

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 ₄ C ₃	1400	2.36			~800		N=2.7 3
Aluminum Fluoride	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 ₂ O 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 ₂ O ₃	Toxic. Evaporates well, film structure is rate-dependent 1
Antimony Trioxide	Sb ₂ O ₃	656	5.2 or 5.76	Subl.	Subl.	Subl.	BN, Al ₂ O ₃	Toxic, decomposes on W.n=2.05 3
Antimony Trisulphide	Sb ₂ S ₃	550	4.64			~200	Al ₂ O ₃	N=3.01 @ .55μ . No decomposition 3
Arsenic	As	814	5.73	107 Subl.	150 Subl.	210 Subl.	Al ₂ O ₃ CG	Toxic. Sublimes rapidly at low temp. 4
Arsenic Trisulphide	As ₂ S ₃	300	3.43			~400	Al ₂ O ₃	N=2.8 3
Barium	Ba	710	3.78	545	627	735	MO	Wets w/o alloying-reacts with ceramics 3
Barium Fluoride	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 ₂ O 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 ₂ O ₃	Vapors are toxic. 1
Bismuth Oxide	Bi ₂ O ₃	820	8.90			~1400		Vapors are toxic. N=2.55 1

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
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 ₄ C	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 ₂ O ₃	460	1.82			~1400		N=1.46 2
Cadmium	Cd	321	8.64	64	120	180	Al ₂ O ₃	Poisons vacuum system, low sticking coefficient. 4
Cadmium Selenide	CdSe	1264	5.81	Subl.	Subl.	540 Subl.	Al ₂ O ₃	Evaporates easily. N=2.4 @ .6μ 2
Cadmium Sulfide	CdS	1750	4.82	Subl.	Subl.	550 Subl.	Al ₂ O ₃	Sticking coefficient strongly effected by substrate temp. Stoichiometry variable. N=2.4
Calcium	Ca	842	1.55	272 Subl.	357 Subl.	459 Subl.	Al ₂ O 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-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 ₂ O 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 ₃ C ₂	1890	6.68			~2000		3

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
Chromium Oxide	Cr ₂ O 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 ₂ O ₃	Alloys with refractory metals. 1
Copper	Cu	1083	8.92	727	857	1017	Ta, Mo, Al ₂ O ₃	Films do not adhere well. Use intermediate layer, e.g., chromium. 1
Copper Oxide	Cu ₂ O	1235	6.00	Subl.	Subl.	~600 Subl.	Al ₂ O ₃	Evaporate in 10 ⁻² -10 ⁻² of O ₂ ; n=2.70 2
Cryolite	Na ₃ AlF ₆	1000	2.90	1020	1260	1480	CG	Large chunks reduce splitting. Little decomposition. N=2.34 @ 6330Å 1
Dysprosium	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 ₂ O ₃	3
Europium Oxide	Eu ₂ O ₃	2056	7.42			~1600		Loses oxygen; iflms hard and clear. 2
Gadolinium	Gd	1312	7.89	760	900	1175	Al ₂ O ₃	High Ta Solubility 1
Gadolinium Oxide	Gd ₂ O ₃	2310	7.41					Loses oxygen. N=1.8 @ .55μ 3
Gallium	Ga	30	5.90	619	742	907	Al ₂ O ₃	Alloys with refractory metals. 2
Gallium 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 ₂ O ₃	Excellent films. N=4.01 1
Germanium Oxide	GeO ₂	1086	6.24			~625	Al ₂ O ₃ , Quartz	Film predominantly GeO 2
Glass Schott 8329			2.20					Evaporate alkali glass. Melt in air before evaporating. N=1.47 1

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
Gold	Au	1062	19.32	807	947	1132	CG, BN, Al ₂ O 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 HfO 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 ₂ O ₃	1565	7.18	Subl.	Subl.	~1200 Subl.	Al ₂ O ₃	Film In ₂ O transparent conductor 2
Iridium	Ir	2459	22.65	1850	2080	2380		3
Iron	Fe	1535	7.86	858	998	1180	Al ₂ O ₃	Attacks W. films hard, smooth. Use gentle preheat to outgas. 1
Iron Oxide	FeO	1425	5.70					Decomposes. 1
Iron Oxide	Fe ₂ O ₃	1565	5.24					Disproportionate to Fe ₃ O ₄ at 1530°C n≅3.0. 2
Lanthanum	La	920	6.17	990	1212	1388	Al ₂ O 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 ₂ O ₃	2250	5.84	5.84		1400		Loses Oxygen n≅1.9 @ .5μ 2
Lead	Pb	328	11.34	342	427	497	Al ₂ O ₃	Toxic. Carefully controlled rates required for superconductors. 1
Lithium	Li	179	0.53	227	307	407	Al ₂ O ₃	Metal reacts violently in air. 2
Lithium Fluoride	LiF	870	2.60	875	1020	1180	Al ₂ O ₃	Rate control important for optical films. Use gentle preheat to outgas. N=1.36 2
Lutetium	Lu	1652	9.84			1300	Al ₂ O ₃	1
Magnesium	Mg	651	1.74	185 Subl.	247 Subl.	327 Subl.	CG, Al ₂ O ₃	Extremely high rates possible. 2
Magnesium Aluminate	MgAl ₂ O ₄	2135	3.60					Natural spinel. 2
NAME	SYMBOL	MELTING	DENSITY	10 ⁻⁸	10 ⁻⁶	10 ⁻⁴	LINER	NOTES

Thermionics Laboratory Inc.

		POINT °C	g/cc	TORR	TORR	TORR		N=INDEX OF REFRACTION
Magnesium Fluoride	MgF ₂	1266	2.90-3.20			100	Al ₂ O ₃	Rate control and substrate heat important for optical films. N=1.38 1
Magnesium Oxide	MgO	2800	3.58			1300	CG, G Al ₂ O ₃	W produces volatile oxides. N=1.7 2
Manganese	Mn	1244	7.20	507 Subl.	572 Subl.	647 Subl.	Al ₂ O 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 ₂ C	2687	9.18					Evaporation of Mo(Co) ₆ yields Mo ₂ C
Neodymium	Nd	1024	7.00	7.31	871	1062	Al ₂ O ₃	Low Ta solubility. 1
Neodymium Fluoride	NdF ₃	1410	6.50			~900	Al ₂ O ₃	Very little decomposition. N=1.61 @ .55μ 2
Neodymium Oxide	Nd ₂ O 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 ₂ O ₃	Alloys with refractory metals. 1
Nickel	Ni	1453	8.90	927	1072	1262	CG, Al ₂ O 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 ₃ Sn							Co-evaporate from two sources. 1
Osmium	Os	1700	22.50	2170	2430	2760		3
Palladium	Pd	1550	12.40	842	992	1192	Al ₂ O ₃	Alloys with refractory metals; rapid evaporation suggested. Spits. 1
Permalloy	Ni/F	1395	8.70	947	1047	1307	CG, Al ₂ O ₃	Films low in Ni content use 84% Ni source. 2

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
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 ₂ O 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 ₂ O ₃	2
Samarium Oxide	Sm ₂ O ₃	2350	7.43					Loses O ₂ Films smooth, clear. 2
Samarium Sulfide	Sm ₂ S ₃	1900	5.72					2
Scandium	Sc	1539	2.99	714	837	1002	Al ₂ O 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 ₂ O 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 ₂ O ₃	1
Sodium Chloride	NaCl	801	2.16			530		N=1.54 2
Sodium Fluoride	NaF	988	2.79			~700		Use gentle preheat. No decomposition. n=1.30 @ .55μ 2
Spinel	MgO ₃ 5Al ₂ O 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.

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
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 ₂ O 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 ₂ O ₃	Wets w/o alloying Toxic 4
Terbium	Tb	1357	8.27	800	850	1150	Al ₂ O ₃	1
Thallium	Tl	302	11.85	280	360	470	Al ₂ O 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 ₂ O ₃	2
Tin	Sn	232	7.75	682	807	997	Ta, Al ₂ O ₃	Wets Mo, use Ta liner. 1
Tin Oxide	SnO ₂	1127	6.95	Subl.	Subl.	~1000 Subl.	Al ₂ O 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

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
Tungsten Carbide	W ₂ C	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 ₂ O ₃	High Ta solubility. 1
Yttrium Aluminum Oxide	Y ₃ Al ₅ O ₁₂	1990						Films not ferroelectric
Yttrium Oxide	Y ₂ O ₃	2680	4.84	Subl.	Subl.	~2000	Al ₂ O ₃ , G	Loses oxygen, films smooth and clear. N=1.79 @ 1μ 2
Zinc	Zn	419	7.14	127	177	250	Al ₂ O 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 degas. 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

Thermionics Laboratory Inc.

Legend

- 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.

Subl.	Subliming Material
n	Index of Refraction
G	Graphite Liner
CG	Coated Graphite Liner
Al ₂ O ₃	Alumina Liner
BN	Boron Nitride Liner
Mo	Molybdenum Liner
Ta	Tantalum Liner