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LETTERS TO THE EDITOR

Electromagnetic interference shielding reaching 130 dB using flexible graphite

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Electromagnetic interference (EMI) shielding is increasingly needed due to the increasing abundance and sensitivity of electronics, particularly radio frequency devices, which tend to interfere with digital devices. A shielding material needs to be an electrical conductor, although the electrical conductivity does not have to be very high. Due to the skin effect (i.e., the phenomenon that high frequency electromagnetic radiation only interacts with the surface region of a conductor), a high surface area of the conductor is desirable. For example, a polymer-matrix composite containing a conducting filler of a small unit size is desirable for shielding, as the fineness of the filler gives rise to a conductor surface area that is much larger than that of a bulk conductor. Although there has been much work on the development of polymer-matrix composites (including those with carbon fibers and carbon black) for EMI shielding [1-6], there has been no previous work on flexible graphite for shielding.

Flexible graphite is a flexible sheet made by compressing a collection of exfoliated graphite flakes without a binder [7-11]. Due to the exfoliation, flexible graphite has a large specific surface area. Due to its microstructure involving graphite layers that are preferentially parallel to the surface of the sheet and somewhat connected perpendicular to the sheet (due to the honeycomb microstructure of exfoliated graphite), flexible graphite is resilient and impermeable to fluids perpendicular to the sheet. Therefore, it is mainly used as a gasket material for high temperature or chemically harsh environments. As the electrical conductivity (especially that in the plane of the sheet) and specific surface area are both quite high in flexible graphite, the effectiveness of this material for shielding was explored in this work. Indeed, we found that the shielding effectiveness of flexible graphite is exceptionally high (up to 130 dB, higher than that of solid copper). In addition to conventional shielding applications, flexible graphite can serve as a shielding gasket material, due to its resilience. As the resilience of a polymer-matrix composite decreases rapidly with increasing filler content, the attainment of a shielding gasket using a polymer-matrix composite has been a challenge [12-13].

The shielding effectiveness of specimens was measured using the coaxial cable method. The set-up, as illustrated in Fig. 1, consists of an Elgal (Israel) SET 19A shielding effectiveness tester, which is connected to a Hewlett-Packard (HP) 8752A network analyzer. An HP85032B calibration kit was used to calibrate the system. Standard attenuators at 110 and 130 dB gave shielding effectiveness values of 112 and 132 dB respectively. The frequency was scanned from 1 to 2 Ghz. The sample was in the form of an annular ring of outer diameter 97 mm and inner diameter 32 mm. The sample thickness was either 0.79 or 3.1 mm.

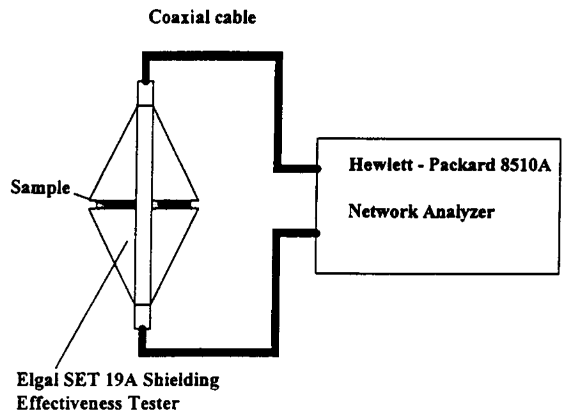

Fig. 1. Set-up for measuring the electromagnetic interference shielding effectiveness.

Flexible graphite sheets (Grade GTB) of thicknesses 0.79 and 3.1 mm were provided by EGC Enterprises, Inc. (Mentor, Ohio). The specific surface area is 15 m^2/g, as determined by nitrogen adsorption and measurement of the pressure of the gas during adsorption using the Micromeritics ASAP 2000 instrument. This specific surface area corresponds to a crystallite layer height of 0.18 μm within a sheet. The DC electrical resistivity, as measured by the four-probe method, using silver paint for the electrical contacts, is 7.5×10^{-4} Ω.cm in the plane of the sheet and, for the sheet of thickness 3.1 mm, is 0.037 ± 0.011 Ω.cm perpendicular to the sheet. the in-plane resistivity corresponds to a skin depth of 44 μm at 1 Ghz. (In contrast, the skin depth of copper is 1.5 μm at 1 Ghz). The AC in-plane impedance rose by a factor of 26 for the flexible graphite sheet of thickness 3.1 mm when the frequency was increased from DC to 2 Mhz, whereas that of copper rose by a factor 980, as measured by using a QuadTech Model 7600 RLC meter, suggesting the more severe consequence of the skin effect for copper than for flexible graphite. The mild consequence of the skin effect for flexible graphite is due to the large skin depth and the high specific surface area. According to the manufacturer, the ash content of flexible graphite is < 5%; the density is 1.1 g/cm^3; the tensile strength in the plane of the sheet is 5.2 Mpa; the compressive strength (10% reduction) perpendicular to the sheet is 3.9 Mpa; the thermal conductivity at 1093°C is 43 W/m.K in the plane of the sheet and 3 W/m.K perpendicular to the sheet; the coefficient of the thermal expansion (CTE) (21-1093°C) is -0.4×10^{-6}/°C in the plane of the sheet.

The EMI shielding effectiveness at 1-2 Ghz is shown in Table 1. The ± number following each effectiveness value refers to the standard deviation over this frequency range, as the effectiveness increased slightly with increasing frequency. The effectiveness value was higher for the greater thickness (3.1 mm) than the smaller thickness (0.79 μm), and exceeded those of solid copper, solid nickel and polycrystalline graphite (Poco Graphite, Inc., Decatur, TX). In spite of the larger skin depth of polycrystalline graphite (Table 1), the shielding effectiveness was lower for polycrystalline graphite than flexible graphite. This is due to the large specific surface area of flexible graphite. In contrast, the specific surface areas of polycrystalline graphite, solid copper and solid nickel were negligible. The value of 130 dB is unusually high among materials for shielding. In particular, it is much higher than those of EMI shielding gasket materials in the prior art (25 - 60 dB) [14,15]. The high shielding effectiveness of flexible graphite at 1 - 2 Ghz is attributed to the high specific surface area and the large skin depth, which is much larger than the crystallite layer height. In contrast, the high shielding effectiveness of copper is attributed mainly to its metallic nature and the associated high electrical conductivity, as the skin depth is much smaller than the solid copper thickness; the high shielding effectiveness of polycrystalline graphite is attributed mainly to its large skin depth (62 μm).

The high thermal conductivity, low CTE, high temperature resistance and excellent chemical resistance of flexible graphite add to the attraction of this material for use in EMI shielding. Moreover, the flexibility, resilience and that the sheet can be cut with scissors facilitate application.

Table 1 EMI shielding effectiveness at 1-2 Ghz

Material	Thickness (mm)	Effectiveness (dB)	Skin depth (μm)at 1 Ghz
Flexible graphite⁺	3.1	129.4 ± 7.1	44
Flexible graphite⁺	0.79	101.9 ± 3.9	44
Polycrystalline graphite*	2.6	91.5 ± 3.4	62
Copper	3.1	100.6 ± 4.9	1.5
Nickel	3.1	85.8 ± 2.0	0.47

⁺ Electrical resistivity = 7.5×10^{-4} Ω.cm.
* Electrical resistivity = 1.9×10^{-3} Ω.cm.

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REFERENCES

1. Mal Murthy, 4th Int. SAMPE Electronics Conference, Vol. 4 (*Electronic Materials - Our Future*, R. W. Allred, R. J. Martinez and K. B. Wischmann, Eds.) 1990, p. 806-818.
2. J.A.E. Bell and G. Hansen, *24th Int. SAMPE Technical Conference*, 1992, p. T902-T911.
3. D.J. Atkins, J.A. Miller and J.D. Sanders, *8th Int. Conf. Electromagnetic Compatibility*, Electronics Division, Institution of Electrical Engineers, London, 1992, p. 100-107.
4. D.M. Bigg, *Adv. Polym. Technol.* **4**, 255 (1984).
5. D.M. Bigg, *Polym. Compos.* **7**(2), 69 (1986).
6. D.S. Dixon and J.V. Masi, SAMPE J. **25**(6), 31 (1989).
7. J.H. Shane, R.J. Russell and R.A. Bochman, US Patent 3 404 061 (1968).
8. Z. Huang, *Runhua Yu Mifeng* **6**, 28 (1981).
9. L. Shi and Y. Fan, *Runhua Yu Mifeng* **27**, 17, 70 (1981).
10. R.K. Flitney, *Tribology Int.* **19**, 181 (1986).
11. D.D.L. Chung, *J. Mater. Sci.* **22**, 4190 (1987).
12. R. Bates, S. Spence, J. Rowan and J. Hanrahan, *8th Int. Conf. Electromagnetic Compatibility*, Electronics Division, Institution of Electrical Engineers, London, 1992, p. 246-250.
13. J.A. Catrysse, *ibid*, p. 251-255.
14. G.A. Annis, W.C. Hoge, Jr. and R.L. Welch, US Patent 5,436,803 (1995).
15. R. Panayappan and J.C. Cooper, US Patent 5,364,574 (1994).