7. Terahertz Absorption Behavior of Polyimides in the 1-10 THz Range

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Abstract: Polyimides (PIs) are promising dielectric materials for 5G/6G wireless applications due to their thermal stability and low dielectric loss. However, the structural origin of the dissipation factor (D_f) across the GHz–THz range remains unclear. In this study, broadband dielectric properties (10–330 GHz) and terahertz (THz) absorption spectra (1–10 THz) were systematically investigated for various aromatic PIs, including highly fluorinated systems.[1–4] The D_f increases monotonically with frequency, and both its absolute value and dispersion strongly depend on the molecular structure. The absence of distinct relaxation peaks in the GHz region strongly suggests that D_f is dominated by the low-frequency tail of vibrational and relaxational modes extending from the sub-THz/THz regime rather than discrete dipolar vibrational relaxations.

The THz spectra reveal characteristic absorption bands arising from the backbone vibrations and intermolecular interactions of polymers, whose distribution reflects chain rigidity, structural symmetry, and molecular packing structures. Rigid and highly ordered PIs exhibit sharp and localized absorption features, whereas flexible or disordered systems show broad and distributed spectra, indicating a wider distribution of vibrational modes.

A clear correlation is observed between the THz absorption and dielectric response: the PIs with broader THz absorption exhibit higher D_f and significant frequency dispersion, while those with localized vibrational modes show suppressed D_f and smaller dispersion. This relationship demonstrates that both the magnitude and frequency dependence of D_f are governed by the distribution and anharmonicity of vibrational modes appearing in the THz region.

These results provide a unified picture linking the molecular structure, THz vibrational dynamics, and broadband dielectric losses, which highlights the molecular rigidity, symmetry, and dense packing as essential factors for minimizing the D_f of polymer dielectrics in the GHz-THz frequency range.

Keywords: 5G/6G materials; dissipation factor; terahertz spectroscopy

Acknowledgements: This work was supported by JST CREST JPMJCR2546 and JSPS KAKENHI 26K17905.

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