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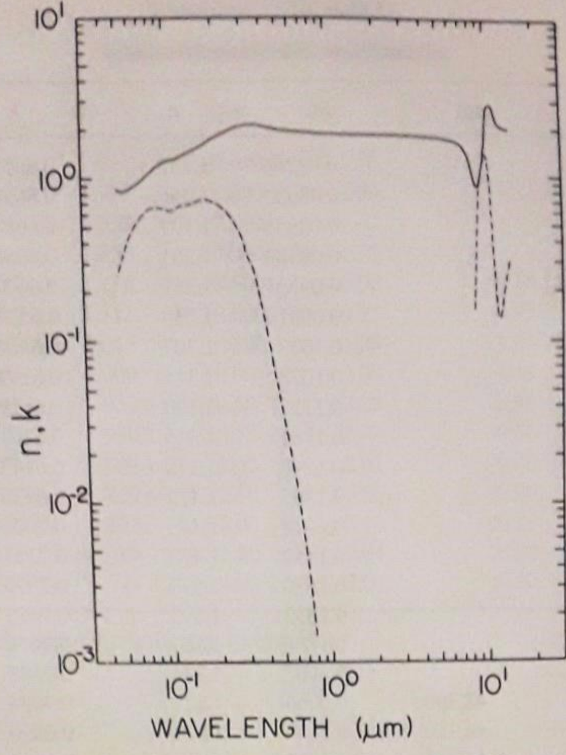

Fig. 11. Log–log plot n (——) and k (----) versus wavelength in micrometers for silicon monoxide (noncrystalline).

TABLE XI
Values of n and k for Silicon Monoxide (Noncrystalline) from Various References [a]

eV	cm^{-1}	μm	n	k
25		0.04959	0.8690 [2]	0.2717 [2]
24		0.05166	0.8444	0.3060
23		0.05391	0.8371	0.3505
22.5		0.05510	0.8391	0.3761
22		0.05636	0.8454	0.3987
21.5		0.05767	0.8519	0.4222
21		0.05904	0.8610	0.4456
20.5		0.06048	0.8721	0.4688
20		0.06199	0.8853	0.4919
19.5		0.06358	0.9007	0.5140
19		0.06526	0.9178	0.5362
18.5		0.06702	0.9376	0.5578
18		0.06888	0.9596	0.5771
17.5		0.07085	0.9825	0.5961
17		0.07293	1.008	0.6147
16.5		0.07514	1.036	0.6309
16		0.07749	1.066	0.6453
15.5		0.07999	1.098	0.6566

(continued)

TABLE XI (*Continued*)

Silicon Monoxide (Noncrystalline)

eV	cm^{-1}	μm	n	k
15		0.08266	1.132	0.6651
14.5		0.08551	1.166	0.6692
14		0.08856	1.199	0.6698
13.5		0.09184	1.231	0.6666
13		0.09537	1.259	0.6602
12.5		0.09919	1.283	0.6523
12		0.1033	1.307	0.6464
11.5		0.1078	1.311	0.6293
11		0.1127	1.320	0.6529
10.5		0.1181	1.345	0.6701
10		0.1240	1.378	0.6843
9.5		0.1305	1.412	0.6920
9		0.1378	1.445	0.7002
8.5		0.1459	1.482	0.7153
8		0.1550	1.530	0.7333
7.5		0.1653	1.593	0.7473
7		0.1771	1.667	0.7479
6.5		0.1907	1.746	0.7348
6	48,390	0.2066	1.829	0.7084
5.75	46,380	0.2156	1.871	0.6890
5.5	44,360	0.2254	1.914	0.6663
5.25	42,340	0.2362	1.957	0.6383
5	40,330	0.2480	2.001	0.6052
4.8	38,710	0.2583	2.034	0.5723
4.6	37,100	0.2695	2.066	0.5364
4.4	35,490	0.2818	2.094	0.4948
4.2	33,880	0.2952	2.119	0.4499
4	32,260	0.3100	2.141	0.4006
3.8	30,650	0.3263	2.157	0.3453
3.6	29,040	0.3444	2.162	0.2872
3.4	27,420	0.3647	2.160	0.2287
3.2	25,810	0.3875	2.144	0.1706
3	24,200	0.4133	2.116	0.1211
2.8	22,580	0.4428	2.085	0.08374
2.6	20,970	0.4769	2.053	0.05544
2.4	19,360	0.5166	2.021	0.03533
2.2	17,740	0.5636	1.994	0.02153
2	16,130	0.6199	1.969	0.01175
1.8	14,520	0.6888	1.948	0.00523
1.6	12,900	0.7749	1.929	0.00151
1.4	11,290	0.8856	1.913	
1.240	10,000	1.000	1.87 [1]	
0.6199	5,000	2.000	1.84	
0.4133	3,333	3.000	1.82	
0.3100	2,500	4.000	1.80	
0.2480	2,000	5.000	1.75	

TABLE XI (*Continued*)

Silicon Monoxide (Noncrystalline)

eV	cm^{-1}	μm	n	k
0.2066	1,667	6.000	1.70	
0.1771	1,492	7.000	1.60	
0.1653	1,333	7.500	1.42	
0.1550	1,250	8.000	1.15	
0.1459	1,176	8.500	0.90	0.18 [1]
0.1378	1,111	9.000	0.91	0.75
0.1305	1,053	9.500	1.20	1.20
0.1240	1,000	10.00	2.00	1.38
0.1181	952.4	10.50	2.85	0.90
0.1153	930.2	10.75	2.86	0.58
0.1127	909.1	11.00	2.82	0.40
0.1078	869.6	11.50	2.50	0.20
0.1033	833.3	12.00	2.13	0.14
0.09537	769.2	13.00	2.04	0.20
0.08856	714.3	14.00	2.01	0.30

[a] References are indicated in brackets.

Silicon Monoxide (SiO) (Noncrystalline)

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Silicon monoxide (SiO) is used as a protective layer and antireflecting coating in optical applications and as the dielectric material in certain microelectronic devices. These layers are generally prepared by the rapid evaporation of silicon monoxide under high-vacuum conditions. If the deposition is carried out slowly in the presence of a partial pressure of oxygen, the condensate acquires excess oxygen and the O-to-Si-atom ratio rises above unity. These materials are often labeled SiO_x ($x > 1.0$). The optical properties of SiO and SiO_x are different, and the values given here should only be applied to materials of stoichiometry SiO. For completeness, references will be given that also describe the optical behavior of SiO_x materials.

Although SiO has some important applications, it is a rather dull material from an optical point of view. For this and other reasons, there is not very much information available on its optical properties. However, in the visible and near-ultraviolet spectral regions in which data from several sources can be compared, the results agree with one another quite well. This would indicate that SiO is a reasonably well defined material, when prepared in the absence of oxygen, with definitive optical properties.

A set of optical parameters n and k for noncrystalline SiO are given in Table XI and plotted in Fig. 11 for the wavelength region 14.0 μm $\geq \lambda \geq$ 0.050 μm. The wavelength λ, index of refraction n, and extinction coefficient k are given to four places in most of the table entries. The accuracy of the values does not warrant this precision. This is done to show the possible presence of weak structure in the optical properties that can often be discerned by comparison of precise, but not necessarily accurate, values over small wavelength ranges.

In the infrared, 14.0 μm $\geq \lambda \geq$ 1.00 μm, the values given in the table were obtained from Hass and Salzberg [1]. The values were derived through analysis of transmittance and reflectance measurements on a series of SiO layers

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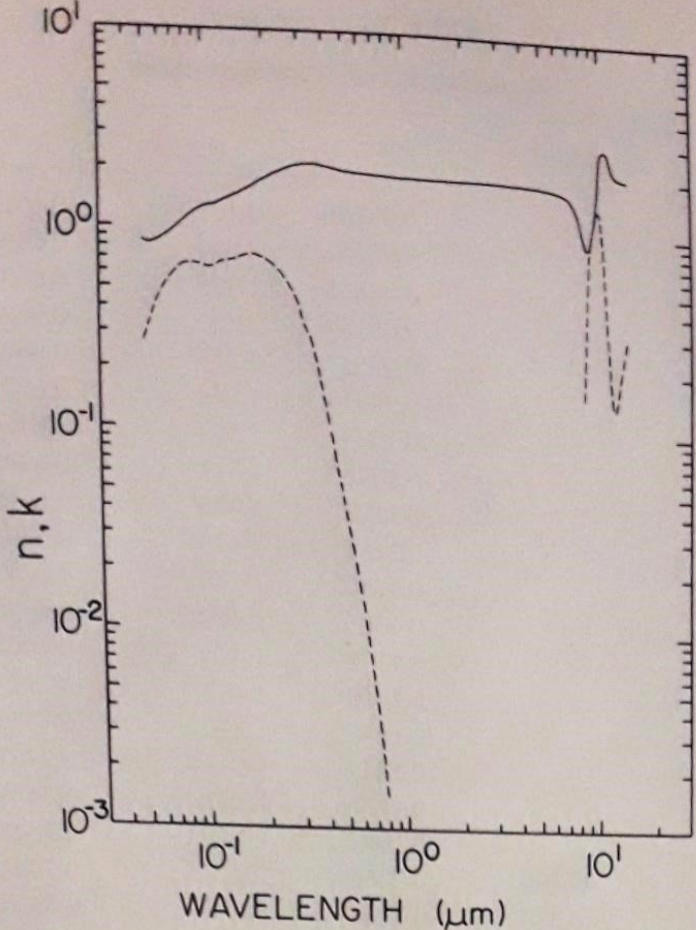
of various thicknesses. Although the overall accuracy of these values cannot be simply specified, they fit the measured transmittance and reflectance to within $\pm 2\%$.

In the region $1.00\ \mu m \geq \lambda \geq 0.049\ \mu m$, the values are taken from Philipp [2]. They were derived from Kramers–Kronig (KK) analysis of reflectance data augmented by transmission measurements in the region of low absorption. These results agree reasonably well with those of Hass and Salzberg [1], whose measurements extend to $0.24\ \mu m$, as well as with the absorption data of Cremer *et al.* [3]. The results of Philipp are given in the table because they cover a wider wavelength range and more explicitly evaluate the extinction coefficient in the region of low absorption compared to the other measurements. They are not necessarily more accurate than those of Hass and Salzberg [1] and Cremer [3]. The differences that are found in these measurements [1–3], $\pm 5\%$ or less in n and slightly larger in k, may be due in part to sample preparation (evapoaration rate, vacuum conditions, substrate temperature, etc.), and as stated earlier, it is encouraging that they agree as well as they do. It should also be pointed out that the table values at the shorter wavelengths, especially those below $0.100\ \mu m$, depend somewhat on the extrapolation used in the KK analysis and should be treated with caution until more definitive measurements are made for $\lambda \leq 0.05\ \mu m$, which more clearly delineate the proper reflectance extrapolation.

It is recommended that anyone who uses the table carefully examine the measurements and references cited in the references discussed [1–3] as well as other references [4–7] that also describe the optical behavior of materials of stoichiometry SiO_x ($x > 1$).

REFERENCES

1. G. Hass and C. D. Salzberg, *J. Opt. Soc. Am.* **44**, 181 (1954).
2. H. R. Philipp, *J. Phys. Chem. Solids* **32**, 1935 (1971).
3. E. Cremer, T. Kraus, and E. Ritter, *Z. Elektrochem.* **62**, 939 (1958).
4. E. Ritter, *Opt. Acta* **9**, 197 (1962).
5. A. P. Bradford and G. Hass, *J. Opt. Soc. Am.* **53**, 1096 (1963).
6. G. Hass, *J. Am. Ceramic Soc.* **33**, 353 (1950).
7. A. P. Bradford, G. Hass, M. McFarland, and E. Ritter, *Appl. Opt.* **4**, 971 (1965).



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0.1181	952.4	10.50	2.85	0.90
0.1153	930.2	10.75	2.86	0.58
0.1127	909.1	11.00	2.82	0.40
0.1078	869.6	11.50	2.50	0.20
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