is lower. The optical constants obtained in this work are also compared to those of Philipp and Ehrenreich. Current data for the real part of the refractive index are lower than those measured by Philipp and Ehrenreich[25], although they are in certain qualitative agreement. Current data for the imaginary part are lower than those of Philipp and Ehrenreich[25] and Cardona (as presented by Palik [4]) in the spectral region of 67.2 nm and below. At 92.0 nm and above again our data are lower than those of Philipp and Ehrenreich, the only available data. Between 67.2 and 92.0 nm, the three data sets are similar, with a peak at 83.5 nm only obtained in the present work. The InSb films prepared in this work are somewhat thin. Hence, due to the low absorption of InSb films, the obtained optical constants are more dependent on the accuracy of the film thickness and on the glass substrate optical constants than all the other materials investigated in this paper. We derived the optical constant error bars by using a range of film thickness values in the optical constant calculation.

As in the case of Mg_2Si, new data on samples deposited and measured in situ in UHV would be desirable in order to obtain conclusive optical constants of InSb.

4.5 Evaporated Chromium

Different authors have measured the EUV optical constants of Cr. Girault *et al.* [26] deposited thin films of Cr by evaporation on both room temperature and 623-K heated substrates. They measured reflectance at two angles of incidence, and obtained the dielectric constant of Cr using the Fresnel equations. Udoev [27] measured the near normal reflectance of a solid, electrolytically polished, Cr polycrystalline sample, and obtained the imaginary part of the dielectric constant using the Kramers-Kronig relations. Wehenkel and Gauthé [28, 29] measured electron energy loss spectra on evaporated Cr films and obtained the dielectric constant of Cr [28] and its absorption coefficient[29]. In the compilation made by Weaver *et al.* [30] they refer to unpublished reflectance data made by Olson and Lynch in the spectral region 4-30 eV on electropolished bulk samples of Cr. Using the Kramers-Kronig relations they obtained the dielectric constant, conductivity, energy loss function and absorption coefficient. All the above data from the different authors were obtained on samples that were exposed to atmosphere for some time before being measured.

We prepared a 28-nm thick Cr sample on a room temperature substrate by evaporation. Deposition rate was 0.3 nm/s and material purity was 99.99%. In Fig. 9 we present the near normal reflectance (15°) of the sample, that was stored in a desiccator for about 2 hours. In Fig. 9 we also present the near normal reflectance measured by Girault *et al.*[26], Olson and Lynch[30], and Udoev[27]. There are important differences among all the data. Our data are closer to those of Girault *et al*[26]. for the heated substrate sample, except for a peak centered around 83 nm that we measured, and was not observed by Girault *et al.* [26]. Olson and Lynch[30] obtained a similar peak on their bulk sample. At shorter wavelengths the latter reflectance is higher, and at longer wavelengths it is somewhat lower than our data. It is interesting to note that our reflectance data are considerably higher than those of Girault *et al.*[26] for the room temperature sample, which in principle was prepared in similar conditions, and our data are even higher than that for the heated substrate. Our film is thinner than that of Girault *et al.*[26] (100-140 nm). Constructive interference with the film/ substrate interface gives a negligible increase in reflectance, except at 121.6 nm, where the increase is of the order of 1%, much lower than reflectance difference among both sets of data.

The optical constants of Cr were also obtained from reflectance measurements as a function of the angle of incidence. Fig. 10 shows our results compared to those of Olson and Lynch[30], and those of Girault *et al.*[26] that were obtained with the sample prepared on room temperature substrate. Table 6 shows our optical constants for Cr. There is a large difference in the imaginary part of the refractive index between the results of Girault *et al.*[26] and our results. There is a much better agreement with data of Olson and Lynch[30], except at 121.6 nm, where our k is higher. The difference in the real part of the refractive index among authors is much smaller. One explanation for the differences among films prepared by evaporation would be that EUV optical properties of Cr might depend on exposure to atmosphere, and/or differences in crystallinity, density, and/or stress, as it is the case for other materials. A thinner film might be denser and become less and less dense with increasing thickness. Depositing onto a heated substrate may increase atom mobility, resulting in a lower density of voids, more compact film, and better EUV performance. Differences between films and bulk samples are common in the EUV, and may be caused by differences in density, crystalline orientation, or surface quality.

Anyway, in order to have definitive data, new measurements on UHV deposited and in situ measured samples would be desirable.

Summary

We have presented here the reflectance and optical constants of IBD SiC, IBD Mo, IBD Mg_2Si, IBD InSb, and evaporated Cr in the EUV spectral region between 49 and 200 nm. These materials were investigated as candidate materials for multilayer coatings in the above spectral region, where in general complete and reliable optical constant data are not available.

No optical constant data for films of the above materials prepared by IBD were available in the literature, and reflectance data for films prepared by this technique was only available for SiC. No data at all were available for Mg_2Si prepared in any manner. Our reflectance and optical constants were compared to the most relevant data in the literature, when available, for bulk samples or films prepared by any technique. Our results show that IBD Mo films show higher reflectance than films prepared by other techniques and close to bulk materials. It is suggested that IBD might be a suitable technique to deposit thin films of transition metals on room temperature substrates, to avoid high substrate temperatures necessary when deposited by evaporation.

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30. Unpublished data of Olson and Lynch as referred to by J. H. Weaver, C. Krafka, D. W. Lynch, E. E. Koch, “Physik Daten- Optical properties of metals”, **18-1**, ed. by Fachinformationszentrum, Karlsruhe, 1981.

Figure Captions

Fig. 1. Near normal incidence reflectance of IBD SiC films compared to data of Ref. 8 for magnetron sputtered SiC films and Ref. 6 for CVD SiC.

Fig. 2. Refractive index (a) and extinction coefficient (b) of IBD SiC films compared to data of Ref. 8 for magnetron sputtered SiC films and Ref. 4 for 6H SiC crystals.

Fig. 3. Near normal incidence reflectance of IBD Mo films compared to data of Kress and Lapeyre (Ref. 16), Windt *et al.* (Ref. 19), Weaver *et al.* (Ref. 13), Juenker *et al.* (Ref. 12), LeBlanc *et al.* (Ref. 11), and Black *et al.* (Ref. 14).

Fig. 4. Refractive index (a) and extinction coefficient (b) of IBD Mo films compared to data of Ref. 13 for Mo crystals

Fig. 5. Near normal incidence reflectance of IBD Mg_2Si films.

Fig. 6. Refractive index and extinction coefficient of IBD Mg_2Si films.

Fig. 7. Near normal incidence reflectance of IBD InSb films compared to data of Ref. 25 for bulk samples and to calculated reflectance for a thick film with the InSb optical constants determined in this paper.

Fig. 8. Refractive index (a) and extinction coefficient (b) of IBD InSb films compared to data of Ref. 24 for evaporated films and Ref. 25 for bulk samples.

Fig. 9. Near normal incidence reflectance of Cr films deposited by evaporation compared to data of Girault *et al.* (Ref. 26), Olson and Lynch (as published in Ref. 30), and Udoev (Ref. 27).

Fig. 10. Refractive index (a) and extinction coefficient (b) of Cr films deposited by evaporation compared to data of Girault *et al.* (Ref. 26) for films prepared by evaporation, and data of Olson and Lynch (Ref. 30) for bulk samples.

Table 1. Optical constants of IBD SiC.

Wavelength (nm)	n	k
54.3	0.55	0.37
58.0	0.52	0.41
67.2	0.48	0.63
74.0	0.49	0.80
83.5	0.58	1.07
92.0	0.63	1.18
104.8	0.74	1.34
121.6	0.97	1.64
143.6	1.25	1.88
160.8	1.56	2.06
200.0	2.30	2.10

Table 2. Optical constants of IBD Mo

Wavelength (nm)	n	k
49.0	0.56	0.67
54.3	0.55	0.74
58.0	0.57	0.82
67.2	0.74	1.10
74.0	0.94	1.08
83.5	0.98	1.08
87.8	1.06	1.09
92.0	1.01	1.04
102.6	1.12	0.98
113.5	0.89	0.89
121.6	0.78	1.03

Table 3. Optical constants of IBD Mg_2Si

Wavelength (nm)	n	k
58.0	0.80	0.20
67.2	0.80	0.20
74.0	0.79	0.26
83.5	0.80	0.49
92.0	0.79	0.40
104.8	0.81	0.52
121.6	0.79	0.68

Table 4. Reflectance of fresh Mg_2Si sample, and the sample stored in a desiccator.

Wavelength (nm)	74.0	92.0	104.8	121.6
Shortly exposed to atmosphere	0.025	0.082	0.128	0.207
10 days	0.0078	0.038	0.063	0.130
16 days	0.0075	0.033	0.056	0.120

Table 5. Optical constants of IBD InSb

Wavelength (nm)	n	k
49.0	0.97±0.02	0.031±0.015
54.3	0.95±0.01	0.055±0.010
58.0	0.92±0.015	0.085±0.025
67.2	0.90±0.01	0.15±0.035
74.0	0.86±0.01	0.18±0.03
83.5	0.76±0.015	0.33±0.05
92.0	0.73±0.015	0.27±0.03
104.8	0.65±0.01	0.42±0.07
121.6	0.58±0.03	0.63±0.05

Table 6. Optical constants of Cr films deposited by evaporation

Wavelength (nm)	n	k
54.3	0.81	0.50
58.0	0.78	0.52
74.0	0.91	0.67
83.5	1.02	0.81
87.8	1.03	0.77
92.0	1.01	0.73
102.6	1.07	0.74
121.6	1.05	0.85

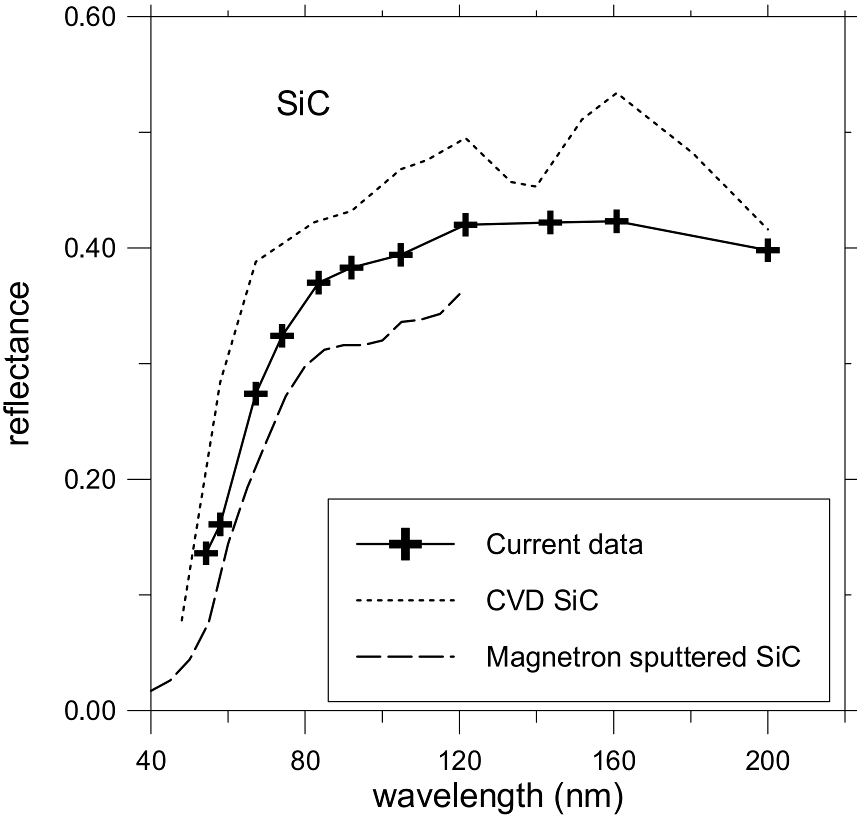
SiC
reflectance
0.60
0.40
0.20
0.00
40
80
120
160
200
wavelength (nm)
Current data
CVD SiC
Magnetron sputtered SiC

Fig 1

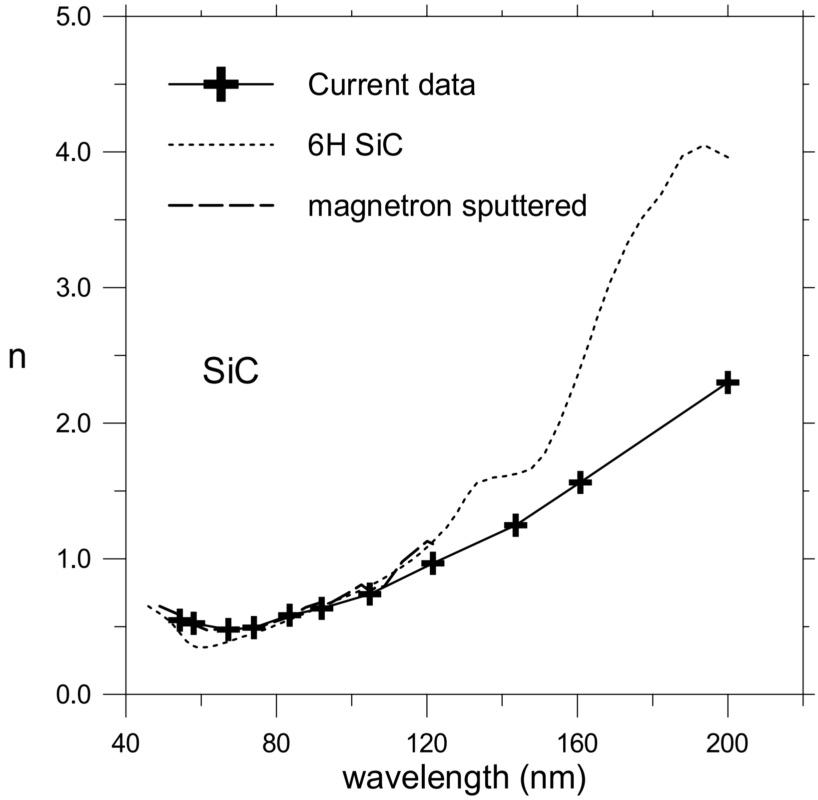
5.0
4.0
3.0
2.0
1.0
0.0
n
40
80
120
160
200
wavelength (nm)
Current data
6H SiC
magnetron sputtered
SiC

Fig. 2a

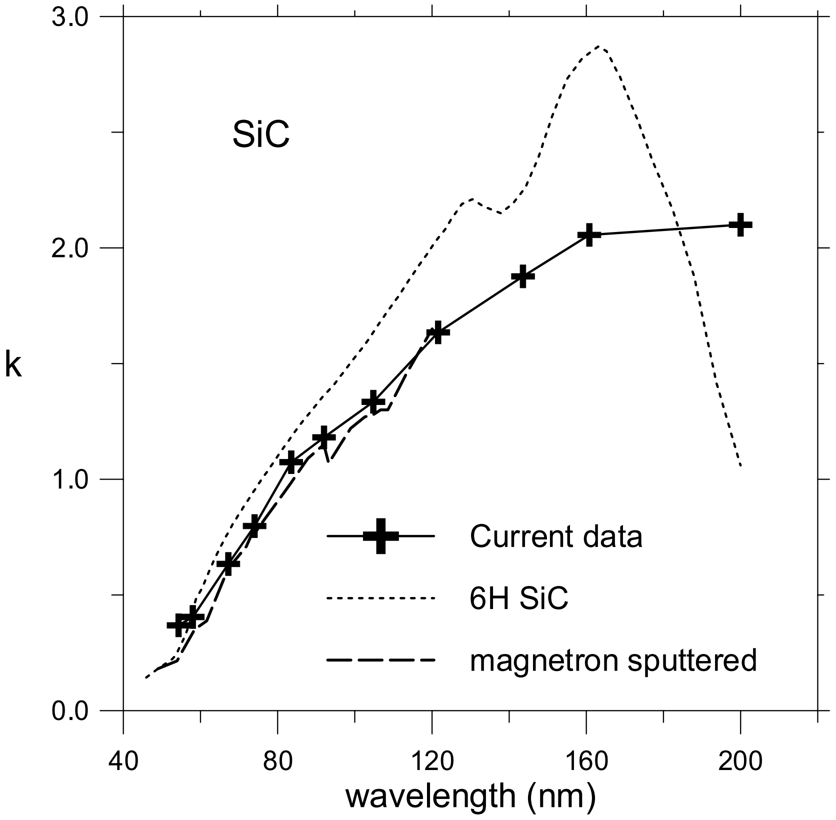
SiC
k
wavelength (nm)
0.0
1.0
2.0
3.0
40
80
120
160
200
Current data
6H SiC
magnetron sputtered

Fig. 2b

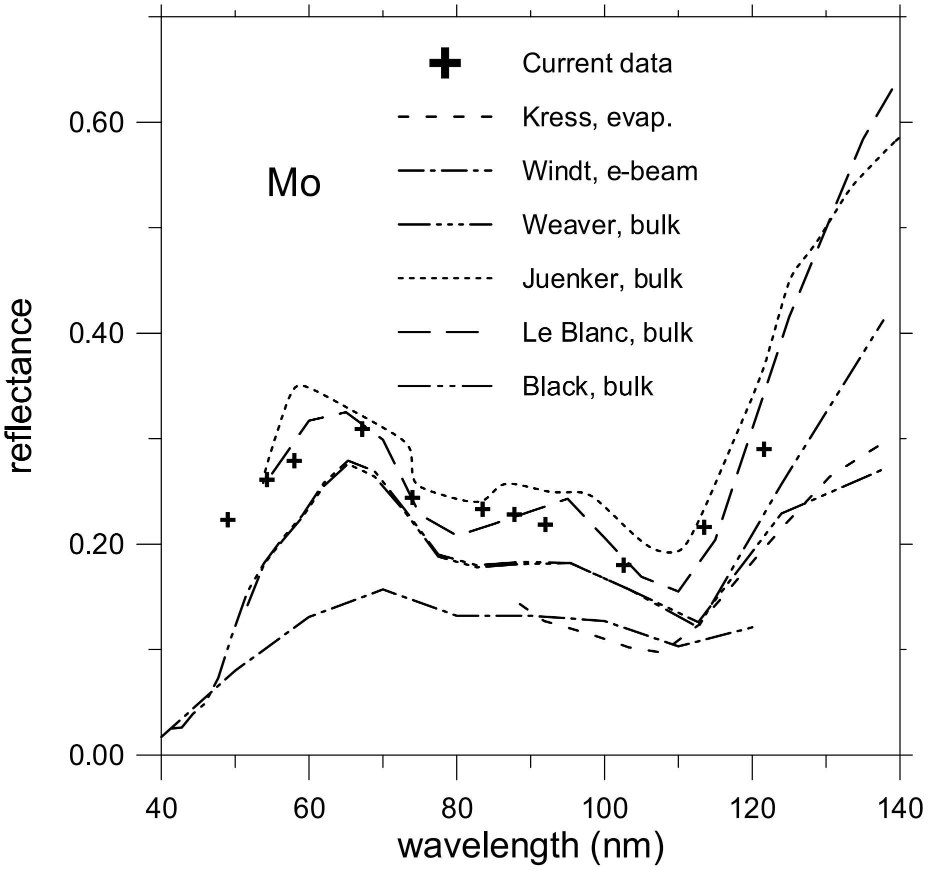
Mo
Current data
Kress, evap.
Windt, e-beam
Weaver, bulk
Juenker, bulk
Le Blanc, bulk
Black, bulk
reflectance
0.00
0.20
0.40
0.60
wavelength (nm)
40
60
80
100
120
140

Fig. 3

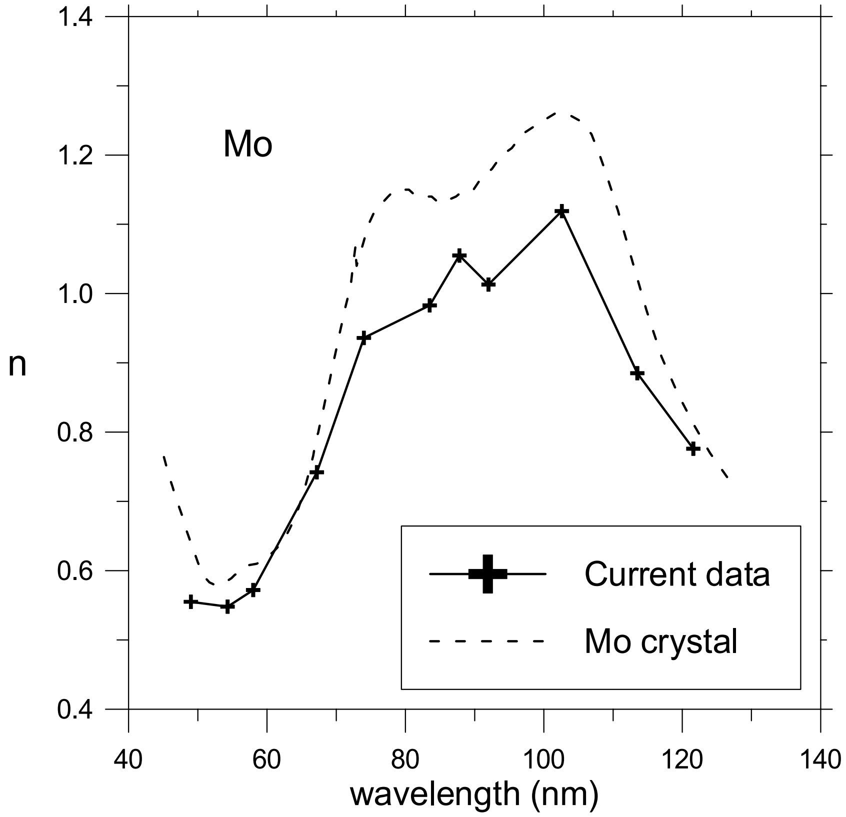
Mo
n
1.4
1.2
1.0
0.8
0.6
0.4
40
60
80
100
120
140
wavelength (nm)
Current data
Mo crystal

Fig. 4a

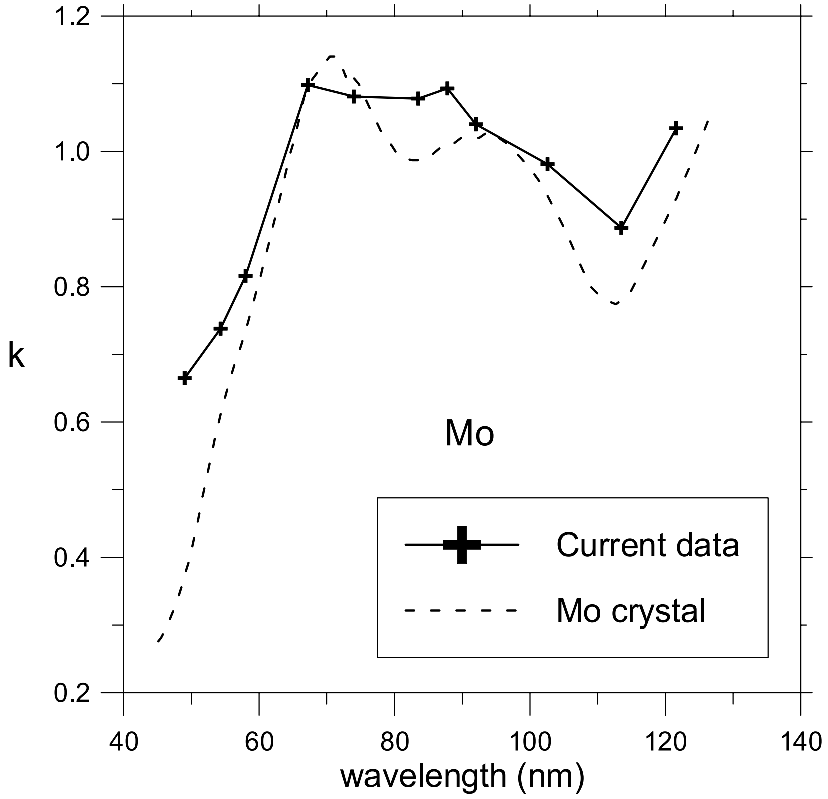
k
wavelength (nm)
1.2
1.0
0.8
0.6
0.4
0.2
40
60
80
100
120
140
Mo
Current data
Mo crystal

Fig. 4b

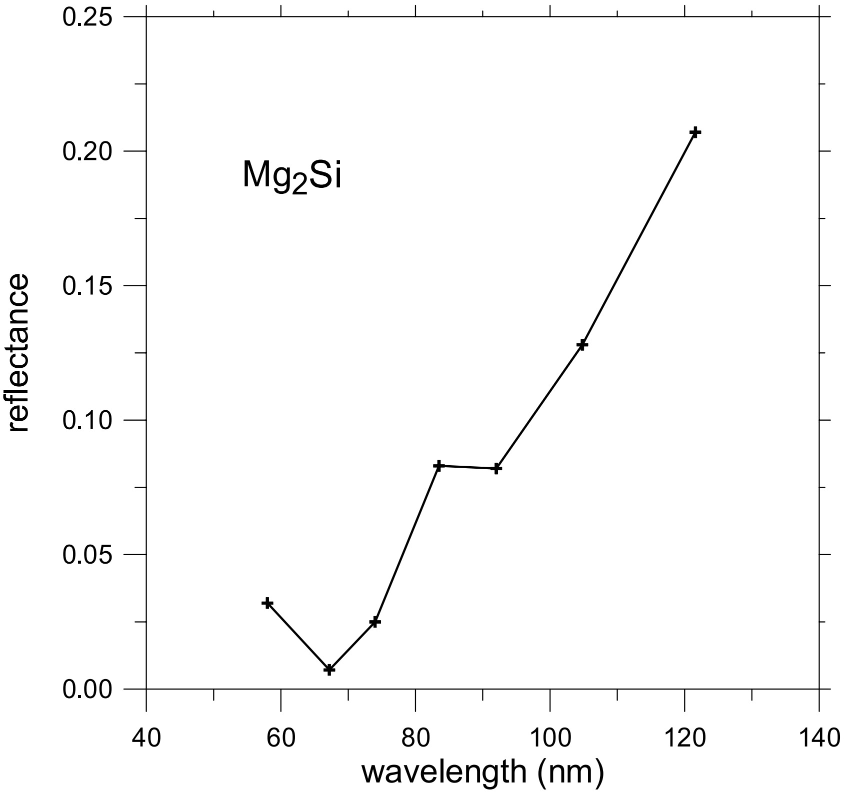
Mg$_2$Si
reflectance
wavelength (nm)
0.00
0.05
0.10
0.15
0.20
0.25
40
60
80
100
120
140

Fig. 5

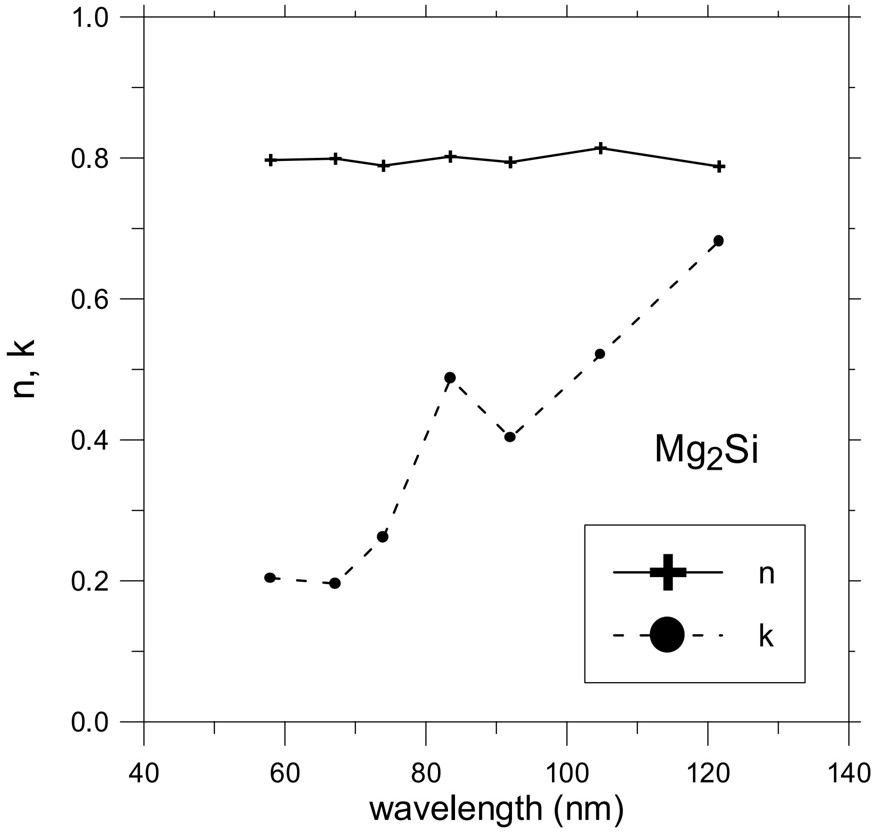

Fig. 6

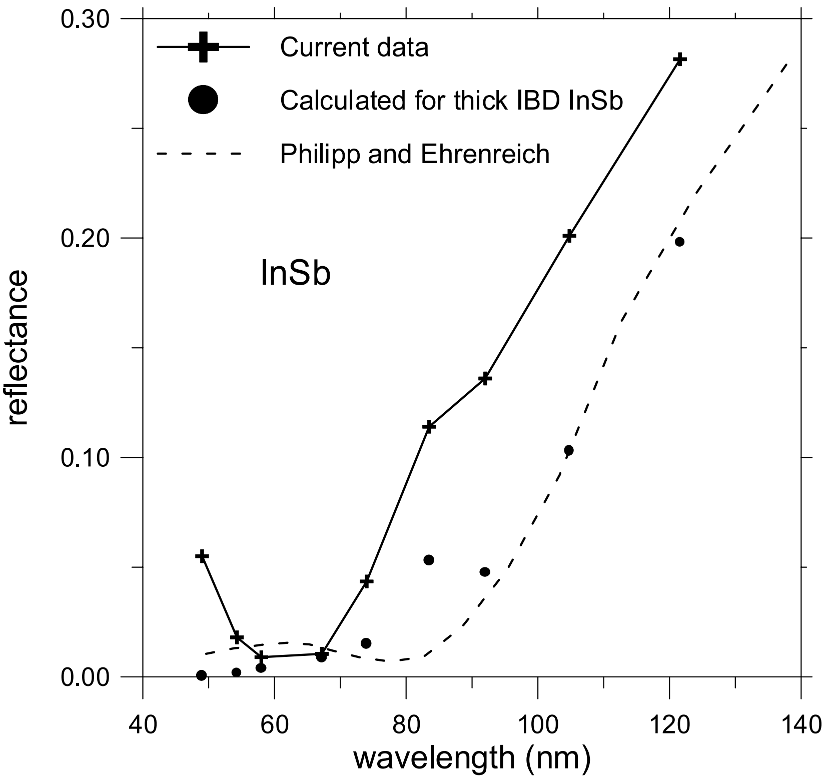
Current data
Calculated for thick IBD InSb
Philipp and Ehrenreich
InSb
reflectance
0.30
0.20
0.10
0.00
40
60
80
100
120
140
wavelength (nm)

Fig. 7

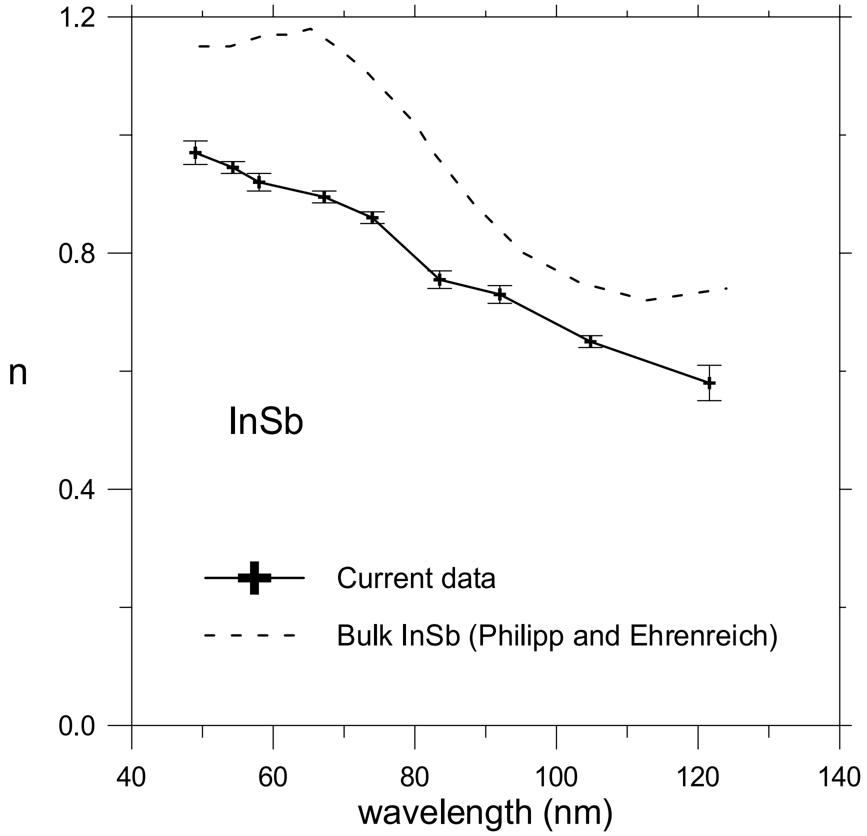
1.2
0.8
0.4
0.0
n
InSb
Current data
Bulk InSb (Philipp and Ehrenreich)
40
60
80
100
120
140
wavelength (nm)

Fig 8a

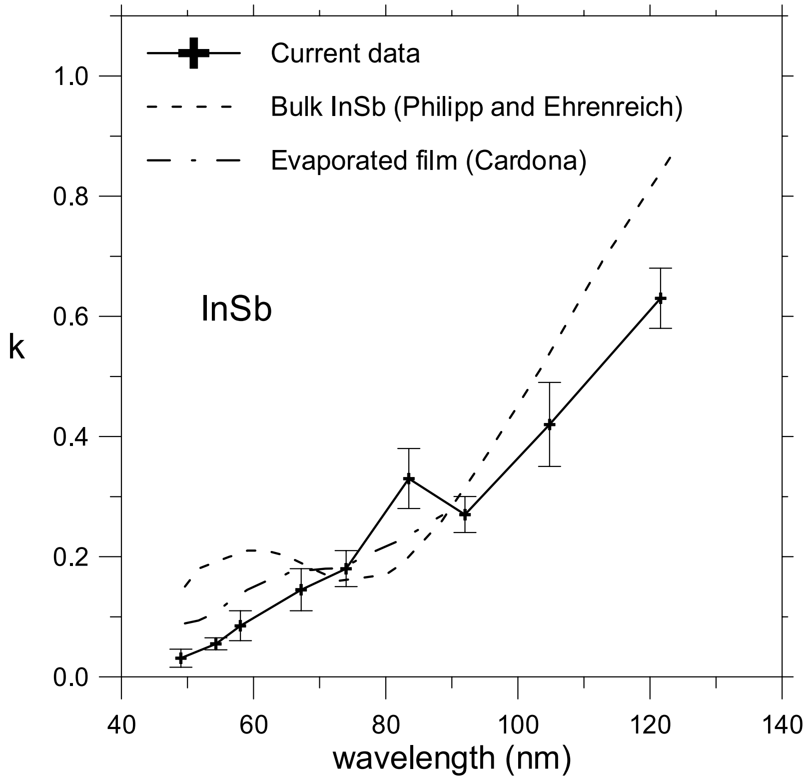
Current data
Bulk InSb (Philipp and Ehrenreich)
Evaporated film (Cardona)
InSb
k
1.0
0.8
0.6
0.4
0.2
0.0
40
60
80
100
120
140
wavelength (nm)

Fig. 8b

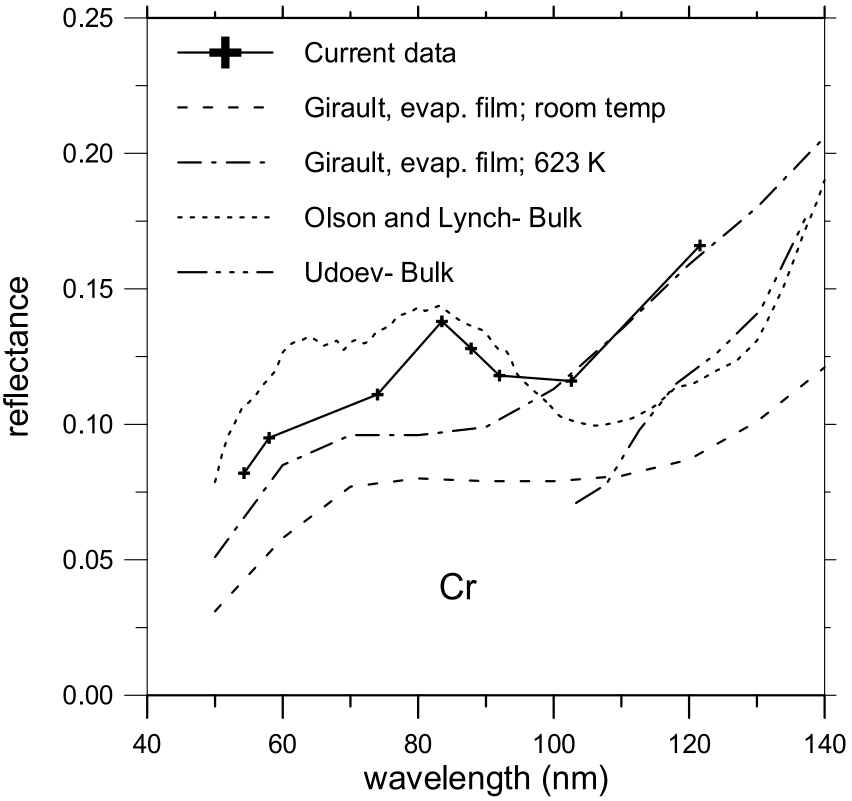
Current data
Girault, evap. film; room temp
Girault, evap. film; 623 K
Olson and Lynch- Bulk
Udoev- Bulk
Cr
reflectance
0.25
0.20
0.15
0.10
0.05
0.00
40
60
80
100
120
140
wavelength (nm)

Fig. 9

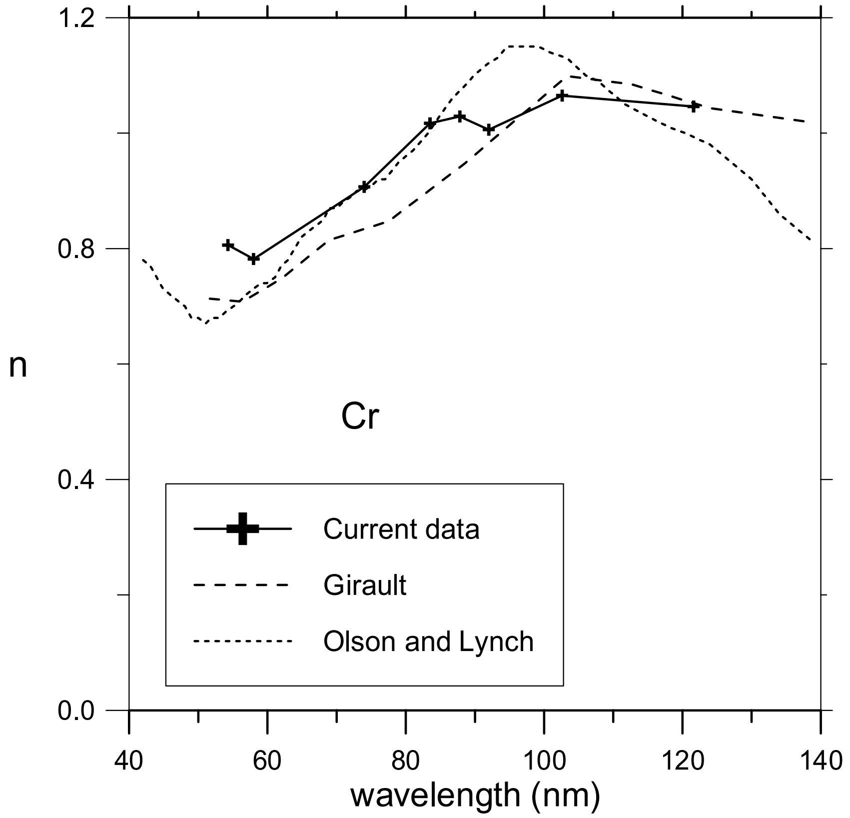
1.2
0.8
0.4
0.0
n
Cr
Current data
Girault
Olson and Lynch
40
60
80
100
120
140
wavelength (nm)

Fig. 10a

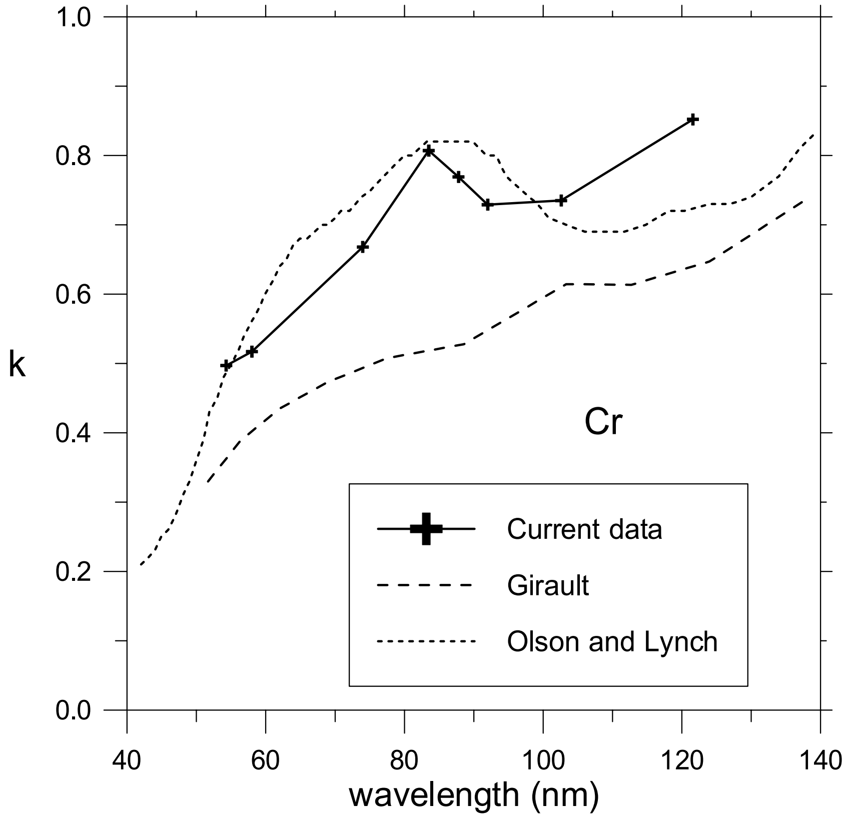
1.0
0.8
0.6
0.4
0.2
0.0
k
40
60
80
100
120
140
wavelength (nm)
Cr
Current data
Girault
Olson and Lynch

Fig. 10b