

Supplementary Information

Preparation and characterization of low dielectric cross-linked polyimide containing fluorene group via post-polymerization cross-linking

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Supplementary Information includes:

Figures S1-S15

Tables S1-S3

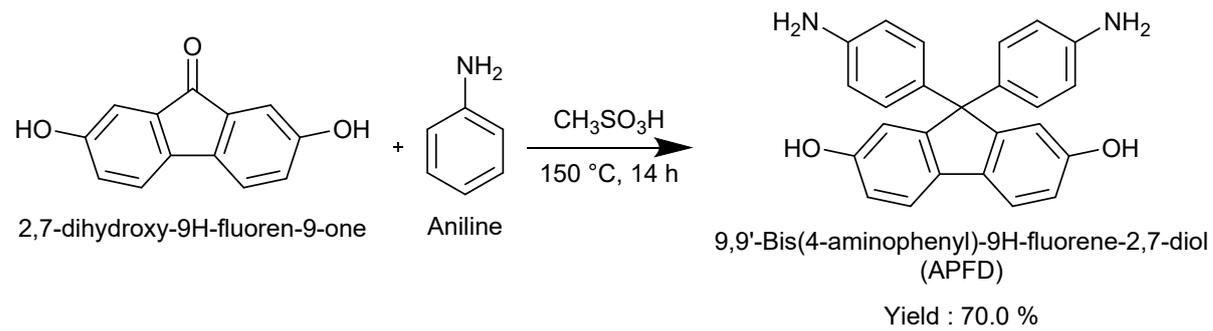


Fig. S1. Schematics for the synthesis of APFD

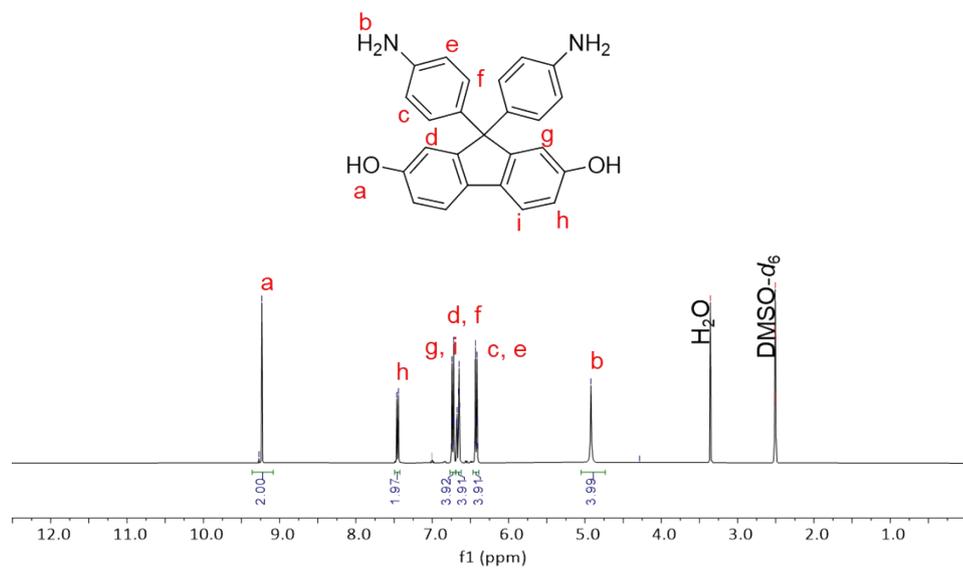


Fig. S2. ¹H NMR spectrum of the APFD. (500 MHz, r.t., in DMSO-*d*₆)

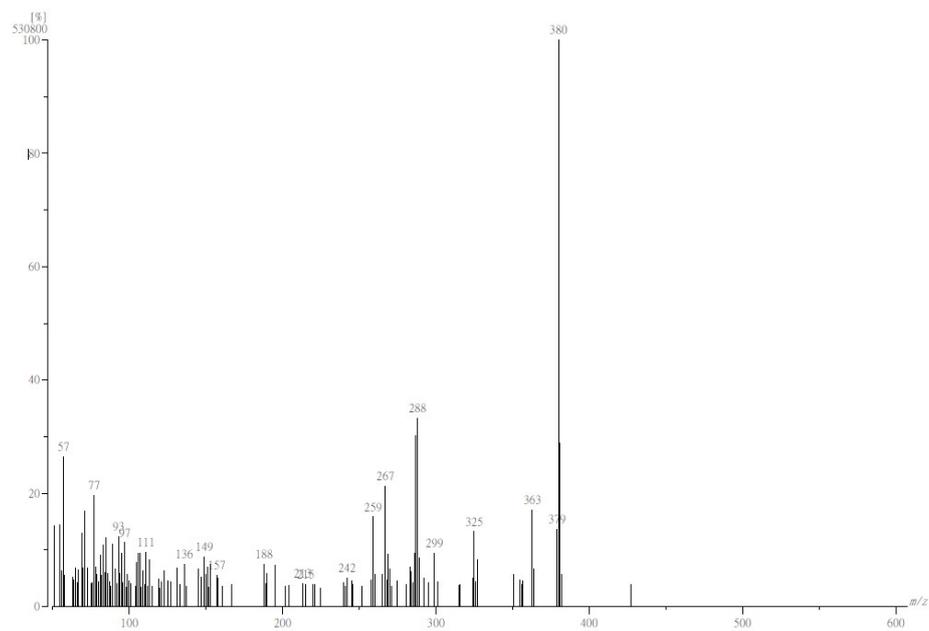


Fig. S3. HRMS mass spectrum of APFD

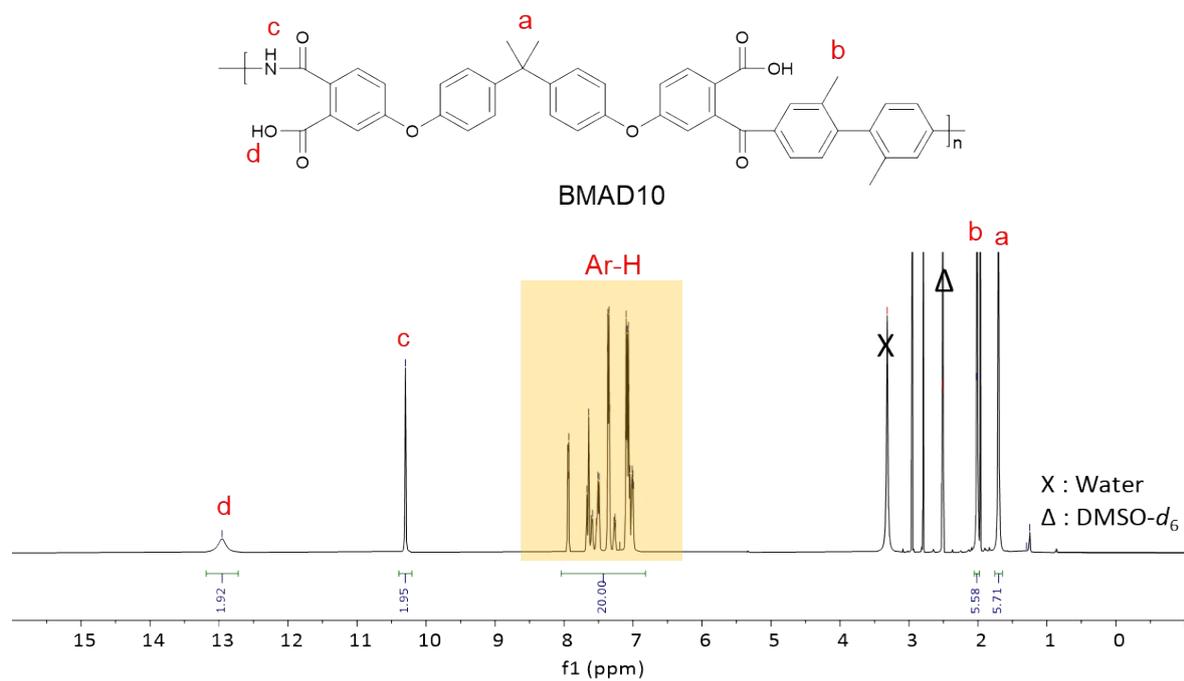


Fig. S4. ¹H NMR spectrum of BMAD10 (500 MHz, r.t., DMSO-*d*₆)

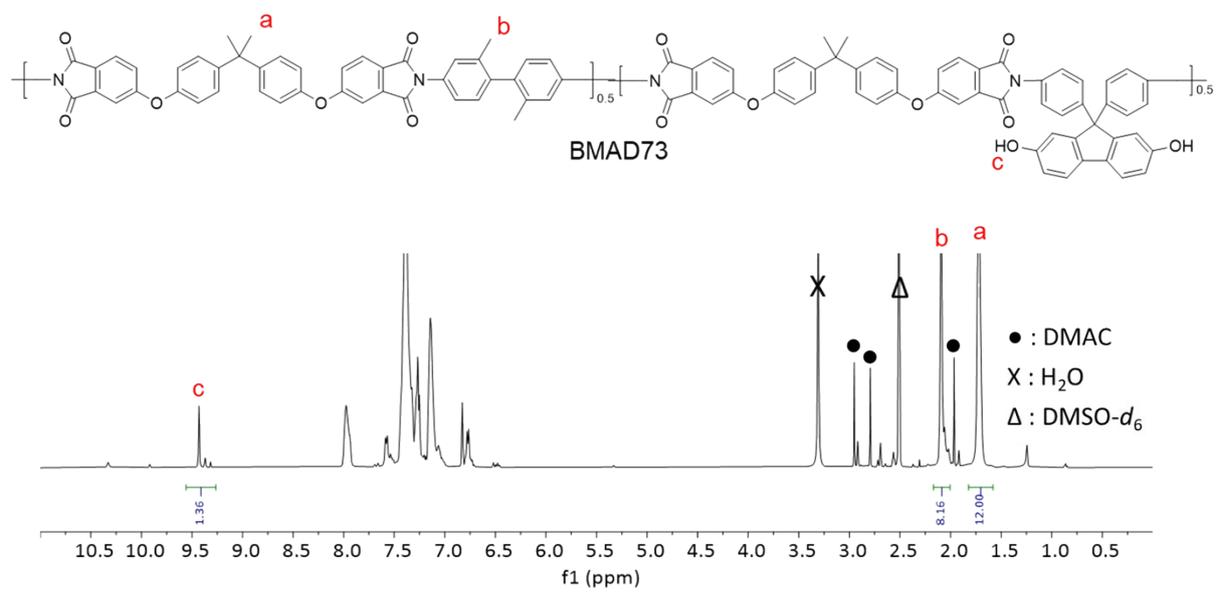


Fig. S5. ^1H NMR spectrum of BMAD73 (500 MHz, r.t., DMSO- d_6)

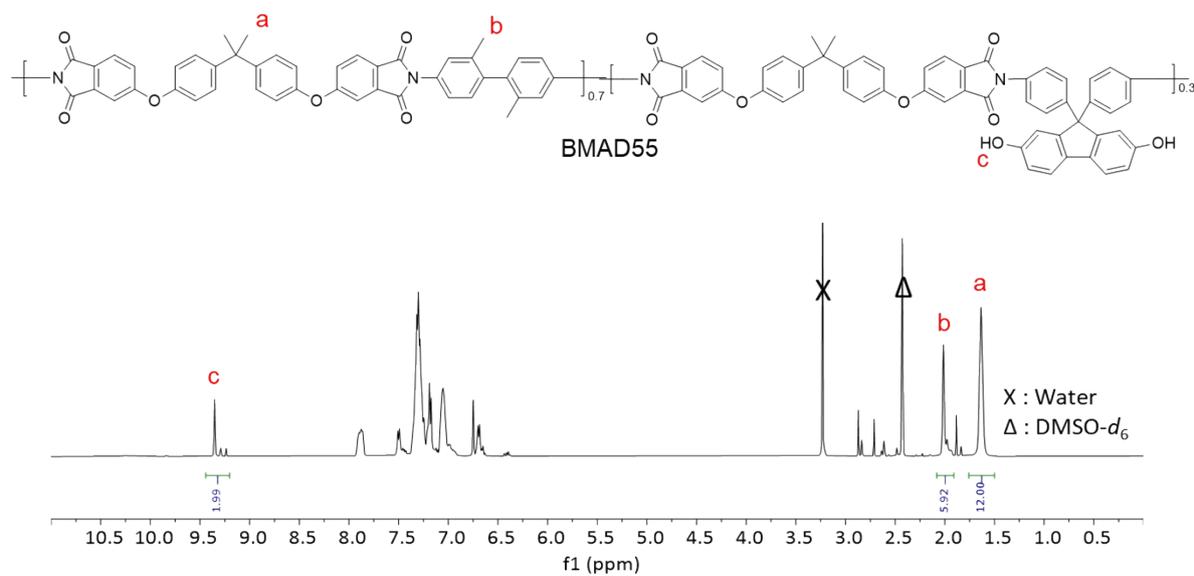


Fig. S6. ^1H NMR spectrum of BMAD55 (500 MHz, r.t., DMSO- d_6)

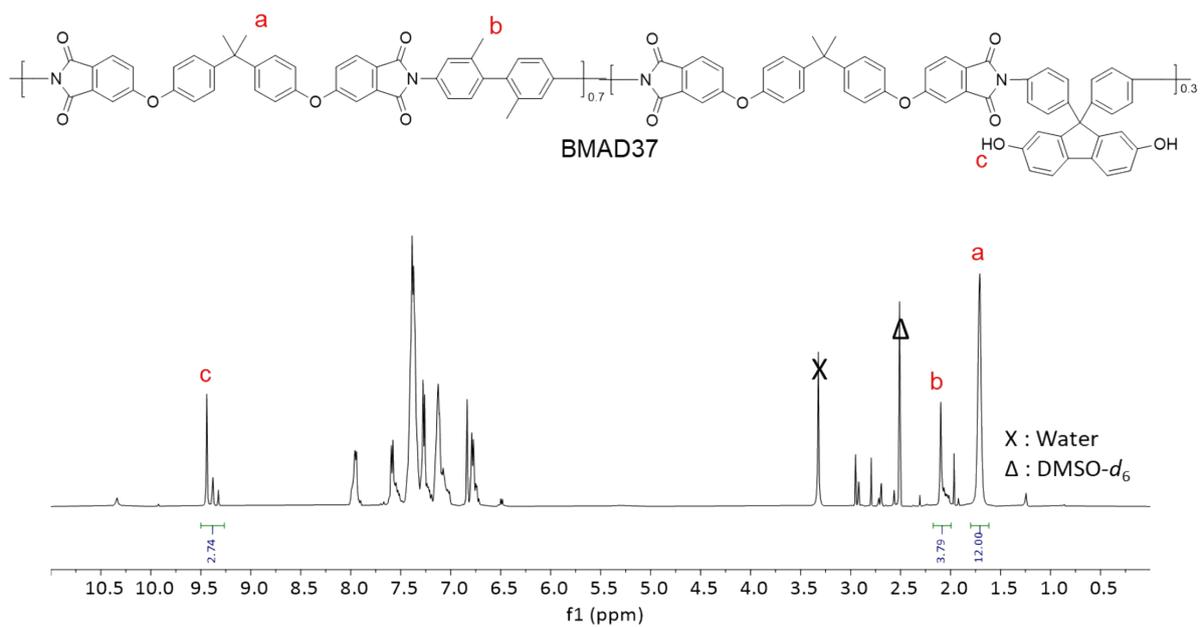


Fig. S7. ^1H NMR spectrum of BMAD37 (500 MHz, r.t., DMSO- d_6)

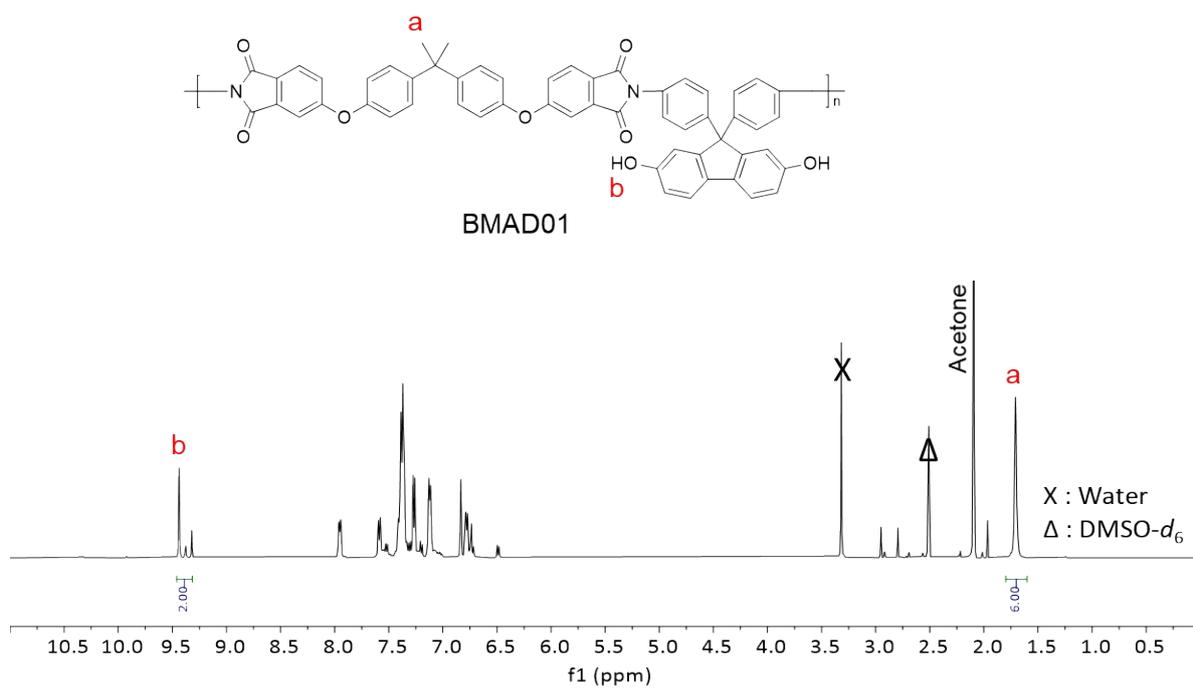


Fig. S8. ^1H NMR spectrum of BMAD01 (500 MHz, r.t., $\text{DMSO-}d_6$)

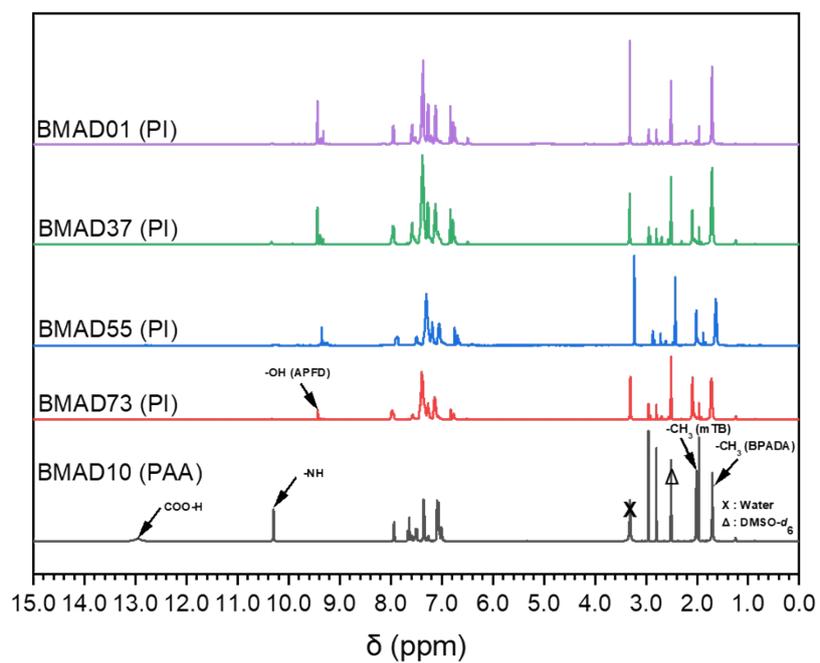


Fig. S9. ¹H NMR spectra of the BMAD series. (500 MHz, r.t., DMSO-*d*₆)

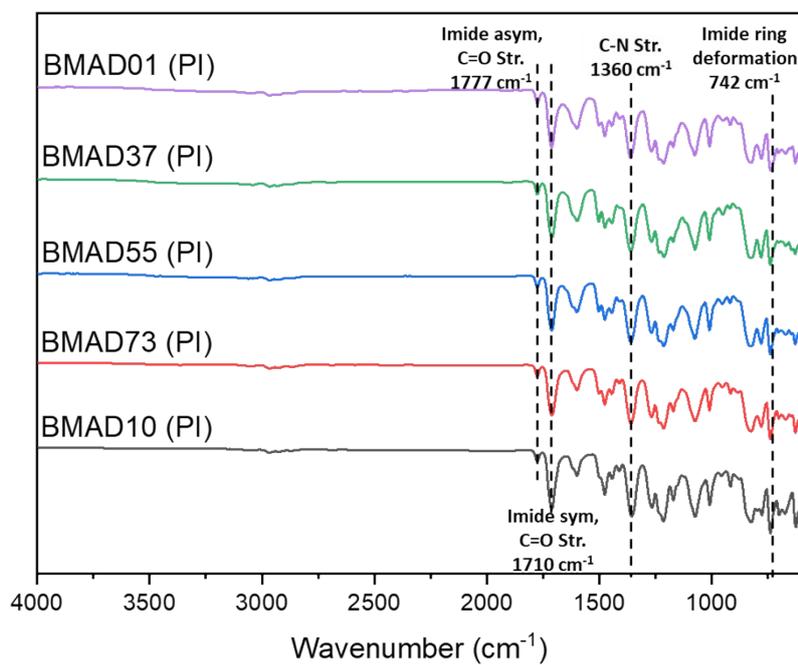


Fig. S10. FT-IR spectra of the BMAD series.

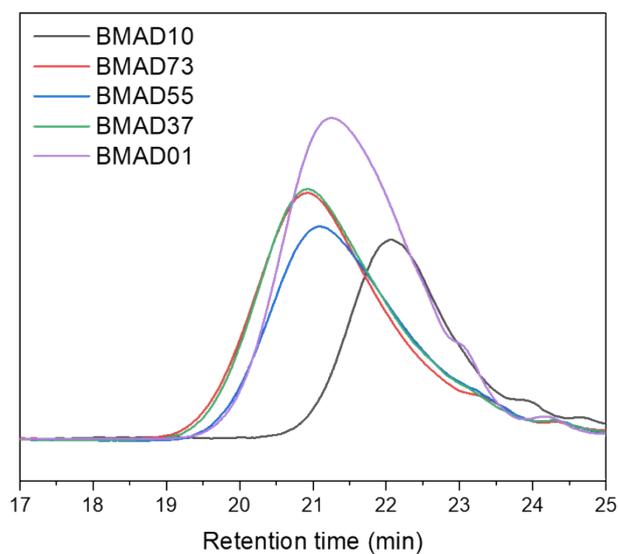


Fig. S11. GPC traces of the BMAD series.

Sample	Type	Feed ratio (mTB:APFD)	Calc. ratio (mTB:APFD)	M_n (g mol ⁻¹)	M_w (g mol ⁻¹)	\mathcal{D}
BMAD10	PAA	100:0	100:0	6,990	10,530	1.50
BMAD73	PI	70:30	67:33	10,507	22,920	2.18
BMAD55		50:50	50:50	8,460	18,479	2.18
BMAD37		30:70	32:68	9,969	21,873	2.19
BMAD01		0:100	0:100	8,169	16,109	1.97

Table S1. Averaged molar mass of BMAD series determined by GPC measurement.

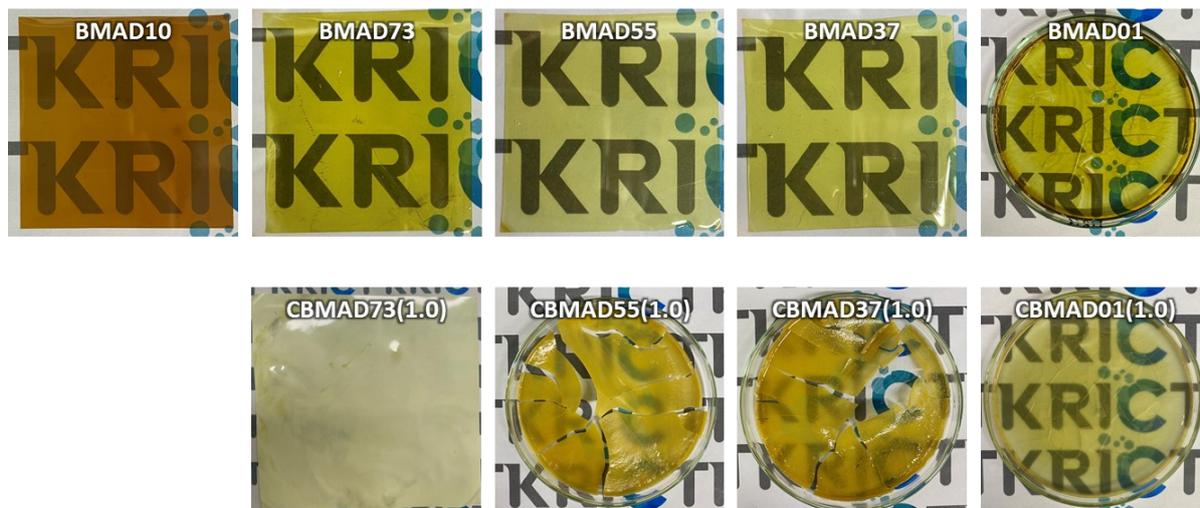


Fig. S12. Fabricated PI films before (up) and after cross-linking (down).

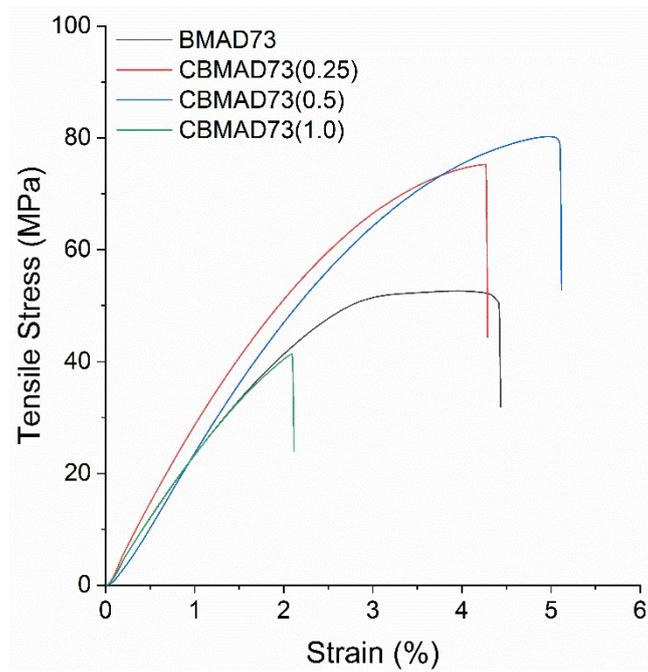


Fig. S13. Strain-stress curve of the polymer films obtained by tensile test.

Table S2. Thickness, film density, and dielectric properties of BMAD73 and CBMAD series.

Sample	Thickness (μm)	Film density (g cm^{-3})	Dielectric properties (@10GHz)	
			D_K	D_F
BMAD73	130	1.24	3.13	0.0246
CBMAD73(0.25)	180	1.23	2.80	0.0210
CBMAD73(0.5)	170	1.22	2.79	0.0117
CBMAD73(1.0) @RH 20%	170	1.17	2.66	0.0056
CBMAD73(1.0) @RH 90%	170	1.17	2.91	0.0139

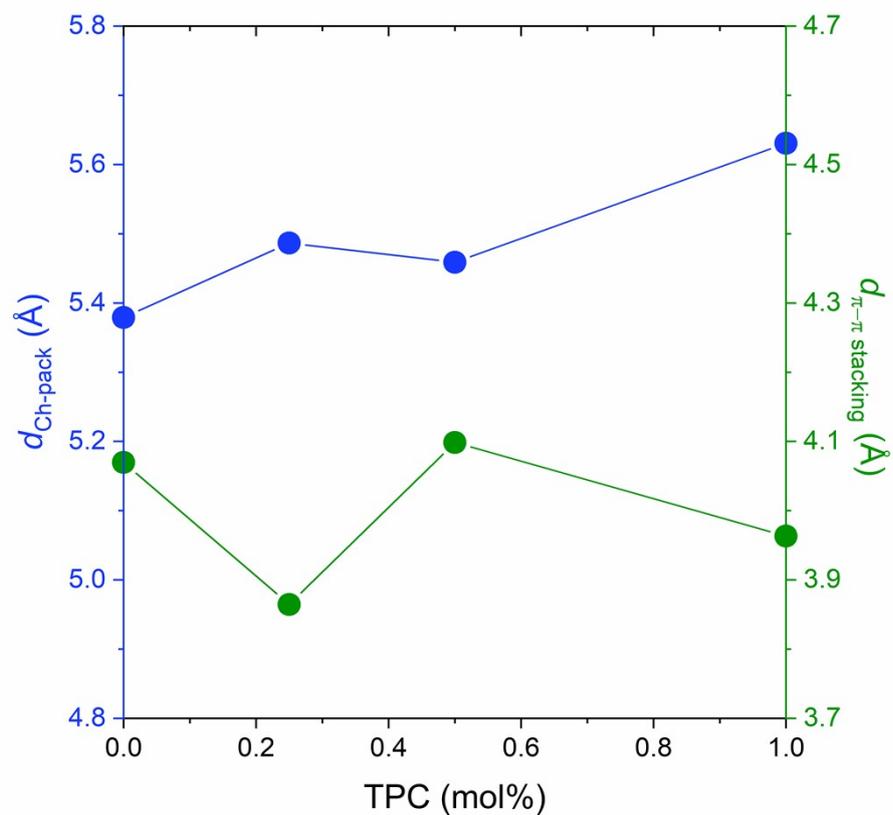


Fig. S14. A plot of ch-packing and π - π stacking distance versus TPC content in CBMAD series.

Table S3. ch-packing and π - π stacking distance of BMAD73 and CBMAD series.

Sample	ch-packing distance (Å)	π - π packing distance (Å)
BMAD73	5.38	4.07
CBMAD73(0.25)	5.49	3.86
CBMAD73(0.5)	5.46	4.10
CBMAD73(1.0)	5.63	3.96

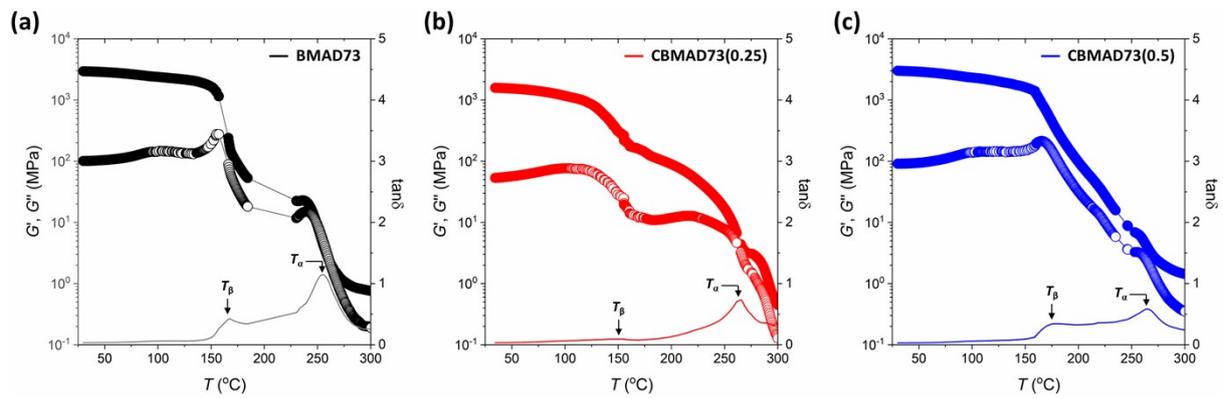


Fig. 15. Temperature-dependent profiles of storage (G' , closed circle) and loss (G'' , open circle) obtained by DMA of (a) BMAD73, (b) CBMAD73(0.25), and (c) CBMAD73(0.5).