# Thermionics Laboratory Inc.

| NAME | SYMBOL | MELTING POINT °C | DENSITY g/cc | $10^{-8}$ TORR | $10^{-6}$ TORR | $10^{-4}$ TORR | LINER | NOTES N=INDEX OF REFRACTION |
|---|---|---|---|---|---|---|---|---|
| Aluminum | Al | 660 | 2.70 | 677 | 821 | 1010 | BN, CG | Alloys and wets May fill volume 70% 1 |
| Aluminum Carbide | $Al_4C_3$ | 1400 | 2.36 | | | ~800 | | N=2.7 3 |
| Aluminum Floride | $AlF_3$ | 1257 Subl. | 3.07 | 410 Subl. | 490 Subl. | 700 Subl. | G, W, MO | N=1.38 @ .55µ 4 |
| Aluminum Nitride | AlN | Subl. | 3.26 | | | ~1750 | | Decomposes Reactive evaporate in $10^{-3}N_2$ with glow discharge 3 |
| Aluminum Oxide (alumina) | $Al_2O_3$ | 2045 | 3.97 | | | 1500 | | N=1.66 forms smooth hard films 1 |
| Antimony | Sb | 630 | 6.68 | 279 Subl. | 345 Subl. | 425 Subl. | BN, G, $Al_2O_3$ | Toxic. Evaporates well, film structure is rate-dependent 1 |
| Antimony Trioxide | $Sb_2O_3$ | 656 | 5.2 or 5.76 | Subl. | Subl. | Subl. | BN, $Al_2O_3$ | Toxic, decomposes on W.n=2.05 3 |
| Antimony Trisulphide | $Sb_2S_3$ | 550 | 4.64 | | | ~200 | $Al_2O_3$ | N=3.01 @ .55µ . No decpomposition 3 |
| Arsenic | As | 814 | 5.73 | 107 Subl. | 150 Subl. | 210 Subl. | $Al_2O_3$ CG | Toxic. Sublimes rapidly at low temp. 4 |
| Arsenic Trisulphide | $As_2S_3$ | 300 | 3.43 | | | ~400 | $Al_2O_3$ | N=2.8 3 |
| Barium | Ba | 710 | 3.78 | 545 | 627 | 735 | MO | Wets w/o alloying-reacts with ceramics 3 |
| Barium Floride | $BaF_2$ | 1280 | 4.83 | Subl. | Subl. | ~700 Subl. | | N=1.29 @ 5µ Density rate dependent 2 |
| Barium Oxide | BaO | 1923 | 5.72 or 5.32 | | | ~300 | $Al_2O_3$ | Decomposes slightly n=1.98 4 |
| Beryllium | Be | 1278 | 1.85 | 710 | 875 | 100 | G, CG | Wets W, Mo, Ta metal powders and oxides are toxic 1 |
| Beryllium Fluoride | $BeF_2$ | 800 | 1.99 | Subl. | Subl. | ~200 | | Toxic 2 |
| Beryllium Oxide | BeO | 2530 | 3.01 | | | 1900 | | Powders are toxic. No decomposition n=1.72 2 |
| Bismuth | Bi | 271 | 9.80 | 330 | 410 | 520 | CG, $Al_2O_3$ | Vapors are toxic. 1 |
| Bismuth Oxide | $Bi_2O_3$ | 820 | 8.90 | | | ~1400 | | Vapors are toxic. N=2.55 1 |

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|---|---|---|---|---|---|---|---|---|
| Boron | B | 2100 | 2.36 | 1278 Subl. | 1548 Subl. | 1797 Subl. | G | Material explodes with rapid cooling. Forms carbide with container 1 |
| Boron Carbide | $B_4C$ | 2350 | 2.50 | 2500 | 2580 | 2650 | | Similar to chromium. 1 |
| Boron Nitride | BN | 2300 | 2.20 | Subl. | Subl. | ~1600 Subl. | | Decomposes. 4 |
| Boron Oxide | $B_2O_3$ | 460 | 1.82 | | | ~1400 | | N=1.46 2 |
| Cadmium | Cd | 321 | 8.64 | 64 | 120 | 180 | $Al_2O_3$ | Poisons vacum system, low sticking coefficient. 4 |
| Cadmium Selenide | CdSe | 1264 | 5.81 | Subl. | Subl. | 540 Subl. | $Al_2O_3$ | Evaporates easily. N=2.4 @ .6μ 2 |
| Cadmium Sulfide | CdS | 1750 | 4.82 | Subl. | Subl. | 550 Subl. | $Al_2O_3$ | Sticking coeffiient strongly effected by substrate temp. Stoichiometry variable. N=2.4 |
| Calcium | Ca | 842 | 1.55 | 272 Subl. | 357 Subl. | 459 Subl. | $Al_2O_3$ | Corrodes in air. 4 |
| Calcium Fluoride | $CaF_2$ | 1360 | 3.18 | | | ~1100 | | Rate control important. Use gentle preheat to outgas. N=1.2-1.4 1 |
| Calcium Silicate | $CaO\text{-}SiO_2$ | 1540 | 2.90 | | | | | N=1.61 2 |
| Calcium Tungstate | $CaWO_4$ | 1620 | 6.06 | | | | | N=1.92 2 |
| Carbon | C | Subl. | 1.80-2.30 | 1657 Subl. | 1867 Subl. | 2137 Subl. | | Poor film adhesion 1 |
| Cerium | Ce | 795 | 8.23 | 970 | 1150 | 1380 | CG, $Al_2O_3$ | Film oxide easily 2 |
| Ceric Oxide | $CeO_2$ | 2600 | 7.30 | 1890 Subl. | 2000 Subl. | 2310 Subl. | | Use 250-300°C substrate temperature n=2.2-2.4. Reacts with W 2 |
| Cerium Fluoride | $CeF_3$ | 1418 | 6.16 | | | ~900 | | Use gentle preheat to outgas. N=1.63 @ .55μ 2 |
| Chromium | Cr | 1890 | 7.20 | 837 Subl. | 977 Subl. | 1157 Subl. | CG | Films very adherent. High rates possible. 2 |
| Chromium Carbide | $CR_3C_2$ | 1890 | 6.68 | | | ~2000 | | 3 |

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|---|---|---|---|---|---|---|---|---|
| Chromium Oxide | $Cr_2O_3$ | 2435 | 5.21 | | | ~2000 | | Disproportionate to lower oxides, reoxides @ 600 °C in air n=2.4 2 |
| Cobalt | Co | 1495 | 8.90 | 850 | 990 | 1200 | $Al_2O_3$ | Alloys with refractory metals. 1 |
| Copper | Cu | 1083 | 8.92 | 727 | 857 | 1017 | Ta, Mo, $Al_2O_3$ | Films do not adhere well. Use intermediate layer, e.g., chromium. 1 |
| Copper Oxide | $Cu_2o$ | 1235 | 6.00 | Subl. | Subl. | ~600 Subl. | $Al_2O_3$ | Evporate in $10^{-2}$-$10^{-2}$ of $O_2$; n=2.70 2 |
| Cryolite | $Na_3AlF_6$ | 1000 | 2.90 | 1020 | 1260 | 1480 | CG | Large chunks reduce splitting. Little decomposition. N=2.34 @ 6330Å 1 |
| Dysposium | Dy | 1409 | 8.54 | 625 | 750 | 900 | | 2 |
| Dysprosium Fluoride | $DyF_3$ | 1360 | | Subl. | Subl. | ~800 | | 2 |
| Erbium | Er | 1497 | 9.06 | 650 Subl. | 775 Subl. | 930 Subl. | | 2 |
| Europium | Eu | 822 | 5.26 | 280 Subl. | 360 Subl. | 480 Subl. | $Al_2O_3$ | 3 |
| Europium Oxide | $Eu_2O_3$ | 2056 | 7.42 | | | ~1600 | | Loses oxygen; iflms hard and clear. 2 |
| Gadolinium | Gd | 1312 | 7.89 | 760 | 900 | 1175 | $Al_2O_3$ | High Ta Solubility 1 |
| Gadolinium Oxide | $Gd_2O_3$ | 2310 | 7.41 | | | | | Loses oxygen. N=1.8 @ .55µ 3 |
| Gallium | Ga | 30 | 5.90 | 619 | 742 | 907 | $Al_2O_3$ | Alloys with refractory metals. 2 |
| Galliuim Antimonide | GaSb | 710 | 5.60 | | | | | 3 |
| Gallium Arsenide | GaAs | 1238 | 5.30 | | | | CG, G | N=5.64 @ 10.6µ 2 |
| Germanium | Ge | 937 | 5.35 | 812 | 957 | 1167 | $Al_2O_3$ | Excellent films. N=4.01 1 |
| Germanium Oxide | $GeO_2$ | 1086 | 6.24 | | | ~625 | $Al_2O_3$, Quartz | Film predominantly GeO 2 |
| Glass Schott 8329 | | | 2.20 | | | | | Evaporate alkali glass. Melt in air before evaporating. N=1.47 1 |

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|---|---|---|---|---|---|---|---|---|
| Gold | Au | 1062 | 19.32 | 807 | 947 | 1132 | CG, BN, $Al_2O_3$ | Films soft, not very adherent 1 |
| Hafnium | Hf | 2230 | 13.09 | 2160 | 2250 | 3090 | | 2 |
| Hafnium Oxide | $HfO_2$ | 2812 | 9.68 | | | ~2500 | | Film HhfO n=2.0 @ .5μ 3 |
| Holmium | Ho | 1470 | 8.80 | 650 Subl. | 770 Subl. | 950 Subl. | | 2 |
| Inconel | Ni/Cr/Fe | 1425 | 8.50 | | | | | Low rate required for smooth film. 2 |
| Indium | In | 157 | 7.30 | 487 | 597 | 742 | Mo | Wets W and Cu; use Mo liner. 1 |
| Indium Oxide | $In_2O_3$ | 1565 | 7.18 | Subl. | Subl. | ~1200 Subl. | $Al_2O_3$ | Film $In_2O$ transparent conductor 2 |
| Iridium | Ir | 2459 | 22.65 | 1850 | 2080 | 2380 | | 3 |
| Iron | Fe | 1535 | 7.86 | 858 | 998 | 1180 | $Al_2O_3$ | Attacks W. films hard, smooth. Use gentle preheat to outgas. 1 |
| Iron Oxide | FeO | 1425 | 5.70 | | | | | Decomposes. 1 |
| Iron Oxide | $Fe_2O_3$ | 1565 | 5.24 | | | | | Dispproportionate to $Fe_3O_4$ at 1530°C n≅3.0. 2 |
| Lanthanum | La | 920 | 6.17 | 990 | 1212 | 1388 | $Al_2O_3$ | Films will burn in air if scraped. 1 |
| Lanthanum Boride | $LaB_6$ | 2210 | 2.61 | | | | | 2 |
| Lanthanum Fluoride | $LaF_3$ | 1490 | 6.0 | Subl. | Subl. | 900 Subl. | | No decomposition n=1.59 @ .55μ 2 |
| Lanthanum Oxide | $La_2O_3$ | 2250 | 5.84 | 5.84 | | 1400 | | Loses Oxygen n≅1.9 @ .5μ 2 |
| Lead | Pb | 328 | 11.34 | 342 | 427 | 497 | $Al_2O_3$ | Toxic. Carefully controlled rates required for superconductors. 1 |
| Lithium | Li | 179 | 0.53 | 227 | 307 | 407 | $Al_2O_3$ | Metal reacts violently in air. 2 |
| Lithium Fluoride | LiF | 870 | 2.60 | 875 | 1020 | 1180 | $Al_2O_3$ | Rate control important for optical films. Use gentle preheat to outgas. N=1.36 2 |
| Lutetium | Lu | 1652 | 9.84 | | | 1300 | $Al_2O_3$ | 1 |
| Magnesium | Mg | 651 | 1.74 | 185 Subl. | 247 Subl. | 327 Subl. | CG, $Al_2O_3$ | Extremely high rates possible. 2 |
| Magnesium Aluminate | $MgAl_2O_4$ | 2135 | 3.60 | | | | | Natural spinel. 2 |
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|---|---|---|---|---|---|---|---|---|
| Magnesium Fluoride | $MgF_2$ | 1266 | 2.90-3.20 | | | 100 | $Al_2O_3$ | Rate control and substrate heat important for optical films. N=1.38 1 |
| Magnesium Oxide | MgO | 2800 | 3.58 | | | 1300 | CG, G $Al_2O_3$ | W produces volatile oxides. N=1.7 2 |
| Manganese | Mn | 1244 | 7.20 | 507 Subl. | 572 Subl. | 647 Subl. | $Al_2O_3$ | 2 |
| Molybdenum | Mo | 2610 | 10.22 | 1592 | 1822 | 2117 | | Films hard smooth. Careful degas required. 1 |
| Molybdenum Boride | $MoB_2$ | 2100 | 7.12 | | | | | 4 |
| Molybdenum Carbide | $Mo_2C$ | 2687 | 9.18 | | | | | Evaporation of $Mo(Co)_6$ yields $Mo_2C$ |
| Neodymium | Nd | 1024 | 7.00 | 7.31 | 871 | 1062 | $Al_2O_3$ | Low Ta solubility. 1 |
| Neodymium Fluoride | $NdF_3$ | 1410 | 6.50 | | | ~900 | $Al_2O_3$ | Very little decomposition. N=1.61 @ .55µ 2 |
| Neodymium Oxide | $Nd_2O_3$ | 2272 | 7.24 | | | ~1400 | | Loses Oxygen, films clear. Hydroscopic n=1.79 n varies with substrate temp. 2 |
| Nichrome IV | Ni/Cr | 1395 | 8.50 | 847 | 987 | 1217 | CG, $Al_2O_3$ | Alloys with refractory metals. 1 |
| Nickel | Ni | 1453 | 8.90 | 927 | 1072 | 1262 | CG, $Al_2O_3$ | Alloys with refractory metals. Forms smooth adherent films. 1 |
| Niobium (Columbium) | Nb | 2468 | 8.55 | 1728 | 1977 | 2287 | | Attacks W. 1 |
| Niobium Carbide | NbC | 3800 | 7.82 | | | | | 3 |
| Niobium – Tin | $Nb_3Sn$ | | | | | | | Co-evaporate from two sources. 1 |
| Osmium | Os | 1700 | 22.50 | 2170 | 2430 | 2760 | | 3 |
| Palladium | Pd | 1550 | 12.40 | 842 | 992 | 1192 | $Al_2O_3$ | Alloys with refractory metals; rapid evaporation suggested. Spits. 1 |
| Permalloy | Ni/F | 1395 | 8.70 | 947 | 1047 | 1307 | CG, $Al_2O_3$ | Films low in Ni content use 84% Ni source. 2 |

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|---|---|---|---|---|---|---|---|---|
| Platinum | Pt | 1769 | 21.45 | 1292 | 1492 | 1747 | CG | Alloys with metals. Films soft poor adhesion. 1 |
| Potassium Chloride | KCl | 776 | 1.98 | | | 510 | | Use gentle preheat to outgas. n=1.49 2 |
| Potassium Fluoride | KF | 880 | 2.48 | | | ~500 | | Use gentle preheat to outgas. n=1.49 2 |
| Praseodymium | Pr | 931 | 6.78 | 800 | 950 | 1150 | | 2 |
| Praseodymium Oxide | $Pr_2O_3$ | 2125 | 6.88 | | | 1400 | | Loses Oxygen. N=2.0 2 |
| Rhenium | Re | 3180 | 20.53 | 1928 | 2207 | 2571 | | 1 |
| Rhodium | Rh | 1966 | 12.41 | 1277 | 1472 | 1707 | CG | 2 |
| Ruthenium | Ru | 2700 | 12.45 | 1780 | 1990 | 2260 | | Splits violently. Requires degas. 1 |
| Samarium | Sm | 1072 | 7.54 | 373 | 460 | 573 | $Al_2O_3$ | 2 |
| Samarium Oxide | $Sm_2O_3$ | 2350 | 7.43 | | | | | Loses $O_2$ Films smooth, clear. 2 |
| Samarium Sulfide | $Sm_2S_3$ | 1900 | 5.72 | | | | | 2 |
| Scandium | Sc | 1539 | 2.99 | 714 | 837 | 1002 | $Al_2O_3$ | Alloys with Ta 1 |
| Scandium Oxide | 2300 | 8.86 | | | | ~400 | | Loses Oxygen n=1.88 @ .5μ 3 |
| Selenium | Se | 217 | 4.79 | 89 | 125 | 170 | CG, $Al_2O_3$ | Toxic. Poisons vacuum systems. 2 |
| Silicon | Si | 1410 | 2.42 | 992 | 1147 | 1337 | CG, Ta | Alloys with W. SiO produced above $4X10^{-6}$torr. N=3.42 3 |
| Silicon Boride | $SiB_6$ | | 2.47 | | | | | 4 |
| Silicon Dioxide | $SiO_2$ | 1610-1710 | 2.20-2.70 | | | ~1025 | | N=1.47 Tunnels must be swept. 1 |
| Silicon Monoxide | SiO | 1702 | 2.10 | Subl. | Subl. | 850 Subl. | Ta | Low rate suggested. N=1.6 3 |
| Silver | Ag | 961 | 10.49 | | 847 958 | 1105 | Mo, $Al_2O_3$ | 1 |
| Sodium Chloride | NaCl | 801 | 2.16 | | | 530 | | N=1.54 2 |
| Sodium Fluoriide | NaF | 988 | 2.79 | | | ~700 | | Use gentle preheat. No decomposition. n=1.30 @ .55μ 2 |
| Spinel | $MgO_3$ $5Al_2O_3$ | | 8.00 | | | | | N=1.72 2 |
| Strontium | Sr | 769 | 2.60 | 239 | 309 | 403 | CG | Wets but does not alloy refractory metals. May react violently in air. |

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|---|---|---|---|---|---|---|---|---|
| Sulfur | $S_8$ | 115 | 2.00 | 13 | 19 | 57 | | Poisons vacuum system. 1 |
| Supermalloy | Ni/Fe/Mo | 1410 | 8.90 | | | | | Co-evaporate from two sources, Prmalloy and Mo. 2 |
| Tantalum | Ta | 2996 | 16.60 | 1960 | 2240 | 2590 | | Forms good films. 1 |
| Tantalum Pentoxide | $Ta_2O_5$ | 1800 | 8.74 | 1550 | 1780 | 1920 | CG | Slight decomposition; evaporate in $10^{-3}$ torr of $O_2$ n≅2.0 @ 1.5μ 2 |
| Tellurium | Te | 452 | 6.25 | 157 | 207 | 277 | $Al_2O_3$ | Wets w/o alloying Toxic 4 |
| Terbium | Tb | 1357 | 8.27 | 800 | 850 | 1150 | $Al_2O_3$ | 1 |
| Thallium | Tl | 302 | 11.85 | 280 | 360 | 470 | $Al_2O_3$ | Wets freely, very toxic. 1 |
| Thorium | Th | 1875 | 11.70 | 1430 | 1660 | 1925 | | Toxic, radioactive. 1 |
| Thorium Dioxide | $ThO_2$ | 3050 | 10.03 | | | ~2100 | | Radioactive. N=1.86 @ 2.2μ 1 |
| Thorium Fluoride | $ThF_4$ | 1110 | 6.30 | | | ~750 | CG | Radioactive n=1.52 Heat substrate to above 150°C 3 |
| Thulium | Tm | 1545 | 9.32 | 461 Subl. | 554 Subl. | 680 Subl. | $Al_2O_3$ | 2 |
| Tin | Sn | 232 | 7.75 | 682 | 807 | 997 | Ta, $Al_2O_3$ | Wets Mo, use Ta liner. 1 |
| Tin Oxide | $SnO_2$ | 1127 | 6.95 | Subl. | Subl. | ~1000 Subl. | $Al_2O_3$ | N=2.0 1 |
| Tin Selenide | SnSe | 861 | 6.18 | | | ~400 | | 2 |
| Titanium | Ti | 1675 | 4.50 | 1067 | 1235 | 1453 | | Alloys with refractory metals; evolves gas on first heating. 1 |
| Titanium Boride | $TiB_2$ | 2980 | 4.50 | | | | | 4 |
| Titanium Dioxide (rutile) | $TiO_2$ | 1640 | 4.29 | | | ~1300 | | Evaporate in $10^{-4}$ of $O_2$ onto 350 °C substrates. N=2.4 3 |
| Titanium Monoxide | TiO | 1750 | 4.93 | | | ~1500 | CG | Use gentle preheat to outgas. 2 |
| Titanium Nitride | TiN | 2930 | 5.43 | | | | | Decomposes. 2 |
| Tungsten | W | 3410 | 19.30 | 2117 | 2407 | 2757 | | Forms violate oxides. Films hard & adherent. 2 |

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| Tungsten Carbide | $W_2C$ | 2860 | 17.15 | 1480 | 1720 | 2120 | | 1 |
| Tungsten Trioxide | $WO_3$ | 1473 | 7.16 | Subl. | Subl. | 980 Subl. | | Use gentle preheat to outgas. n=1.68 2 |
| Uranium | U | 1132 | 19.07 | 1132 | 1327 | 1582 | | Films oxidize. 2 |
| Vanadium | V | 1890 | 5.96 | 1162 | 1332 | 1547 | | Wets Mo. 1 |
| Ytterbium | Yb | 824 | 6.98 | 520 Subl. | 590 Subl. | 690 Subl. | | 2 |
| Yttrium | Y | 1509 | 4.48 | 830 | 973 | 1157 | $Al_2O_3$ | High Ta solubility. 1 |
| Yttrium Aluminum Oxide | $Y_3Al_5O_{12}$ | 1990 | | | | | | Films not ferroelectric |
| Yttrium Oxide | $Y_2O_3$ | 2680 | 4.84 | Subl. | Subl. | ~2000 | $Al_2O_3$, G | Loses oxygen, films smooth and clear. N=1.79 @ 1μ 2 |
| Zinc | Zn | 419 | 7.14 | 127 | 177 | 250 | $Al_2O_3$ | 1 |
| Zinc Oxide | ZnO | 1975 | 5.61 | | | ~1800 | | Anneal in air at 450°C to reoxidize. N=2.0 3 |
| Zinc Sulfide | ZnS | 1830 | 4.09 | Subl. | Subl. | ~800 | | Use gentle preheat to gegas. Films partle decompose Sticking coefficient varies with substrate temp. n≅2.3 @ .5μ 2 |
| Zirconium | Zr | 1852 | 6.40 | 1477 | 1702 | 1987 | | Alloys with W. Films oxide readily. 1 |
| Zirconium Boride | $ZrB_2$ | 3040 | 6.08 | | | | | 2 |
| Zirconium Oxide | $ZrO_2$ | 2700 | 5.49 | | | ~2200 | | Films oxide deficient, clear and hard. N=2.05 @ .75μ 2 |

## Legend

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|---|---|
| 1 | Excellent material for electron beam evaporation. |
| 2 | Good material for electron beam evaporation. |
| 3 | Fair material for electron beam evaporation. |
| 4 | Poor material for electron beam evaporation. |

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|---|---|
| Subl. | Subliming Material |
| n | Index of Refraction |
| G | Graphite Liner |
| CG | Coated Graphite Liner |
| $Al_2O_3$ | Alumina Liner |
| BN | Boron Nitride Liner |
| Mo | Molybdenum Liner |
| Ta | Tantalum Liner |