

# Products for Mono-Crystalline Silicon Ingot Production

MorganAM&T's Solar Grade Felt Insulation was developed for optimal performance in Czochralski (CZ) and similar design mono-crystalline silicon furnace hot zones.

Two grades are available, each able to be supplied in bulk rolls, cut sections, or pre-rolled cylinders:

- VDG: A standard high purity grade suitable for most CZ applications.
- VDG-P: An enhanced high purity grade for use in CZ applications where high insulation purity is critical.

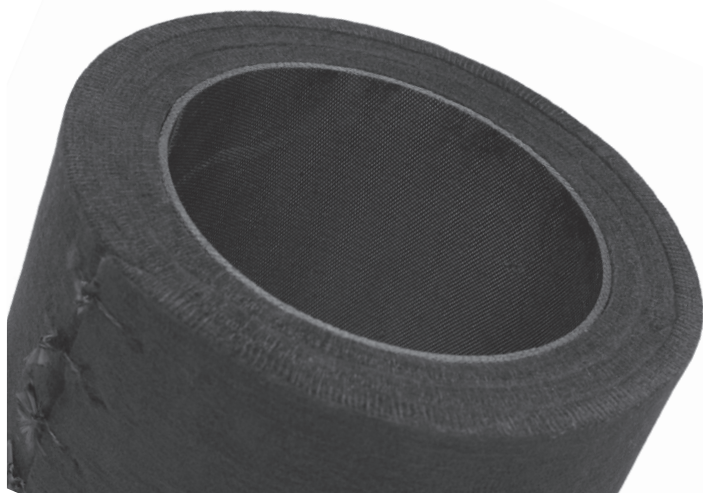
### General material characteristics include:

- High Purity Carbon Felt Insulation
- 100% Rayon-Based Fiber Precursor
- Carbon Content > 99% (VDG) or >99.9% (VDG-P)
- Thermally Processed to Minimum 1900 °C
- Low Shrinkage and Volatile Release

High quality raw materials, careful product development, and proprietary manufacturing processes ensure a consistent product with the potential to maximize CZ Furnace performance and mono-crystalline ingot quality at a low total cost of ownership.

An applications focused approach was taken while designing our Solar Grade Felt Insulation product, resulting in a product that exhibits the following key features:

- Low Thermal Conductivity
- Low Particle Release
- Low Metallic Impurity Levels
- High Silicon Environment Tolerance
- High Oxidation Resistance



## Solar Grade Felt Insulation

### Typical Elemental Impurities

All values are ppm

Total Metals	Na	Mg	Al	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Sr	W	
VDG	216.6	22.7	2.1	32.0	17.3	80.3	4.2	0.075	10.0	.02	38.7	0.12	4.5	3.2	0.78	0.31	0.07
VDG-P	7.9	2.5	—	0.35	—	2	2.7	0.16	—	—	0.15	—	—	—	—	—	—

Total Metals																	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
IA	IIA	IIIA	IIIA	IVB	VIB	VIB	VIB	VIB	VIB	IB	IIIB	IIIA	IIIA	IIIA	IIIA	IIIA	IIIA
H	Li	Be	B	C	N	O	F	Ne	Na	Mg	Al	Si	P	S	Cl	Ar	He
1.01	6.94	9.01	10.81	12.01	14.01	16.00	19.00	20.18	22.99	24.31	26.98	28.09	30.97	32.07	35.45	39.95	4.00
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
39.1	40.08	44.96	47.88	50.94	54.94	55.85	58.93	58.93	58.93	63.55	65.39	69.72	72.61	74.92	78.96	79.90	83.80
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
85.47	87.62	88.91	91.22	92.91	95.94	98.91	101.07	101.07	106.42	107.87	112.41	114.82	118.71	121.76	127.6	126.9	131.29
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs	Ba	La*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
132.9	137.3	138.9	178.4	180.9	183.9	186.2	193.2	195.1	195.1	197.0	200.6	204.4	207.2	209	(209)	(210)	(222)
87	88	89	104	105	106	107	108	109	110	111							
Fr	Ra	Ac*	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg							
(223)	(226)	(227)	(261)	(262)	(263)	(264)	(265)	(266)	(267)	(268)							
58	59	60	61	62	63	64	65	66	67	68	69	70	71				
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu				
140.1	140.9	141.9	(144)	150.4	151.9	157.3	158.9	162.5	164.9	167.3	168.9	173.0	175.0				
90	91	92	93	94	95	96	97	98	99	100	101	102	103				
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr				
232.0	(231)	238.0	(237)	(244)	(243)	(247)	(247)	(251)	(251)	(257)	(258)	(259)	(260)				

Total Metals are defined by the highlighted elements. Those elements not listed in the table were below GDMS detection limits.

MorganAM&T's Solar Grade Felt Insulation demonstrates excellent thermal performance throughout its use range and was proven to release fewer particles than competitors during competitive analysis testing. Customer testing has consistently demonstrated lower energy consumption compared to competitive materials. Reduced energy requirements may also translate to lower heating element stress affording the potential of longer heating element life.

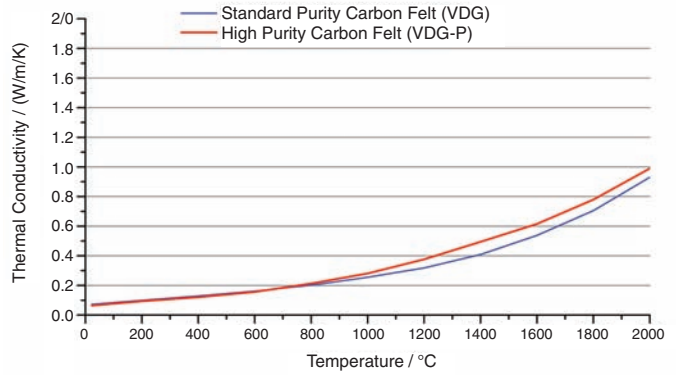
Since it has been processed to temperatures well in excess of CZ process temperatures, customers can expect high dimensional and thermal stability. Customers report reduced ingot breakage and improved ingot yield performance compared to competitive materials.

Industry leading purity levels ensure low metallic contamination risk to the silicon melt. In-house testing of oxidation resistance and silicon tolerance have shown superior performance compared to competitive materials, enabling the potential for long service life and reduced down time and maintenance costs.

Although 10mm is the typical felt insulation thickness used in CZ Furnace applications, a wide range of other sizes are available which affords design flexibility. Custom sizes can also be supplied to the customer's specifications.

## Thermal Conductivity

Thermal Conductivity of Solar Grade Felt Insulation Measured by Laser Flash in One Atmosphere of Argon



## Typical CZ Furnace Felt Insulation Dimensional Data

Size Designation	Thickness (inches/mm)			Width Grade	Width (inches/cm)			Length (yards/meters)			Weight per Area (lbs/kg per yd <sup>2</sup> )		Typical Roll Weight (pounds/kilogram)														
	Typical	Min	Max		Typical	Min	Max	Typical	Min	Max	VDG Typical	WDF Typical	VDG Typical	WDF Typical													
10mm	0.41	10.3	0.36	9.0	0.44	11.2	Std	42	106.7	41	104.1	46	116.8	17	15.5	8	7.3	17	15.5	1.96	0.89	1.87	0.85	38.87	17.67	37.09	16.86
							Wide	47	119.4	46	116.8	49	121.9	17	15.5	8	7.3	17	15.5	1.96	0.89	1.87	0.85	43.50	19.77	41.50	18.87

## Solar Grade Rigid Insulation

In addition to felt insulation, for designers that prefer the use of machined rigid insulation MorganAM&T offers its Solar Grade Rigid Insulation product. Rigorous product development and testing standards have yielded a product custom designed for optimal performance in high temperature silicon environments. Key benefits include:

- High Purity, Short Fiber Rigid Insulation
- Thermally Processed to Minimum 1900 °C
- Density 0.15 g/cc – 0.19 g/cc
- Low Particle Release
- Low Metallic Impurity Levels
- High Silicon Environment Tolerance
- High Oxidation Resistance
- High Machinability

## Solar Grade Rigid Insulation

### Typical Elemental Impurities

All values are ppm

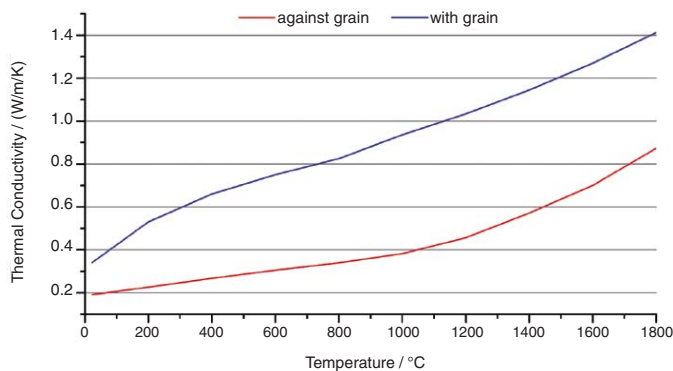
Total Metals	Na	Mg	Al	K	Ca	Ti	V	Fe	Ni	Cu	Ba
10.2	2.8	0.79	0.24	0.13	4.1	0.09	0.73	0.27	0.08	0.12	0.83

Total Metals																	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
H	He	Li	Be	B	C	N	O	F	Ne	Na	Mg	Al	Si	P	S	Cl	Ar
1.01	4.00	6.94	9.01	10.81	12.01	14.01	16.00	18.99	20.18	22.99	24.31	26.98	28.09	30.97	32.07	35.45	39.95
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Na	Mg	Al	Si	P	S	Cl	Ar	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni
22.99	24.31	26.98	28.09	30.97	32.07	35.45	39.95	39.09	40.08	44.96	47.88	50.94	51.99	54.94	55.94	58.93	58.93
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
39.09	40.08	44.96	47.88	50.94	51.99	54.94	55.94	58.93	58.93	63.55	65.39	69.72	72.61	74.92	78.96	79.90	83.80
59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
85.47	87.63	88.91	91.22	92.91	95.94	(98)	101.07	101.07	106.42	107.87	112.41	114.82	118.71	121.76	127.6	126.9	131.29
87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104
Ca	Ba	La*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
40.08	137.3	138.9	178.5	180.9	183.8	186.2	193.2	195.1	195.1	197.0	200.6	204.4	207.2	209	(209)	(210)	(222)
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106
Fr	Ra	Ac*	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	(111)	(112)	(113)	(114)	(115)	(116)	(117)
(223)	(226)	(227)	(261)	(262)	(263)	(264)	(265)	(266)	(267)	(268)	(269)	(270)	(271)	(272)	(273)	(274)	(275)
78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	(118)	(119)	(120)	(121)
140.1	140.9	144.2	(145)	150.4	151.9	157.3	158.9	162.5	164.9	167.3	168.9	173.0	175.0	(176)	(177)	(178)	(179)
106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123
Tb	Pu	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	(124)	(125)	(126)	(127)
158.9	(242)	238.0	(237)	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(260)	(261)	(262)	(263)	(264)

Total Metals are defined by the highlighted elements. Those elements not listed in the table were below GDMS detection limits.

## Thermal Conductivity

Thermal Conductivity of Solar Grade Rigid Board Insulation Measured by Laser Flash in One Atmosphere of Argon



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