

Polarization Analysis and Humidity/Water Absorption Dependence of Dielectric Properties of Polyimides for 5G/6G Communications

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Abstract: Polyimides (PIs) are expected to be used as low-dielectric insulators for 5G/6G wireless communications. In our study, dielectric constants (D_k) and dissipation factors (D_f) of 15 types of PIs were measured in the transverse electric (TE_{011}) mode at 10 GHz, and the relationships among the dipolar orientational (P_d) and electronic (P_e) polarizations, as well as D_k and D_f , were quantitatively investigated.¹ The total polarization per unit volume, namely P_t ($\propto D_k$), shows a positive linear correlation with P_e , which indicates that P_t is mainly dominated by the P_e calculated from average (n_{av}) or in-plane refractive index (n_{TE}). Besides, we have newly found that the D_f of PIs is anisotropic and linearly proportional to P_d in the in-plane direction ($P_{d(TE)}$), which points out that they are closely related to the in-plane component of dipole moment (μ_{TE}) and their relaxation motions at 10 GHz. Furthermore, the D_k and D_f of all PIs increased linearly with respect to the relative humidity (RH) of the environment, and their slopes (h_{Dk} and h_{Df}), *i.e.*, the RH sensitivities of D_k and D_f , showed a proportional relationship with each other. In particular, perfluorinated PI² and highly fluorinated PIs exhibited extremely low h_{Dk} and h_{Df} values owing to their hydrophobicity and low water absorption. Intriguingly, the PIs containing plural sulfur atoms³ also showed low h_{Dk} and h_{Df} due to their high specific gravity which prevents local dipolar oscillation of PI chains under humid conditions. Most recently, the D_k and D_f of 11 types of PIs were systematically measured between 25 and 330 GHz using Fabry-Pérot resonators.⁴ As the frequency increased, all the PIs exhibited a continuous decrease in D_k and a consistent increase in D_f . Notably, no distinct peaks were observed over the entire frequency range, and the per- and highly fluorinated PIs containing no $-CF_3$ groups in the diamine moieties exhibited the best dielectric performance over 100 GHz, which can be supported by molecular dynamics simulations.

Keywords: Polyimides, Dielectric constant, Dissipation factor, Polarization analysis, Humidity dependence, Water absorption, 5G/6G Wireless applications.

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