

Precise Polarization Analysis and Humidity Dependence of Dielectric Properties of Polyimides for 5G/6G Wireless Applications

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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 clarifies 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 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, a PFAS-free perfluorinated PI^[2] developed for optical waveguide-circuit materials and highly fluorinated PIs exhibited extremely low h_{Dk} and h_{Df} values owing to their hydrophobicity. Intriguingly, commercial PIs derived from *s*BPDA dianhydride also showed low h_{Dk} and h_{Df} due to their dense molecular packing^[3] which prevents the permeation of water. 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 PIs containing $-CF_3$ groups in the diamine moieties exhibited a gradual increase in D_f with frequency over 100 GHz, suggesting characteristic absorptions in the terahertz (THz) domain. These data will be beneficial for developing high-performance polymer-based insulating materials for 5th/6th generation wireless communication technologies.

Keywords: Polyimides, Dielectric constant, Dissipation factor, Anisotropic property, Polarization analysis, Humidity dependence, 5G/6G wireless application

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