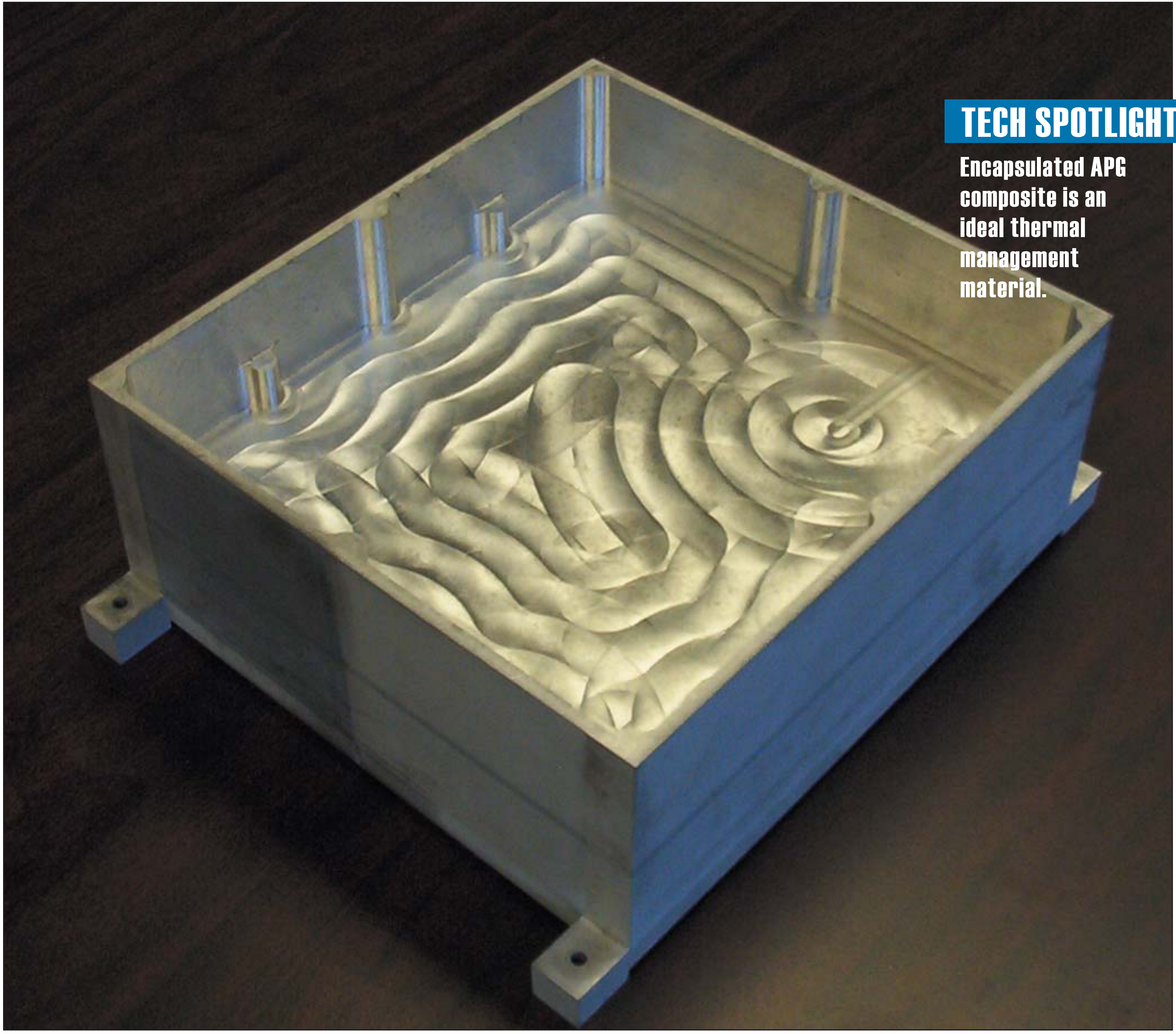

TECH SPOTLIGHT

Encapsulated APG composite is an ideal thermal management material.

This magnesium-encapsulated APG chassis was developed for an airborne electronics application. Compared with a baseline aluminum part of the same geometry, the conductance of the magnesium/APG chassis is nearly four times higher, and mass is 31% lower.

Annealed Pyrolytic Graphite

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Annealed pyrolytic graphite (APG) is a unique form of pyrolytic graphite manufactured by decomposition of a hydrocarbon gas at high temperature in a vacuum furnace. This highly aligned crystalline graphite has an in-plane thermal conductivity of 1700 W/mK, which is more than four times that of copper. The high thermal conductivity, as well as high strength properties, run parallel to the hexagonal layer lattice (*ab* or basal plane). Unfortunately, overall mechanical properties are poor because of the weak van der Waals forces that bond the lattice in the *c* axis (Table 1).

However, encapsulating APG within a structural shell addresses this structural limitation (Fig. 1). The APG encapsulation scheme combines the beneficial properties of two materials in a configuration that allows the cost-effective optimization of the assembly. The encapsulated APG composite is an ideal thermal management material because of its high thermal conductivity (up to 1400 W/mK), low mass density (as low as 1.9 g/cm^3), high stiffness (up to 50 Msi), and the ability to have an engineered coefficient of thermal expansion.

Specific thermal conductivity

Specific thermal conductivity can be defined as the thermal conductivity per unit mass. Specific thermal conductivity is a useful unit of measure in the evaluation of heat sinks for mobile systems in which both high conductivity and low mass are needed. Table 2 lists the properties of several common packaging materials. Note the outstanding specific conductivity of the beryllium and the beryllium composite materials. Aluminum also has high specific conductance, and because it is also affordable, it is frequently selected for mobile packaging applications.

When these listed materials encapsulate an APG heat sink, they provide extremely high specific thermal conductivity values (Table 3). Magnesium is a poor thermal conductor compared with aluminum, but its low density makes it ideal for weight-sensitive components. Combining this low-density material with APG solves the low conductivity problem, and provides a composite with a specific conductivity more than four times greater than that of beryllium.

Table 1 — Mechanical properties of annealed pyrolytic graphite

Modulus (psi)			Poissons's ratio			Shear modulus, psi			Coefficient of thermal expansion, ppm/K		
E1	E2	E3	v12	v13	v23	G12	G13	G23	a1	a2	a3
8×10^{7}	8×10^{7}	5×10^{5}	0.3	0.002	0.002	3.07×10^{7}	2×10^{5}	2×10^{5}	-6×10^{-7}	-6×10^{-7}	2.49×10^{-5}

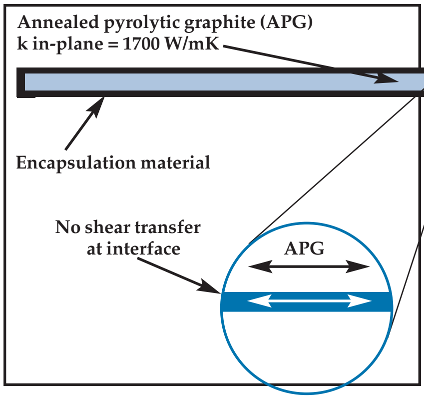


Fig. 1 — The patented encapsulation technique creates a gliding contact between the APG graphite core and the encapsulation material. This results in a composite assembly in which the encapsulation material's properties govern the structure (strength, stiffness, and coefficient of thermal expansion) while the APG graphite core properties control thermal conductance. k Technology Corp. markets its encapsulated APG materials under the trade name k-Core.

In addition to outstanding thermal performance and low density, these parts can have a favorable coefficient of thermal expansion (CTE). For example, an APG part encapsulated with Kovar (an iron-nickel-cobalt, low-expansion alloy) has both high specific thermal conductivity (218 W/mK/g/cm^3) and low CTE (5.9 ppm/K). In electronic packaging designs, the CTE of the heat sink typically must match that of a ceramic packaged device, which is typically between 5 and 8 ppm/K. The primary reason for choosing Kovar as a packaging material is that its CTE is a close match to silicon and gallium arsenide devices. However, the low thermal conductivity of Kovar limits its service in high power devices. By selecting Kovar as the encapsulation material for APG, all the benefits of Kovar can be realized with the addition of high thermal conductivity.

Thermal loading

APG is orthotropic, and as such the direction of the thermal loading may also determine the functionality of the heat sink. The low through-the-thickness thermal conductivity of the APG can lower the effective thermal conductivity of the part when a thermal path is normal to the plane of the APG. For most applications, this characteristic is minimal because the high in-plane conductivity of the APG quickly spreads the heat, thus lowering the thermal density (Q/A).

At reduced thermal density, the temperature rise through-the-thickness is significantly reduced. However, for designs that require a high flux density energy (>10 W/cm^2), the heat path normal to the plane of the APG, the temperature rise can be significant.

In such applications, where the spreading within the APG is insufficient, thermal vias may solve the problem. Thermal vias effectively provide a through-plane conductivity equal to that of the encapsulation material. For example, with a copper/tungsten encapsulant, the thermal vias would improve the through-the-thickness conductivity from 10 W/mK to 230 W/mK. These inserts are effective because the conduction length through-the-thickness (TTT) is typically small (Fig. 2).

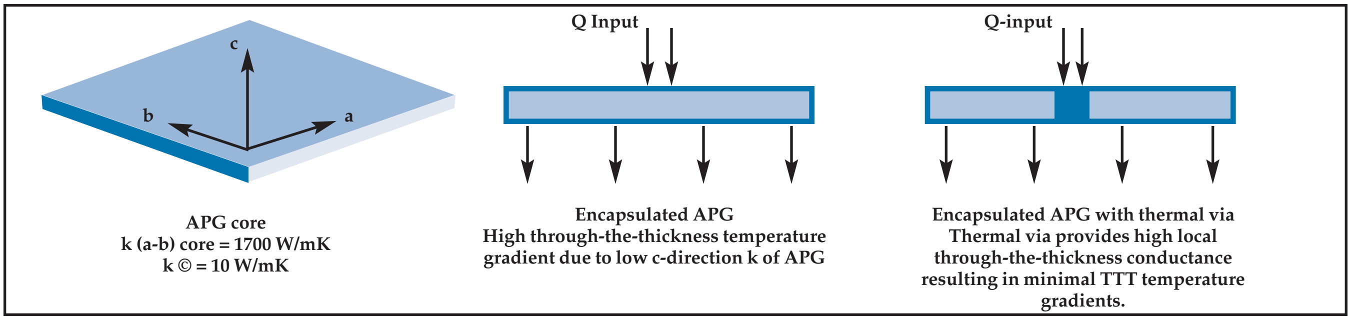
Application note

As shown in Table 3, magnesium encapsulated APG provides an outstanding combination of thermal performance at low mass. In this particular application, the baseline aluminum chassis for a space platform has become thermally limited. Upgrades to its electronics have increased dissipated power, but the chassis cannot be made larger be-

Table 2 — Common electronic packaging materials.

Material	Thermal conductivity, W/mK	Density, g/cm^3	Coef. of thermal expansion, ppm/K	Specific conductivity, conductivity/ density. W/mK/g/cm^3
Copper (OFHC)	390.0	8.90	16.9	43.8
Beryllium	220.0	1.80	13.5	122.2
Aluminum Beryllium (62% Be)	210.0	2.10	13.9	100.0
Aluminum (6061)	180.0	2.80	23.6	64.3
AlSi (40% Si)	126.0	2.53	15.0	49.8
Magnesium (AZM)	79.0	1.80	27.3	43.9
Kovar	14.0	8.40	5.9	1.7

The relatively high specific conductivity of aluminum, combined with its affordability, explains its prevalence as a heat sink material for space and airborne applications.



APG core
k (a-b) core = 1700 W/mK
k © = 10 W/mK

Encapsulated APG
High through-the-thickness temperature gradient due to low c-direction k of APG

Encapsulated APG with thermal via
Thermal via provides high local through-the-thickness conductance resulting in minimal TTT temperature gradients.

Fig. 2 — The placement of a thermal via raises the through-the-thickness conductivity to that of the encapsulation material.

cause of weight and volume constraints. Replacing this baseline aluminum chassis with a magnesium encapsulated APG chassis will significantly increase its conductance while reducing its mass.

A magnesium-encapsulated chassis design was established, then parts were fabricated and evaluated. The conductance of the chassis was tested and found to be nearly four times greater than the baseline aluminum components (13.7 W/ ºC vs. 3.5 W/ ºC) with a 31% lower mass. These measured results show a clear advantage in conductance and weight management, two crucial issues in the development of advanced ther-mal transport devices. The lead figure presents a photograph of this part. ◆

Table 3 — Encapsulated APG components with common electronic packaging materials

Material with APG insert	Thermal conductivity, W/mK	Density, g/cm^3	Coef. of thermal expansion, ppm/K	Specific conductivity, conductivity/ density. $W/mK/g/cm^3$
Copper (OFHC)	1176.0	4.92	16.9	239.2
Beryllium	1108.0	2.08	13.5	533.7
Aluminum beryllium (62% Be)	1104.0	2.20	13.9	502.7
Aluminum (6061)	1092.0	2.48	23.6	441.0
AlSi (40% Si	1070.4	2.37	15.0	452.0
Magnesium (AZM)	1051.6	2.08	27.3	506.6
Kovar	1025.6	4.72	5.9	217.5

The calculated values are for in-plane heat flow with a 60% volume fraction of the APG insert.

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APG encapsulation technique protected by U.S patent #5296310 and several international patents pending.

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