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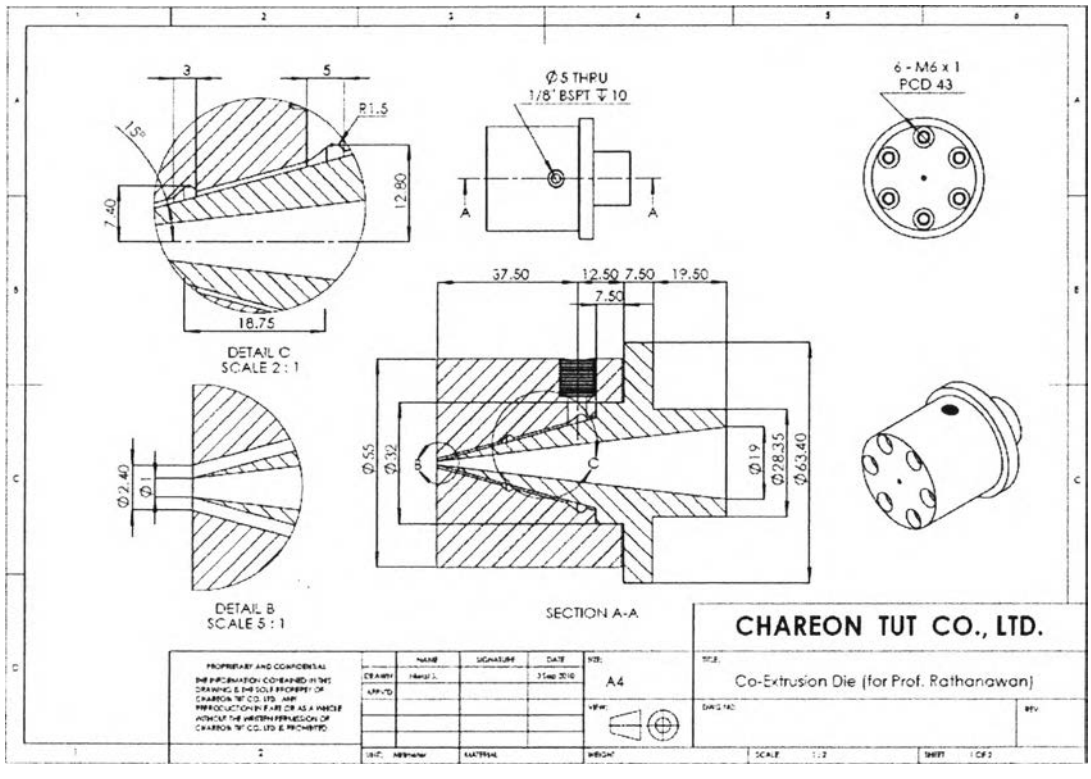
# APPENDICES

**Appendix A** Co-extrusion die model




**Appendix B** Molecular weight of synthesized PASE

**Table B1** Molecular weight of synthesized PASE

| Conditions | Weight-A.M.W (Mw) | Number-A.M.W (Mn) | Z-A.M.W (Mz) | Z+1-A.M.W (Mz1) | $M_w/M_n$ | $M_z/M_w$ |
|---|---|---|---|---|---|---|
| $Et_3N$, DMF, rt, 72 h. | 4699 | 3670 | 6221 | 7979 | 1.28027 | 1.32394 |
| $CaH_2$, DMF, 80 o C, 48 h. | 4056 | 3397 | 4944 | 5940 | 1.19413 | 1.21879 |
| Et3N, DMAP, THF, rt, 24 h. | | | | | | |
| 2:1 (PASE 1) | 811 | 727 | 908 | 1015 | 1.11561 | 1.11999 |
| 1:1 (PASE 2) | 30517 | 19851 | 46789 | 67599 | 1.53729 | 1.53322 |
| 1:1.25 (PASE 3) | 37443 | 22037 | 60435 | 87172 | 1.69911 | 1.61403 |
| 1:2 (PASE 4) | 17659 | 4561 | 57694 | 107184 | 3.87155 | 3.26705 |
| 1:3 (PASE 5) | 2818 | 1108 | 11061 | 30576 | 2.54439 | 3.92452 |

**Appendix C** Raw Data of Capillary Rheometer

**Table C1** Shear rate and viscosity of PC in different temperature

| Shear Rate ($s^{-1}$) | Viscosity (Pa.s) Temperature (° C) | | | |
|---|---|---|---|---|
| | 225 | 235 | 245 | 250 |
| 10 | 5305 | 2121 | 2405 | 2900 |
| 20 | 5234 | 1202 | 1626 | 1979 |
| 50 | 5262 | 579 | 2316 | 2334 |
| 100 | 4887 | 480 | 2277 | 2272 |
| 150 | 5220 | 2287 | 2230 | 2136 |
| 300 | 4121 | 2371 | 2065 | 1768 |
| 450 | 2837 | 2161 | 1735 | 1458 |
| 600 | 2032 | 1956 | 1478 | 1239 |
| 1000 | 1271 | 1139 | 1073 | 889 |
| 2000 | 639 | 471 | 594 | 545 |
| 4000 | 338 | 233 | 300 | 271 |
| 10000 | 141 | 123 | 111 | 98 |

**Table C2** Shear rate and viscosity of PMMA in different temperature

| Shear Rate ($s^{-1}$) | Viscosity (Pa.s) Temperature (° C) | | | |
|---|---|---|---|---|
| | 225 | 235 | 245 | 250 |
| 10 | 4385 | 2333 | 2121 | 1980 |
| 20 | 3571 | 1273 | 1131 | 1308 |
| 50 | 2121 | 806 | 777 | 933 |
| 100 | 1407 | 912 | 657 | 650 |
| 150 | 1089 | 796 | 556 | 546 |
| 300 | 700 | 530 | 393 | 389 |
| 450 | 539 | 407 | 315 | 309 |
| 600 | 435 | 335 | 264 | 258 |
| 1000 | 304 | 238 | 192 | 186 |
| 2000 | 182 | 147 | 120 | 116 |
| 4000 | 108 | 88 | 75 | 71 |
| 10000 | 54 | 45 | 39 | 36 |

**Table C3** Shear rate and viscosity of PASE/PMMA at 225 $^{o}$ C

| Shear Rate ($s^{-1}$) | Viscosity (Pa.s) | | |
|---|---|---|---|
| | 10 wt% PASE/PMMA | 20 wt% PASE/PMMA | 25 wt% PASE/PMMA |
| 10 | 4385 | 2333 | 2121 |
| 20 | 3571 | 1273 | 1131 |
| 50 | 2121 | 806 | 777 |
| 100 | 1407 | 912 | 657 |
| 150 | 1089 | 796 | 556 |
| 300 | 700 | 530 | 393 |
| 450 | 539 | 407 | 315 |
| 600 | 435 | 335 | 264 |
| 1000 | 304 | 238 | 192 |
| 2000 | 182 | 147 | 120 |
| 4000 | 108 | 88 | 75 |
| 10000 | 54 | 45 | 39 |

**Appendix D** Raw Data of attenuation experiment

**Table D1** Data and calculation of attenuation experimentof different cladding-type fibers

| Cladding type | $V_o$ | $V_i$ | $V_o/V_i$ | $\log(V_o/V_i)$ | $20\log(V_o/V_i)/L\text{-}X$ | average of attenuation | standard deviation | confidence at $\alpha = 0.05$ |
|---|---|---|---|---|---|---|---|---|
| free falling and 20 min/mm of piston speed | | | | | | | | |
| PMMA | 397.9 mV | 1580mV | 0.25183 | -0.5988831 | -59.88831478 | 60.0897356 | 3.46375254 | 3.03605718 |
| | 542 mV | 2155mV | 0.25145 | -0.5995484 | -59.954836 | | | |
| | 428.7 mV | 1512mV | 0.283356 | -0.5476676 | -54.76675868 | | | |
| | 298.5mV | 1310mV | 0.22773 | -0.6425798 | -64.25797539 | | | |
| | 345.99mV | 1428mV | 0.24221 | -0.6158079 | -61.58079303 | | | |
| 10% PASE/PMMA | 1.68V | 3.4V | 0.49411 | -0.3061696 | -20.41130902 | 20.0069807 | 1.32776596 | 1.16381679 |
| | 290mV | 542.59mV | 0.53447 | -0.2720767 | -18.13844446 | | | |
| | 177.8mV | 361.73mV | 0.49152 | -0.3084588 | -20.5639204 | | | |
| | 34.5mV | 67.2mV | 0.51338 | -0.2895611 | -19.30407029 | | | |
| | 68.9mV | 145.37mV | 0.473961 | -0.3242574 | -21.61715953 | | | |
| 20% PASE/PMMA | 37.6mV | 54.25mV | 0.693 | -0.1590801 | -10.60533924 | 14.6528756 | 2.72337669 | 2.38710106 |
| | 122.3mV | 208.82mV | 0.58567 | -0.232347 | -15.48980143 | | | |
| | 87.5mV | 140.46mV | 0.62295 | -0.2055468 | -13.70312066 | | | |
| | 672.3mV | 1250mV | 0.53771 | -0.2694519 | -17.96345911 | | | |
| | 977.6mV | 1669mV | 0.58541 | -0.2325399 | -15.50265755 | | | |
| 25% PASE/PMMA | 84.51mV | 140mV | 0.603684 | -0.2191921 | -14.61280357 | 14.7834317 | 0.60165409 | 0.52736337 |
| | 120.5mV | 203.25mV | 0.59284 | -0.2270625 | -15.13750009 | | | |
| | 78mV | 129.94mV | 0.60025 | -0.2216678 | -14.77785542 | | | |
| | 353.9mV | 571.88mV | 0.61883 | -0.2084286 | -13.8952427 | | | |
| | 256mV | 437.16mV | 0.58559 | -0.2324063 | -15.49375655 | | | |

**Table D1** Data and calculation of attenuation experimentof different cladding-type fibers (cont.)

| Cladding type | $V_o$ | $V_i$ | $V_o/V_i$ | $\log(V_o/V_i)$ | 20 $\log(V_o/V_i)/L$-X | average of attenuation | standard deviation | confidence at $\alpha = 0.05$ |
|---|---|---|---|---|---|---|---|---|
| free falling and 24.5 min/mm of piston speed | | | | | | | | |
| PMMA | 1.28mV | 5.34mV | 0.239497 | -0.6207019 | -62.07019492 | -67.8579477 | 4.66978183 | 4.09316903 |
| | 2.67mV | 12.98mV | 0.20559 | -0.686998 | -68.69980135 | | | |
| | 1.26mV | 6.85mV | 0.18372 | -0.7358436 | -73.58435633 | | | |
| | 1.24mV | 5.45mV | 0.22745 | -0.6431141 | -64.31140588 | | | |
| | 1.5mV | 7.62mV | 0.19668 | -0.7062398 | -70.62398004 | | | |
| 10% PASE/PMMA | 1.92V | 2.53V | 0.75709 | -0.120848 | -8.0565347 | -8.82492026 | 0.90089675 | 0.7896563 |
| | 3.55V | 4.82V | 0.73559 | -0.1333642 | -8.890945562 | | | |
| | 8.79V | 12.01V | 0.73158 | -0.1357382 | -9.049211721 | | | |
| | 12.56V | 16.52V | 0.75992 | -0.1192321 | -7.948808356 | | | |
| | 34.21mV | 48.62mV | 0.70358 | -0.1526865 | -10.17910095 | | | |
| 20% PASE/PMMA | 56.3mV | 62.8mV | 0.896375 | -0.0475087 | -3.167249842 | -2.93040205 | 0.69377735 | 0.60811149 |
| | 78.2mV | 83.39mV | 0.93771 | -0.0279315 | -1.862096835 | | | |
| | 91mV | 102.82mV | 0.88502 | -0.0530469 | -3.53646099 | | | |
| | 70.3mV | 76.99mV | 0.91305 | -0.0395054 | -2.633695946 | | | |
| | 102mV | 114.91mV | 0.88759 | -0.0517876 | -3.452506625 | | | |

**Table D1** Data and calculation of attenuation experimentof different cladding-type fibers (cont.)

| Cladding type | $V_o$ | $V_i$ | $V_o/V_i$ | $\log(V_o/V_i)$ | 20 $\log(V_o/V_i)$/L-X | average of attenuation | standard deviation | confidence at $\alpha = 0.05$ |
|---|---|---|---|---|---|---|---|---|
| 1.179 of draw ratio and 20 min/mm of piston speed | | | | | | | | |
| PMMA | 752.8mV | 4504mV | 0.16714032 | -0.7769188 | -77.69187714 | -78.7732993 | 1.12949176 | 0.99002499 |
| | 1.24mV | 7.74mV | 0.16003 | -0.7957986 | -79.57985948 | | | |
| | 1.26mV | 7.88mV | 0.159841 | -0.7963118 | -79.63118121 | | | |
| | 2.4mV | 14.26mV | 0.1683 | -0.7739159 | -77.3915884 | | | |
| | 3.5mV | 21.86mV | 0.160059 | -0.7957199 | -79.57199008 | | | |
| 10% PASE/PMMA | 2.72V | 3.346V | 0.813429 | -0.0896827 | -5.978846352 | -5.78897089 | 0.7963238 | 0.69799576 |
| | 26mV | 30.5mV | 0.85224 | -0.0694381 | -4.629205732 | | | |
| | 54.5mV | 66.96mV | 0.8139 | -0.089429 | -5.961930101 | | | |
| | 93mV | 117.71mV | 0.79005 | -0.1023454 | -6.823028172 | | | |
| | 34.9mV | 42.27mV | 0.82551 | -0.0832777 | -5.551844096 | | | |
| 20% PASE/PMMA | 63mV | 88.19mV | 0.714331 | -0.1461006 | -9.740043077 | -9.85139908 | 0.36201586 | 0.31731506 |
| | 105mV | 148.03mV | 0.709301 | -0.1491694 | -9.944628524 | | | |
| | 89.4mV | 127.83mV | 0.699353 | -0.1553036 | -10.35357052 | | | |
| | 69.5mV | 95.99mV | 0.724001 | -0.1402608 | -9.350722263 | | | |
| | 94.3mV | 132.59mV | 0.71118 | -0.1480205 | -9.868031014 | | | |

**Table D1** Data and calculation of attenuation experimentof different cladding-type fibers (cont.)

| Cladding type | $V_o$ | $V_i$ | $V_o/V_i$ | $\log(V_o/V_i)$ | 20 $\log(V_o/V_i)/L$-X | average of attenuation | standard deviation | confidence at $\alpha = 0.05$ |
|---|---|---|---|---|---|---|---|---|
| 1.179 of draw ratio and 24.5 min/mm of piston speed | | | | | | | | |
| PMMA | 1.28mV | 4.04mV | 0.316169 | -0.5000817 | -50.00816845 | -52.3479901 | 2.27472591 | 3.98769707 |
| | 1.26mV | 4.49mV | 0.28005 | -0.5527644 | -55.2764423 | | | |
| | 1.26mV | 4.29mV | 0.29312 | -0.5329545 | -53.2954548 | | | |
| | 2mV | 6.79mV | 0.2945 | -0.5309147 | -53.09147009 | | | |
| | 2.4mV | 7.6mV | 0.31573 | -0.5006842 | -50.06841504 | | | |
| 10% PASE/PMMA | 8mV | 8.8mV | 0.909096 | -0.0413927 | -2.759512344 | -2.60629131 | 0.41599677 | 0.36463055 |
| | 36mV | 38.48mV | 0.93551 | -0.0289516 | -1.930104387 | | | |
| | 48mV | 53.3mV | 0.900471 | -0.0455303 | -3.035351282 | | | |
| | 26.4mV | 29.04mV | 0.90906 | -0.0414075 | -2.760496761 | | | |
| | 44.6mV | 48.69mV | 0.91582 | -0.0381899 | -2.545991762 | | | |
| 20% PASE/PMMA | 49.2mV | 98.57mV | 0.4991 | -0.3018124 | -20.12082868 | -18.6600563 | 1.17862737 | 1.03309345 |
| | 120mV | 227.13mV | 0.52831 | -0.2771112 | -18.47407792 | | | |
| | 88.5mV | 160.92mV | 0.54995 | -0.2596768 | -17.31178624 | | | |
| | 93.4mV | 183.68mV | 0.508473 | -0.2937321 | -19.58214022 | | | |
| | 1.76V | 3.256V | 0.54054 | -0.2671717 | -17.81144856 | | | |
| 25% PASE/PMMA | 88mV | 100.27mV | 0.87764 | -0.0566828 | -3.778856089 | -3.76621622 | 0.66219744 | 0.58043098 |
| | 146.3mV | 165.14mV | 0.8859 | -0.0526153 | -3.507686554 | | | |
| | 63.4mV | 72.66mV | 0.87253 | -0.0592196 | -3.947975458 | | | |
| | 77mV | 90.59mV | 0.84995 | -0.0706066 | -4.707108118 | | | |
| | 144.2mV | 159.33mV | 0.90502 | -0.0433418 | -2.889454882 | | | |

**Appendix E** Raw data of numerical aperture experiment

**Table E1** Data and calculation of numerical aperture experimentof different cladding-type fibers

| Cladding type | d.a of light (cm); d | d/2 | arctan(d/2) | sin(arctan(d/2)) | $NA_{avg}$ | standard deviation | confidence at $\alpha = 0.05$ |
|---|---|---|---|---|---|---|---|
| free falling and 20 min/mm of piston speed | | | | | | | |
| PMMA | 3.52 | 1.76 | 1.054101188 | 0.869456557 | 0.866528 | 0.007429236 | 0.006511893 |
| | 3.36 | 1.68 | 1.033885584 | 0.859292884 | | | |
| | 3.67 | 1.835 | 1.071831503 | 0.878078382 | | | |
| | 3.42 | 1.71 | 1.041631763 | 0.86322911 | | | |
| | 3.41 | 1.705 | 1.040354803 | 0.862583782 | | | |
| 10% PASE/PMMA | 3.33 | 1.665 | 1.029935325 | 0.857265692 | 0.838393 | 0.022657347 | 0.019859675 |
| | 3.44 | 1.72 | 1.044169055 | 0.864507187 | | | |
| | 2.75 | 1.375 | 0.94200004 | 0.808736084 | | | |
| | 2.95 | 1.475 | 0.975011779 | 0.827708498 | | | |
| | 3.02 | 1.51 | 0.985856501 | 0.833745312 | | | |
| 20% PASE/PMMA | 2.64 | 1.32 | 0.922464338 | 0.797092148 | 0.822653 | 0.019101052 | 0.016742503 |
| | 2.98 | 1.49 | 0.979702543 | 0.830331643 | | | |
| | 2.5 | 1.25 | 0.896055385 | 0.780868809 | | | |
| | 2.85 | 1.425 | 0.958893892 | 0.818556692 | | | |
| | 2.74 | 1.37 | 0.940266189 | 0.807715067 | | | |
| 25% PASE/PMMA | 3.54 | 1.77 | 1.056531199 | 0.870654437 | 0. 813234 | 0.047520084 | 0.041652425 |
| | 2.85 | 1.425 | 0.958893892 | 0.818556692 | | | |
| | 2.2 | 1.1 | 0.832981267 | 0.739940073 | | | |
| | 2.98 | 1.49 | 0.979702543 | 0.830331643 | | | |
| | 2.73 | 1.365 | 0.93852406 | 0.80668673 | | | |

**Table E1** Data and calculation of numerical aperture experimentof different cladding-type fibers (cont.)

| Cladding type | d.a of light (cm); d | d/2 | arctan(d/2) | sin(arctan(d/2)) | $NA_{avg}$ | standard deviation | confidence at $\alpha = 0.05$ |
|---|---|---|---|---|---|---|---|
| free falling and 24.5 min/mm of piston speed | | | | | | | |
| PMMA | 2.57 | 1.285 | 0.909483834 | 0.78918684 | 0.788083 | 0.020533583 | 0.017998148 |
| | 2.86 | 1.43 | 0.960539846 | 0.819501061 | | | |
| | 2.59 | 1.295 | 0.913237464 | 0.791486579 | | | |
| | 2.45 | 1.225 | 0.886179162 | 0.7746612 | | | |
| | 2.38 | 1.19 | 0.871939458 | 0.765578113 | | | |
| 10% PASE/PMMA | 2.91 | 1.455 | 0.968654838 | 0.824124548 | 0.810865 | 0.010113083 | 0.008864345 |
| | 2.83 | 1.415 | 0.955578667 | 0.816647847 | | | |
| | 2.71 | 1.355 | 0.93501478 | 0.804607854 | | | |
| | 2.65 | 1.325 | 0.924283179 | 0.79818915 | | | |
| | 2.77 | 1.385 | 0.945443108 | 0.810756402 | | | |
| 20% PASE/PMMA | 2.48 | 1.24 | 0.892133836 | 0.778413039 | 0.779367 | 0.017576936 | 0.015406581 |
| | 2.35 | 1.175 | 0.865684979 | 0.76153939 | | | |
| | 2.39 | 1.195 | 0.874003822 | 0.766904574 | | | |
| | 2.52 | 1.26 | 0.89993886 | 0.783288903 | | | |
| | 2.73 | 1.365 | 0.93852406 | 0.80668673 | | | |

**Table E1** Data and calculation of numerical aperture experimentof different cladding-type fibers (cont.)

| Cladding type | d.a of light (cm); d | d/2 | arctan(d/2) | sin(arctan(d/2)) | $NA_{avg}$ | standard deviation | confidence at $\alpha = 0.05$ |
|---|---|---|---|---|---|---|---|
| 1.179 of draw ratio and 20 min/mm of piston speed | | | | | | | |
| PMMA | 3.37 | 1.685 | 1.035190794 | 0.859959746 | 0.885028 | 0.02620093 | 0.022965709 |
| | 4.95 | 2.475 | 1.186811703 | 0.927179289 | | | |
| | 4.23 | 2.115 | 1.129133703 | 0.904042236 | | | |
| | 3.59 | 1.795 | 1.062516069 | 0.873582756 | | | |
| | 3.94 | 1.97 | 1.101075918 | 0.891694876 | | | |
| 10% PASE/PMMA | 2.3 | 1.15 | 0.855052737 | 0.754605522 | 0.860265 | 0.07631742 | 0.066893938 |
| | 2.84 | 1.42 | 0.957240181 | 0.817605639 | | | |
| | 5.105 | 2.5525 | 1.197402446 | 0.931094699 | | | |
| | 5.18 | 2.59 | 1.202329502 | 0.932880669 | | | |
| | 3.45 | 1.725 | 1.045429453 | 0.865140001 | | | |
| 20% PASE/PMMA | 4.05 | 2.025 | 1.112099172 | 0.896630133 | 0.887279 | 0.05365261 | 0.04293024 |
| | 2.79 | 1.395 | 0.948853649 | 0.812748158 | | | |
| | 4.4 | 2.2 | 1.144168834 | 0.910366477 | | | |
| | 4.99 | 2.495 | 1.189599104 | 0.928219896 | | | |
| | 5.67 | 2.835 | 1.231688231 | 0.943051729 | | | |

**Table E1** Data and calculation of numerical aperture experimentof different cladding-type fibers (cont.)

| Cladding type | d.a of light (cm); d | d/2 | arctan(d/2) | sin(arctan(d/2)) | $NA_{avg}$ | standard deviation | confidence at $\alpha = 0.05$ |
|---|---|---|---|---|---|---|---|
| 1.179 of draw ratio and 24.5 min/mm of piston speed | | | | | | | |
| PMMA | 7.68 | 3.84 | 1.316038024 | 0.967724235 | 0.789637 | 0.04505168 | 0.039488814 |
| | 3.24 | 1.62 | 1.017764883 | 0.85093611 | | | |
| | 2.1 | 1.05 | 0.809783573 | 0.724137931 | | | |
| | 2.62 | 1.31 | 0.918800277 | 0.794874231 | | | |
| | 2.53 | 1.265 | 0.901866457 | 0.784485753 | | | |
| 10% PASE/PMMA | 2.61 | 1.305 | 0.916954954 | 0.793753184 | 0.867595 | 0.01505758 | 0.013198311 |
| | 3.88 | 1.94 | 1.094854255 | 0.888861482 | | | |
| | 3.56 | 1.78 | 1.058940484 | 0.871837025 | | | |
| | 3.27 | 1.635 | 1.021875913 | 0.853088311 | | | |
| | 3.76 | 1.88 | 1.081943972 | 0.882872389 | | | |
| 20% PASE/PMMA | 3.37 | 1.685 | 1.035190794 | 0.859959746 | 0.902058 | 0.02427859 | 0.021280735 |
| | 4.75 | 2.375 | 1.172273881 | 0.921635375 | | | |
| | 4.34 | 2.17 | 1.138973176 | 0.908204221 | | | |
| | 4.51 | 2.255 | 1.153395212 | 0.914145578 | | | |
| | 4.29 | 2.145 | 1.134552064 | 0.906344995 | | | |
| 25% PASE/PMMA | 4.33 | 2.165 | 1.138095683 | 0.907836617 | 0.929044 | 0.01918832 | 0.016818992 |
| | 4.44 | 2.22 | 1.147567869 | 0.911767747 | | | |
| | 5.07 | 2.535 | 1.195059931 | 0.930237648 | | | |
| | 6.18 | 3.09 | 1.257808937 | 0.951417993 | | | |
| | 5.72 | 2.86 | 1.234433034 | 0.943961223 | | | |

# CURRICULUM VITAE

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**Proceedings:**

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**Presentations:**

1. Paiboon, S.; Magaraphan, R.; and Lunvongsa, S. (2011, April 26) Hybrid cladding to Enhance Light Intensity for Plastic Optical Fiber. Paper presented at the 17th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.