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Mechanical Properties and Electromagnetic Shielding Performance of Single-Source-Precursor Synthesized Dense Monolithic SiC/HfC$_x$N$_{1-x}$/C Ceramic Nanocomposites

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Theory of EM shielding

For a transverse electromagnetic (EM) wave propagating into materials with negligible magnetic interaction, the shielding effectiveness (SE) of the materials is expressed by the following equation in units of decibel (dB):[1-3]

$$SE = 10Log_{10}\left(\frac{1}{|S_{ij}|^2}\right) \qquad (S1)$$

where, S_{ij} represents the power transmitting from the testing port i to port j.

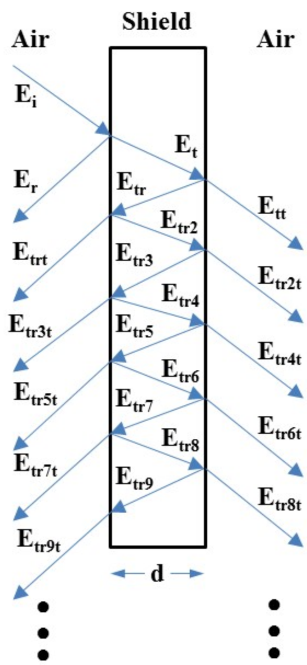

Figure S1 Schematic illustration of reflection and transmission of electromagnetic wave.[4]

The electromagnetic (EM) shielding process can be shown schematically in **Figure S1**. An EM shield has two boundaries where reflection and transmission of EM waves occur. The incident EM wave is identified by "i" subscripts, the reflected EM wave by "r" subscripts and the transmitted EM wave by "t" subscripts. At each air/shield interface, a part of the EM wave is reflected, and the remainder is transmitted. During transmission, part of the energy is absorbed by the shield. Thus, the total shielding effectiveness (SE_T, in dB) of an electrically conductive shielding material can be expressed as the sum of an absorption shielding effectiveness (SE_A), a reflection shielding effectiveness (SE_R) as well as a multiple reflection correction term (SE_{MR}):[1-3]

$$SE_T = SE_A + SE_R + SE_{MR} \qquad \text{(S2)}$$

Reflection occurs due to an impedance mismatch, and absorption occurs due to energy losses (e.g., dielectric loss) within the shield. Generally, the values of SE_A and SE_R are positive, while the values of the SE_{MR} can be positive, zero or negative, depending on the feature of the shielding materials. The shielding materials in this work are dense monoliths, the multiple reflection therefore manifests itself as a negative SE_{MR} term in equation (S2) according to Figure S1.[4]

For a good EM shield (*e.g.*, metal, conductive ceramics), a large part of the incident EM wave (E_i) is reflected, and only a small part is transmitted (E_t). Accordingly, there is a large reflection loss (SE_R) at the first air/shield interface. The transmitted EM wave experiences an absorption loss (SE_A) before encountering the second shield/air interface. Then, a small portion of this EM wave (E_{tt}) transmits through the shield to the other air medium. If the absorption loss (SE_A) is large enough (> 10 dB), the transmitted portion determines the total shielding effectiveness of the shield (*i.e.*, $SE_T = SE_A + SE_R$). However, if the absorption loss is less than 10 dB, multiple reflections within the EM shield can lead to a reduction in the total shielding effectiveness (SE_T) due to the presence of numerous significant higher order terms (*i.e.*, E_{tr2t}, E_{tr4t}, E_{tr6t}, E_{tr8t}, etc.) that add vectorially to the transmitted EM wave (E_{tt}), see **Figure S1**.

In the present work, the absorption loss is much higher than 10 dB (**Figure 6** and **Figure 7**), which indicates that most of the re-reflected wave (*e.g.*, E_{tr}, E_{tr2}, E_{tr3}, etc) within the shielding material can be absorbed. Therefore, the multiple reflection correction term (SE_{MR}) can be ignored in this work.[1]

In general, when an EM wave is propagating into a shielding material, the incident power can be divided into the reflected power (R), absorbed power (A) and transmitted power (T). Using the scattering parameters (S_{ij}) measured on the vector network analyzer, the total shielding effectiveness (SE_T), absorption shielding effectiveness (SE_A), reflection shielding effectiveness (SE_R), R, T and A can be calculated using the following equations:[1-3]

$$SE_R = -10Log_{10}(1 - R) \qquad (S3)$$

$$SE_A = -10Log_{10}\left(\frac{T}{1 - R}\right) \qquad (S4)$$

$$SE_T = SE_A + SE_R = -10Log_{10}(T) \qquad (S5)$$

$$R = |S_{11}|^2 = |S_{22}|^2 \qquad (S6)$$

$$T = |S_{12}|^2 = |S_{21}|^2 \qquad (S7)$$

$$A = 1 - R - T \qquad (S8)$$

where, S_{ij} represents the power transmitting from port i to port j.

References

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