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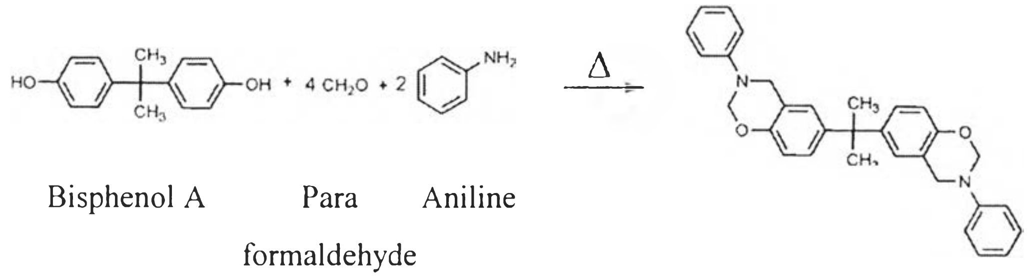
APPENDICES

Appendix A Synthesis route of Aniline-Based Benzoxazine Monomer



Bisphenol A   Para formaldehyde   Aniline

Aniline based benzoxazine monomer

Table A1 Synthesis route of aniline-based benzoxazine monomer

	Precursors			**Reaction time**
	Bisphenol A	**Paraformaldehyde**	**Aniline**	
Mole	0.06	0.24	0.12	30 min
Molecular weight	228.29	30.03	93.13	
Weight (g)	13.70	7.21	11.18	

Appendix B Synthesis route of Methylendianiline-Based Benzoxazine (BA-mda) Precursor

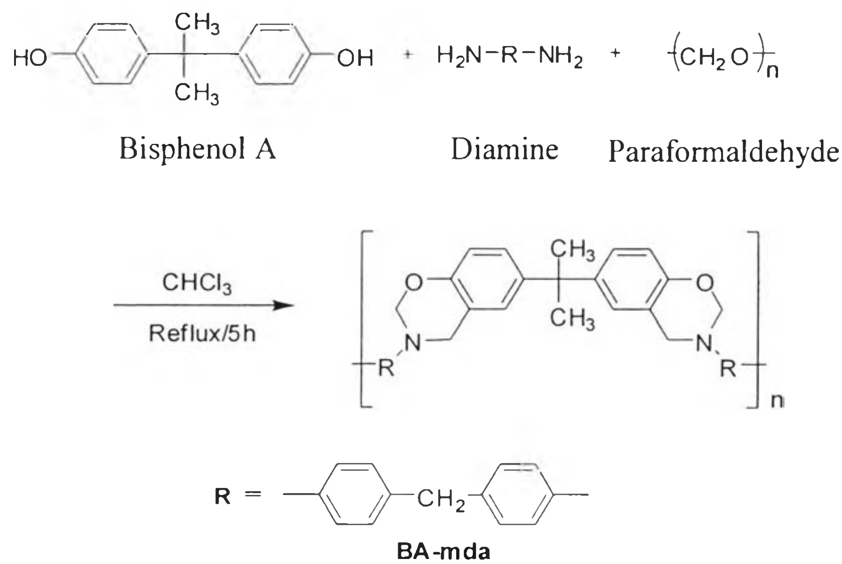


Table B1 Synthesis route of methylendianiline-based (BA-mda) benzoxazine precursor

	Precursors			**Refluxed time**
	Bisphenol A	**Paraformaldehyde**	**Methylendianiline**	
Mole	0.08	0.344	0.08	6 hr.
Molecular weight	228.29	30.03	198.26	
Weight (g)	18.26	10.33	15.86	

Appendix C Synthesis route of Hexamethylenediamine -Based Benzoxazine (BA-hda) Precursor

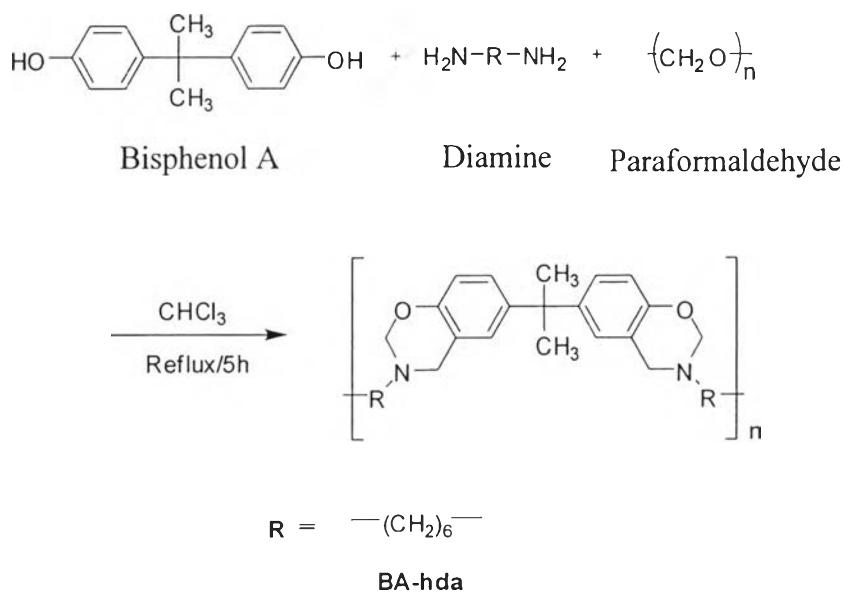


Table C1 Synthesis route of hexamethylenediamine-based benzoxazine (BA-hda) precursor

	Precursors			**Refluxed time**
	Bisphenol A	**Paraformaldehyde**	**hexamethylenediamine**	
Mole	0.08	0.344	0.08	6 hr.
Molecular weight	228.29	30.03	116.2	
Weight (g)	18.26	10.33	9.30	

Appendix D Preparation of Barium strontium titanate (BST) by Sol-Gel method

Precursor materials

1. Barium acetate ($Ba(CH_3COO)_2$), d = 2.47 g/cm^3
2. Strontium acetate ($Sr(CH_3COO)_2$), d = 2.099 g/cm^3
3. Titanium tetra-n-butoxide ($Ti(CH_3(CH2)_3O_4)$), d = 0.998 g/cm^3
4. Glacial acetic acid
5. Methanol

Table D1 Experimental data precursor for $Ba_{0.3}Sr_{0.7}TiO_3$

	Precursors		
	Barium acetate	**Strontium acetate**	**Titanium tetra-n-butoxide**
Mole	0.00882	0.02058	0.0294
Molecular weight	225.42	205.71	340.36
Weight (g)	1.988	4.23	-
Volume (ml)	-	-	10

Appendix E Calculation of BST Volume Fraction in [poly(BA-a)/PU]/BST Composites

The volume fraction of BST was calculated by using the following formula:

$$f = \frac{(\frac{M_c}{\rho_c})}{(M_c/\rho_c) + (M_p/\rho_p)}$$

Where M_c and ρ_c are the mass and density (5.412 g/cm^3) of BST powder

M_p and ρ_p are the mass and density (1.179 g/cm^3) of BA-a/PU polymer matrix

Table E1 Volume fraction of BST powder at various BST wt.% in the composites

[poly(BA-a)/PU]/BST Composites	BST volume fraction
30 wt.% BST	0.0918
40 wt.% BST	0.1359
50 wt.% BST	0.1908
60 wt.% BST	0.2614

Appendix F Calculation of BST Volume Fraction in BA-mda/BST Composites

The volume fraction of BST was calculated by using the following formula:

$$f = \frac{(\frac{M_c}{\rho_c})}{(M_c/\rho_c) + (M_p/\rho_p)}$$

Where M_c and ρ_c are the mass and density (5.412 g/cm^3) of BST powder

M_p and ρ_p are the mass and density (1.182 g/cm^3) of methylendianiline-based (BA-mda) polybenzoxazine

Table F1 Volume fraction of BST powder at various BST wt% in the composites

Poly(BA-mda)/BST Composites	BST volume fraction
30 wt.% BST	0.0917
40 wt.% BST	0.1357
50 wt.% BST	0.1906
60 wt.% BST	0.2610

Appendix G DMA Thermograms of BA-a/PU Alloys

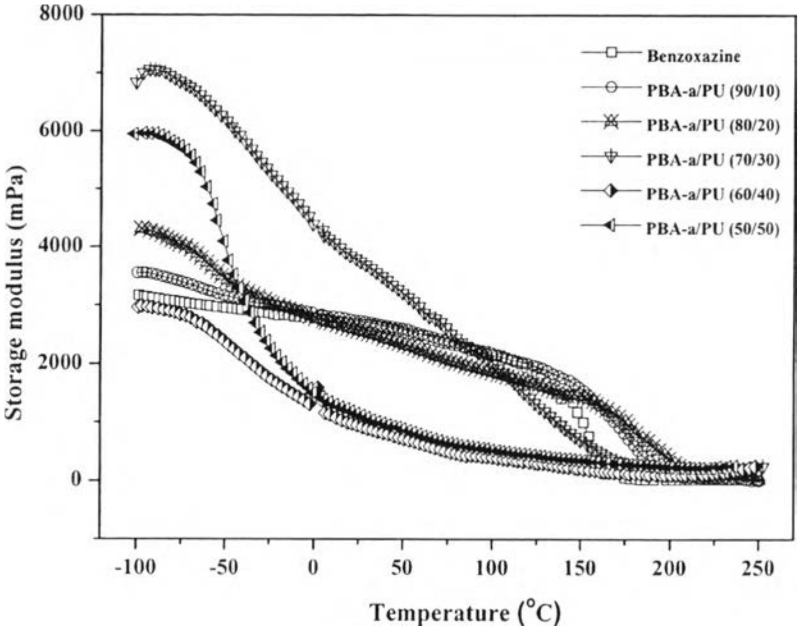


Figure G1 Storage modulus of BA-a/PU alloys at various components: 100/0, 90/10, 80/20, 70/30, 60/40, and 50/50.

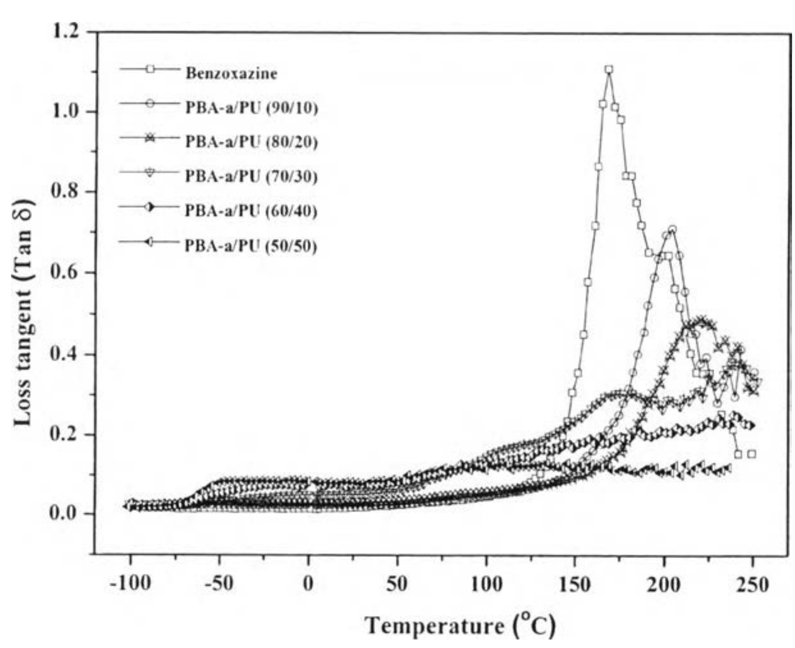


Figure G2 Tan δ of BA-a/PU alloys at various components: 100/0, 90/10, 80/20, 70/30, 60/40, and 50/50.

Appendix H The Dielectric Constant and Loss Tangent of Poly(benzoxazine/urethane) based at Microwave Frequency (300 MHz – 1 GHz)

Table H1 The dielectric constant of poly(benzoxazine/urethane) based

BA-a/PU (vol.%)	Frequency (GHz)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
100/0	3.39	3.39	3.39	3.40	3.41	3.41	3.41	3.41
90/10	3.55	3.56	3.55	3.55	3.56	3.56	3.57	3.56
80/20	3.51	3.49	3.49	3.49	3.49	3.49	3.49	3.49
70/30	3.42	3.40	3.38	3.37	3.37	3.37	3.36	3.35
60/40	3.27	3.24	3.20	3.18	3.17	3.16	3.14	3.13
50/50	3.15	3.12	3.11	3.10	3.09	3.09	3.08	3.08

Table H2 The loss tangent of poly(benzoxazine/urethane) based

BA-a/PU (vol.%)	Frequency (GHz)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
100/0	0.0102	0.0118	0.0115	0.0119	0.0133	0.0124	0.0134	0.0139
90/10	0.0178	0.0194	0.0189	0.0191	0.0200	0.0195	0.0203	0.0206
80/20	0.0237	0.0258	0.0246	0.0239	0.0260	0.0247	0.0254	0.0258
70/30	0.0295	0.0308	0.0301	0.0298	0.0300	0.0294	0.0293	0.0298
60/40	0.0245	0.0258	0.0244	0.0248	0.0251	0.0241	0.0240	0.0244
50/50	0.0454	0.0454	0.0451	0.0441	0.0434	0.0428	0.0425	0.0417

Appendix I The Dielectric Constant and Loss Tangent of the (90/10 vol.%) Poly(benzoxazine/urethane) Based Composites at Microwave Frequency (300 MHz – 1 GHz)

Table I1 The dielectric constant of poly(benzoxazine/urethane) based/BST composites

Materials	Frequency (GHz)							
	0.3	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
BA-a/PU	3.55	3.56	3.55	3.55	3.56	3.56	3.57	3.56
$Ba_{0.3}Sr_{0.7}TiO_3$	192.88	189.46	172.86	163.25	160.10	141.96	142.71	136.98

Table I2 The dielectric constant of poly(benzoxazine/urethane) based/BST composites

Materials	Frequency (Hz)							
	0.3	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
30 wt.% BST	4.49	4.49	4.50	4.50	4.50	4.51	4.50	4.50
40 wt.% BST	5.95	5.94	5.96	5.96	5.95	5.94	5.95	5.95
50 wt.% BST	6.29	6.29	6.30	6.31	6.32	6.32	6.32	6.31
60 wt.% BST	8.00	7.97	7.98	7.98	8.00	8.00	8.10	8.10

Table I3 The dielectric constant of poly(benzoxazine/urethane) based/silane treated BST composites

Materials	Frequency (Hz)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
30 wt.% BST	4.89	4.88	4.88	4.88	4.88	4.88	4.89	4.88
40 wt.% BST	7.16	7.14	7.15	7.15	7.15	7.17	7.17	7.17
50 wt.% BST	11.07	11.06	11.06	11.07	11.07	11.07	11.09	11.08
60 wt.% BST	13.83	13.81	13.82	13.82	13.84	13.85	13.88	13.90

Table I4 The dielectric constant of poly(benzoxazine/urethane) based/(BA-a/PU) treated BST composites

Materials	Frequency (Hz)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
30 wt.% BST	4.76	4.75	4.73	4.73	4.71	4.71	4.70	4.70
40 wt.% BST	6.28	6.23	6.23	6.22	6.22	6.21	6.26	6.25
50 wt.% BST	7.77	7.72	7.73	7.71	7.72	7.72	7.78	7.78
60 wt.% BST	10.04	9.96	9.96	9.93	9.91	9.91	9.87	9.86

Table I5 The loss tangent of poly(benzoxazine/urethane) based/BST composites

Materials	Frequency (GHz)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
BA-a/PU	0.0178	0.0194	0.0189	0.0191	0.0200	0.0195	0.0203	0.0206
$Ba_{0.3}Sr_{0.7}TiO_3$	0.28	0.33	0.42	0.49	0.55	0.60	0.62	0.72

Table I6 The loss tangent of poly(benzoxazine/urethane) based/BST composites.

Materials	Frequency (Hz)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
30 wt.% BST	0.0107	0.0131	0.0129	0.0133	0.0147	0.0140	0.0145	0.0147
40 wt.% BST	0.0100	0.0123	0.0114	0.0125	0.0132	0.0123	0.0139	0.0122
50 wt.% BST	0.0103	0.0131	0.0125	0.0129	0.0140	0.0135	0.0138	0.0137
60 wt.% BST	0.0135	0.0136	0.0157	0.0136	0.0102	0.0160	0.0077	0.0125

Table I7 The loss tangent of poly(benzoxazine/urethane) based/silane treated BST composites

Materials	Frequency (Hz)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
30 wt.% BST	0.0134	0.0128	0.0140	0.0140	0.0138	0.0154	0.0154	0.0145
40 wt.% BST	0.0101	0.0099	0.0114	0.0113	0.0105	0.0122	0.0111	0.0111
50 wt.% BST	0.0072	0.0073	0.0087	0.0081	0.0077	0.0083	0.0074	0.0079
60 wt.% BST	0.0079	0.0089	0.0090	0.0088	0.0094	0.0082	0.0080	0.0095

Table I8 The loss tangent of poly(benzoxazine/urethane) based/(BA-a/PU) treated BST composites

Materials	Frequency (Hz)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
30 wt.% BST	0.0120	0.0129	0.0139	0.0144	0.0148	0.0143	0.0154	0.0151
40 wt.% BST	0.0198	0.0206	0.0223	0.0200	0.0163	0.0223	0.0128	0.0189
50 wt.% BST	0.0154	0.0163	0.0191	0.0165	0.0130	0.0197	0.0099	0.0161
60 wt.% BST	0.0143	0.0152	0.0159	0.0151	0.0155	0.0163	0.0145	0.0150

Appendix J The Dielectric Constant and Loss Tangent of High Molecular Weight Polybenzoxazine/BST Composites at Low Frequency (1 kHz – 1 MHz)

Table J1 The dielectric constant of high molecular weight polybenzoxazines at low frequency (1 kHz – 1 MHz)

Materials	Frequency (Hz)			
	10^3	10^4	10^5	10^6
Poly(BA-mda)	58.15	56.91	54.74	52.07
Poly(BA-hda)	42.54	42.18	41.34	40.52

Table J2 The dielectric constant of methylenedianiline-based polybenzoxazine/BST composites at low frequency (1 kHz – 1 MHz)

Materials	Frequency (Hz)			
	10^3	10^4	10^5	10^6
30 wt% BST	105.87	101.65	99.51	97.91
40 wt% BST	157.46	150.89	146.68	141.73
50 wt% BST	156.32	152.06	148.74	144.27
60 wt% BST	200.47	193.20	188.12	182.83

Table J3 The Loss tangent of high molecular weight polybenzoxazines at low frequency (1 kHz – 1 MHz)

Materials	Frequency (Hz)			
	10^3	10^4	10^5	10^6
Poly(BA-mda)	0.0087	0.0130	0.0111	0.0144
Poly(BA-hda)	0.0200	0.0099	0.0048	0.0030

Table J4 The Loss tangent of methylenedianiline-based polybenzoxazine/BST composites at low frequency (1 kHz – 1 MHz)

Materials	**Frequency (Hz)**			
	10^3	**10^4**	**10^5**	**10^6**
30 wt% BST	0.0288	0.0193	0.0217	0.0272
40 wt% BST	0.0380	0.0292	0.0284	0.0373
50 wt% BST	0.0209	0.0159	0.0177	0.0201
60 wt% BST	0.0475	0.0269	0.0242	0.0275

Appendix K The Dielectric Constant and Loss Tangent of High Molecular Weight Polybenzoxazine/BST Composites at Microwave Frequency (300 MHz – 1 GHz)

Table K1 The dielectric constant of high molecular weight polybenzoxazines

Materials	Frequency (GHz)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Poly(BA-mda)	4.59	4.56	4.57	4.56	4.57	4.57	4.58	4.57
Poly(BA-hda)	3.01	3.00	3.02	3.02	3.03	3.03	3.03	3.04

Table K2 The dielectric constant of methylenedianiline-based polybenzoxazine/BST composites

Materials	Frequency (Hz)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
30 wt.% BST	6.42	6.36	6.30	6.27	6.23	6.19	6.17	6.12
40 wt.% BST	6.96	6.89	6.85	6.82	6.73	6.73	6.68	6.63
50 wt.% BST	7.63	7.61	7.58	7.57	7.55	7.54	7.55	7.53
60 wt.% BST	8.57	8.44	8.31	8.23	8.15	8.07	8.02	7.94

Table K3 The dielectric constant of of methylenedianiline-based polybenzoxazine /silane treated BST composites

Materials	Frequency (Hz)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
30 wt.% BST	5.76	5.72	5.73	5.72	5.72	5.72	5.72	5.72
40 wt.% BST	6.31	6.29	6.26	6.24	6.22	6.19	6.16	6.11
50 wt.% BST	6.73	6.70	6.70	6.71	6.71	6.71	6.72	6.72
60 wt.% BST	8.24	8.19	8.18	8.15	8.15	8.15	8.14	8.16

Table K4 The dielectric constant of methylenedianiline-based polybenzoxazine /BA-mda treated BST composites

Materials	Frequency (Hz)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
30 wt.% BST	5.55	5.51	5.46	5.45	5.42	5.38	5.35	5.32
40 wt.% BST	7.01	6.97	6.94	6.91	6.88	6.85	6.82	6.79
50 wt.% BST	7.73	7.67	7.60	7.56	7.51	7.45	7.39	7.33
60 wt.% BST	8.25	8.22	8.21	8.21	8.21	8.20	8.21	8.19

Table K5 The loss tangent of high molecular weight polybenzoxazines

Materials	Frequency (GHz)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Poly(BA-mda)	0.0240	0.0228	0.0231	0.0222	0.0216	0.0231	0.0210	0.0220
Poly(BA-hda)	0.0061	0.0046	0.0063	0.0061	0.0071	0.0073	0.0082	0.0087

Table K6 The loss tangent of methylenedianiline-based polybenzoxazine/BST composites

Materials	Frequency (Hz)							
	0.3	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
30 wt.% BST	0.0327	0.0321	0.0329	0.0325	0.0326	0.0337	0.0327	0.0326
40 wt.% BST	0.0280	0.0296	0.0291	0.0279	0.0287	0.0286	0.0279	0.0288
50 wt.% BST	0.0146	0.0149	0.0147	0.0147	0.0142	0.0151	0.0143	0.0148
60 wt.% BST	0.0674	0.0672	0.0678	0.0678	0.0681	0.0689	0.0680	0.0690

Table K7 The loss tangent of methylenedianiline-based polybenzoxazine/silane treated BST composites

Materials	Frequency (Hz)							
	0.3	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
30 wt.% BST	0.0264	0.0253	0.0249	0.0248	0.0241	0.0241	0.0243	0.0242
40 wt.% BST	0.0288	0.0299	0.0301	0.0294	0.0307	0.0301	0.0294	0.0307
50 wt.% BST	0.0240	0.0208	0.0198	0.0187	0.0174	0.0165	0.0162	0.0158
60 wt.% BST	0.0168	0.0171	0.0173	0.0173	0.0173	0.0176	0.0174	0.0177

Table K8 The loss tangent of methylenedianiline-based polybenzoxazine/BA-mda treated BST composites

Materials	Frequency (Hz)							
	0.3	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
30 wt.% BST	0.0203	0.0217	0.0213	0.0202	0.0209	0.0206	0.0206	0.0207
40 wt.% BST	0.0195	0.0210	0.0223	0.0241	0.0258	0.0267	0.0265	0.0285
50 wt.% BST	0.0199	0.0212	0.0211	0.0203	0.0211	0.0206	0.0214	0.0206
60 wt.% BST	0.0281	0.0276	0.0274	0.0259	0.0256	0.0277	0.0237	0.0268

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Publications:

1. Drennan-Harris, L. R.; Wongwilawan, S.; and Tyson, J. F. (2012) "Trace determination of total mercury in rice by conventional inductively coupled plasma mass spectrometry", Journal of Analytical Atomic Spectrometry, 28(2), 259-265.
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1. Wongwilawan, S.; Ishida, H.; and Manuspiya, H. (2013, April 23) Dielectric properties of durable polybenzoxazines in the microwave frequency region. Proceedings of the 4th Research Symposium on Petrochemical and Materials Technology and the 19th PPC Symposium on Petroleum, Petrochemicals and Polymers, Balloom, Queen Sirikit National Convention Center, Bangkok, Thailand.

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