HIGH-FREQUENCY BROADBAND (10~330 GHz) DIELECTRIC PROPERTIES OF POLYIMIDES APPLICABLE TO 5G/6G WIRELESS COMMUNICATIONS

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Abstract

Insulating materials with a low dielectric constant (D_k) and low dissipation factor (D_f) are essential for modern electronics, particularly in 5G and upcoming 6G communication technologies that operate within the millimetre-wave band (30–300 GHz). Polyimides (PIs) are promising candidates due to their excellent thermal stability, mechanical strength, and adaptability to harsh environments. However, their dielectric properties at frequencies beyond 100 GHz remain underexplored, posing challenges for 6G applications. In this study, we employed Fabry–Pérot resonators[1] to systematically measure the dielectric properties of 16 types of PIs (Figure 1) across a broad high-frequency range (10–330 GHz). The investigated samples include commercial PIs, bio-based PIs, partly fluorinated PIs, and highly fluorinated PIs (FPIs) with 27–36 wt% fluorine contents.[2]

The local motion of polymer chains in the GHz domain causes a statistical decrease in D_k, approaching the squared refractive index (n^2) in the near-infrared region. D_f rises linearly at different rates, highlighting that PIs with low D_f at lower frequencies may not necessarily exhibit favourable performance at higher frequencies.[3] The absence of absorption peaks across the frequency range is attributed to the lack of significant relaxation processes with localized chain motions dominating dielectric dispersion. Kapton, a widely used commercial PI, exhibited a D_k over 3.4 and a D_f over 0.015 at 300 GHz. In contrast, FPIs exhibited superior performance, with D_k values below 2.8, D_f values below 0.01 at 100 GHz, and below 0.015 at 300 GHz. However, PIs containing the 2,2'-bis(trifluoromethyl)benzidine (TFDB) structure showed higher D_f due to their molecular architecture, underscoring the importance of molecular design in optimizing the high-frequency performance. Using a home-built variable humidity dielectric measurement system at 10 GHz, it was further demonstrated that all FPIs maintained low D_k and D_f even under 60% relative humidity, whereas Kapton exhibited a D_k close to 3.6 and a D_f around 0.02 under the same conditions.[4] These findings confirm the FPIs' excellent resistance to moisture-induced deterioration, a critical factor for real-world applications in humid environments. FPIs benefit from the low polarizability of fluorine and reduced water absorption, contributing to their outstanding dielectric performance at the 5G/6G frequencies.

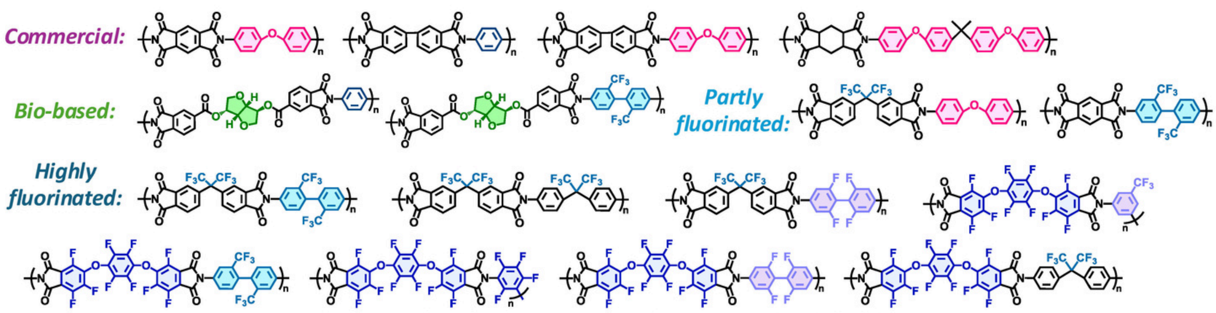

Figure 1. Chemical Structures of 16 types of polyimides.

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[1] EM Labs Inc., Japan, www.emlabs.jp

[2] S. Ando, T. Matsuura, S. Sasaki, *Macromolecules* **1992**, *25*, 5858-5860.

[3] H. Liu, R. Sawada, S. Yanagimoto, Y. Yanagimoto, S. Ando, *Appl. Phys. Lett.* **2024**, *124*, 232903.

[4] R. Sawada, S. Ando, *J. Phys. Chem. C* **2024**, *128*, 6979-6990.