White Paper

Touch Sensor Transparent Conductor Optical Comparison

Touch Sensor Transparent Conductor Optical Comparison

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Abstract: *Various transparent conductor materials utilized for touch sensors are compared for optical transmission and reflectance performance.*

Keywords: transparent; conductor; ITO; transmission; reflectance; SCI; SCE; 2D; 3D

1. Introduction

Several transparent conductor materials are currently being utilized in touch sensor manufacturing. These materials include but are not limited to:

- Silver nanowire on Film
- Copper mesh on Film
- PEDOT on Film
- Carbon nanotube on Film
- ITO on Film
- ITO on glass reference touch sensor

Furthermore with the desire to produce 2D and 3D touch sensors for automotive application it is important to recognize the limitations associated with each transparent conductor material type. Generally all of the materials may be "bent" to a certain degree, but 3D forming of most conductor materials is limited.

2. Background/Objective

The objective of the study is to provide an optical comparison between the various transparent conductor materials. With all of the various transparent conductor materials on the market, it is difficult to understand the performance tradeoffs. In addition, since the carbon nanotube material may be the most 3D formable, it is important to understand the optical performance characteristics. Information provided by the various suppliers is included for reference.

2.1 Kodak PEDOT

Eastman Kodak Company markets a portfolio of conductive polymer films under the KODAK HCF Film family. The KODAK HCF family are polyester (PET) films with a proprietary conductive PEDOT/PSS formulation coated in-line during the polyester manufacturing process. The unique manufacturing process produces an exceptionally uniform material, which is optically clear with excellent surface quality. The KODAK HCF films are available as single-sided and dual coated films at various resistivities [1].

The PEDOT/PSS complex shown in Figure 2.1-1 consists of polymeric cationic PEDOT and a polymeric counter anion derived from polystyrenesulfonic acid. Typically every third or fourth thiophene unit carries a positive charge. The long loops and tails of PSS stabilize the particles against coagulation and precipitation. PEDOT:PSS dispersions are stable at room temperature under ambient conditions and can be coated to yield transparent, conductive films [2].

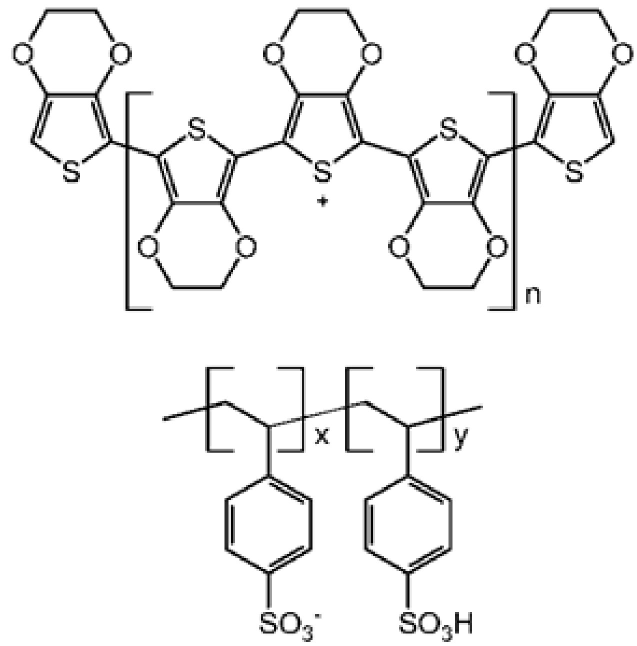

Figure 2.1-1. PEDOT/PSS [2]

Figure 2.1-2 shows a calculated transmission from the material supplier, Heraeus, of 84.4% when absorption is included.

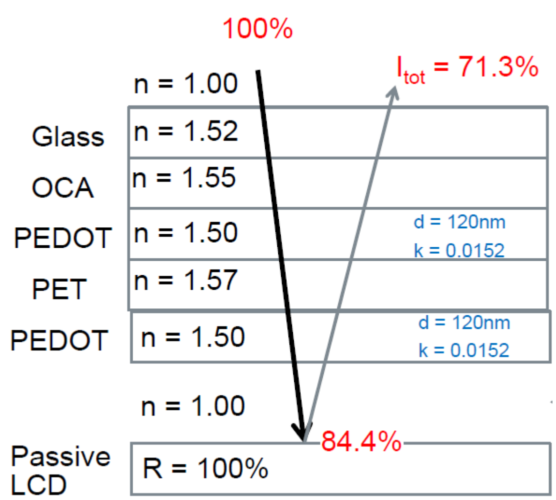

Figure 2.1-2. PEDOT Transmission including Absorption [courtesy of Heraeus]

The absorption per PEDOT layer is about 4.1% per Table 2.1-1.

Material	n	R	Absorption	T
Air	1.00		0	1.000
glass	1.52	4.26E-02	0	0.957
OCA	1.55	9.55E-05	0	0.957
PEDOT	1.50	2.69E-04	0.041	0.918
PET	1.57	5.20E-04	0	0.917
PEDOT	1.50	5.20E-04	0.041	0.879
Air	1.00	4.00E-02	0	0.844

Table 2.1-1. Transmission Calculation based on Kodak Data

The reflectance, R, in Table 2.1-1 is determined per Equation 2.1-1 based on an index of refraction change from n_1 to n_2.

$$R = \left[\frac{n_2 - n_1}{n_2 + n_1}\right]^2 \qquad \text{Eq 2.1-1}$$

The absorption losses within the PEDOT:PSS layer are calculated per Lambert's Law of Absorption equation as shown in Figure 2.1-3 provided by the material supplier, Heraeus.

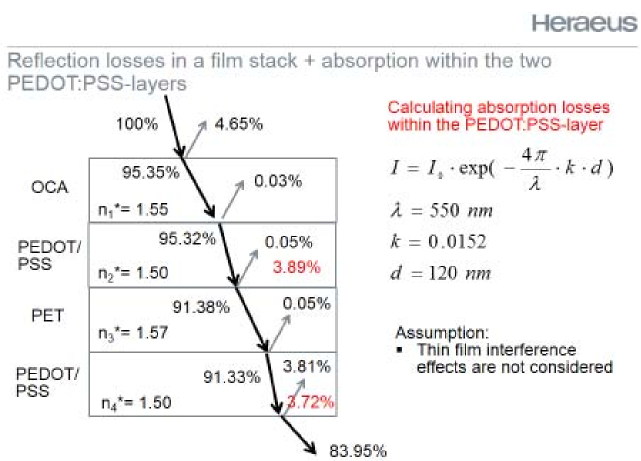

Figure 2.1-3. PEDOT:PSS Absorption Equation [courtesy of Heraeus]

An interesting observation is that PEDOT has an index of refraction that is well matched with most optical materials versus ITO which has an index of refraction of around 1.95 without the use of index matching layers. Even with the PEDOT absorption, PEDOT will have better optical performance. Therefore the PEDOT patterning will be much less visible. However Kodak/Heraeus only offers PEDOT on PET film which may have birefringence problems with polarized sunglasses. However other PEDOT suppliers may be available on alternative birefringent friendly materials.

2.2 Carbon Nanotube

There are several carbon nanotube transparent conductor systems being proposed. Recently [3], Canatu described a carbon NanoBud® transparent conductor system that has a big benefit because it can be 3D formed (stretched) without a substantial change in resistivity as indicated in Figure 2.2-1. A depiction of the carbon NanoBud® is shown in Figure 2.2-2. Canatu Generation 6 material shows a dramatic transmission improvement per Figure 2.2-3 with potential for further improvements per the "Best lab results". Per reference [3], Canatu describes that there is no reflection component from the transparent conductor and only an absorption component consistent with Figure 2.2-3 should be observed.

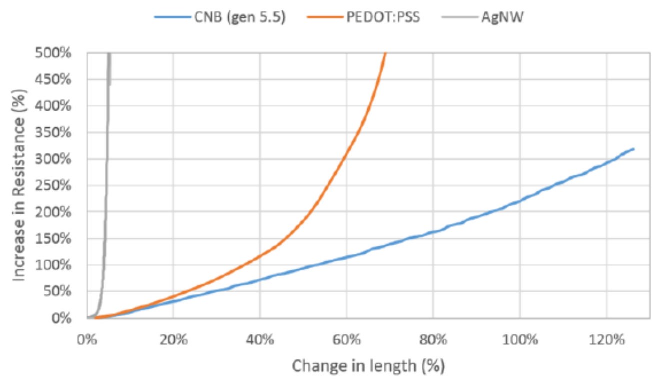

Figure 2.2-1. Carbon NanoBud® Stretchability [3]

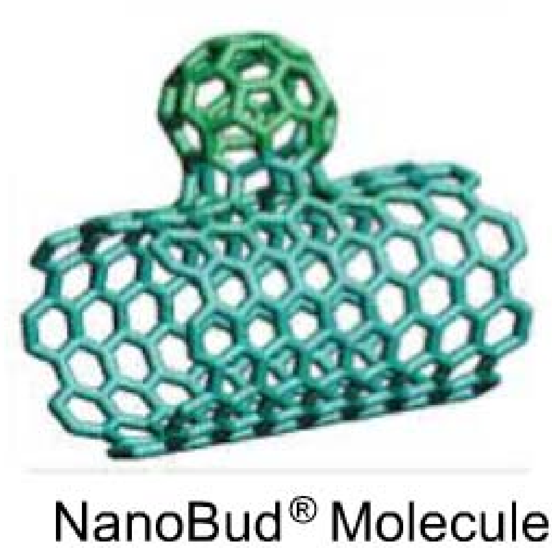

Figure 2.2-2. Carbon NanoBud® Depiction [4]

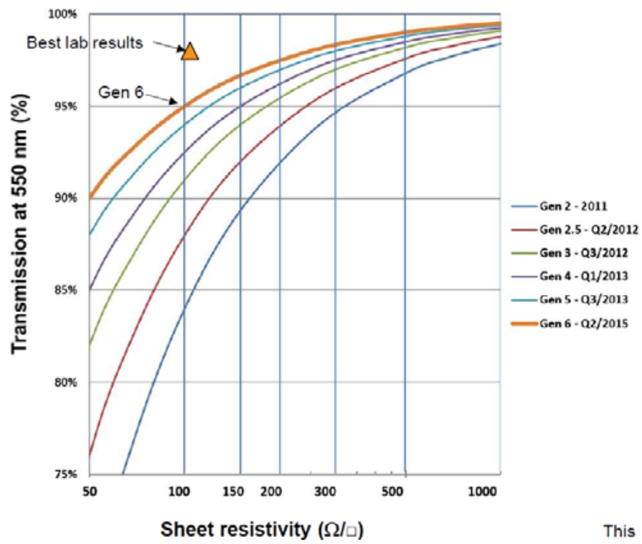

Figure 2.2-3. Gen 6 Performance [4]

2.3 Copper Mesh

Copper mesh systems are available that provide a type of transparent conductor system due to the small feature size of the metal mesh as shown in Figure 2.3-1. One big advantage of copper mesh is low resistance including the touch sensor tracking that can be low resistance copper which improves touch sensor response times. In addition, the low resistance minimizes sensor tracking edge dimensions.

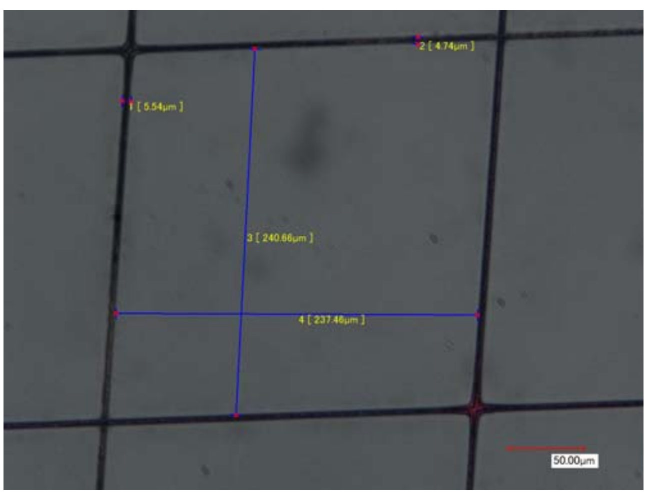

Figure 2.3-1. Copper Mesh

In addition to the "normal" copper mesh, a lower reflectance absorbing type copper mesh is becoming available. Unipixel has recently begun sampling its XTouch™ copper metal mesh sensors with a secondary metal plating (called hybrid-metal) that replaces the previous chemical darkening process. This secondary metal plating not only reduces reflection, but is also expected to further enhance robustness of the sensor under environmental stress conditions. XTouch™ is also highly appropriate for 2.5D curved and flexible designs. In addition, the use of copper allows the possibility of an integrated connection tail thereby eliminating a separate tail to sensor connection. Figure 2.3-1 shows a SEM picture of the hybrid-metal mesh.

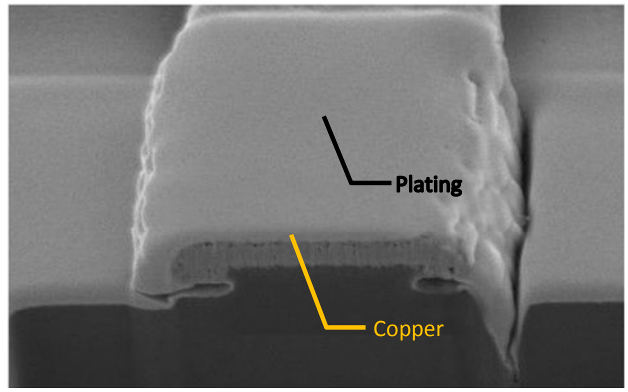

Figure 2.3-1. XTouch™ Hybrid-Metal SEM (courtesy of Unipixel)

2.4 Silver Nanowire

The use of silver nanowire conductor material such as Cambrios ClearOhm® is being used for touch sensor transparent conductor material. The silver nanowires as shown in Figure 2.4-1 are in the nanometer range and therefore should have minimal effect on the light transmission.

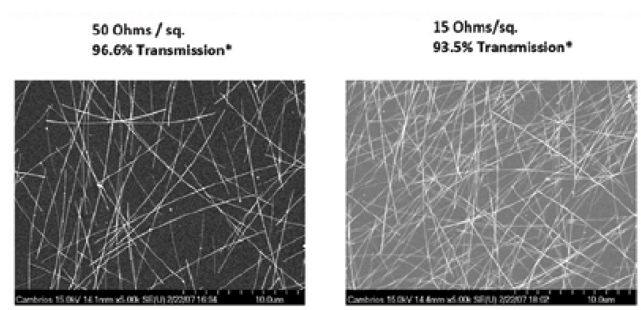

Figure 2.4-1. Silver nanowire SEM [5]

2.5 ITO Touch Screen

ITO is the historical reference against which other transparent conductor alternatives should be compared. The best possible ITO touch screens utilize index matching (IM) materials to minimize reflection and maximize transmission since ITO is not well index matched to most substrate materials. In addition the index matching materials minimize the tracking pattern visibility. ITO may be deposited on glass and on film substrates.

3. Description

The materials tested were:

- Silver nanowire on PC
- Index matched ITO on glass touch sensor (reference)
- ITO on PC
- Copper mesh on PET
- Copper mesh on COC
- Hybrid Copper Mesh on PET
- Carbon Nanotube on PET (two resistances)
- Kodak PEDOT on PET

The approach towards measuring the internal absorption and reflection characteristics was to optically bond the samples to a front glass surface and to laminate moth-eye film on the rear surface. The front glass surface holds the flexible sensor flat to the measurement system which is important to ensure that the specular component is properly reflected into the receiver. In addition the glass surface will not be scratched when touched to the integrating sphere input port. Dexerials SVME (Super View Moth Eye) film was laminated to the rear surface of the samples to simplify the analysis. The rear surface reflection of the moth-eye film is assumed negligible at about 0.28% which greatly simplifies the analysis and the system can be modeled per Figure 3-1. For reference, Figure 3-2 shows the reflectance characteristics of the Dexerials SVME film.

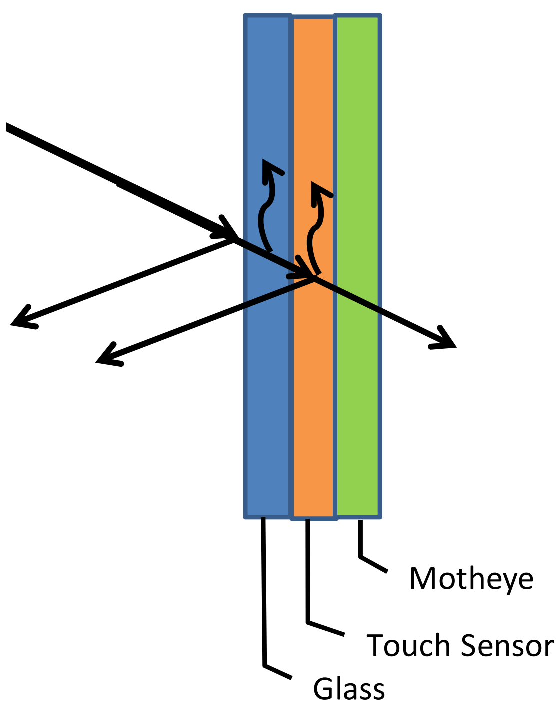

Figure 3-1. Optical Analysis Model

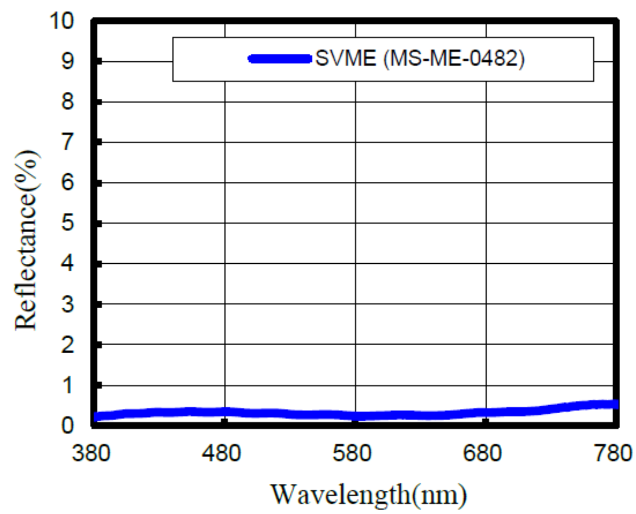

Figure 3-2. Dexerials SVME Spectral Reflectance

In order to assess the absorption and reflection of the soda lime carrier glass and moth-eye structure, data was taken as shown in Table 3-1. From Table 3-1, the Glass+PSA+PSA+Motheye transmission without a sensor is 93.94% and the total reflectance is 4.75%. Since the moth-eye film has a minimal reflectance of 0.28%, Equation 3-1 may be written. Equation 3-1 is simplified to account for the fact that most of the reflectance is from the front glass to air interface and that a negligible amount of reflection comes from the rear surface.

$$TT \cong (1 - RT)(1 - A_G) \qquad \text{Eq 3-1}$$

- TT is the total sample transmittance (measured)
- RT is the total sample reflectance (measured)

Specular Component Excluded (SCE)		
ID	**SCE**	
Glass	0.03	
Glass w/Moth-eye	0.03	
Glass w/PSA w/PSA w/Motheye	0.03	
Specular Component Included (SCI)		
ID	**SCI**	
Glass	8.13	
Glass w/Moth-eye	4.75	
Glass w/PSA w/PSA w/Motheye	4.75	
Transmission (TRAN)		
ID	**Xmission**	**Haze %**
Glass	90.48	0.1
Glass w/Moth-eye	93.96	0.1
Glass w/PSA w/PSA w/Moth-eye	93.94	0.1
0.87% Standard Haze	91.65	0.8

Table 3-1. Glass + Moth-Eye Optical Performance

Equation 3-2 solves for the glass absorbtion, A_G.

$$A_G \cong \frac{0.9394}{1-0.0475} = 0.013753 = 1.38\% \qquad \text{Eq 3-2}$$

Therefore if all the reflection including the relatively small moth-eye reflectance is lumped into the front surface reflectance, the simplified first order model is as shown in Figure 3-3.

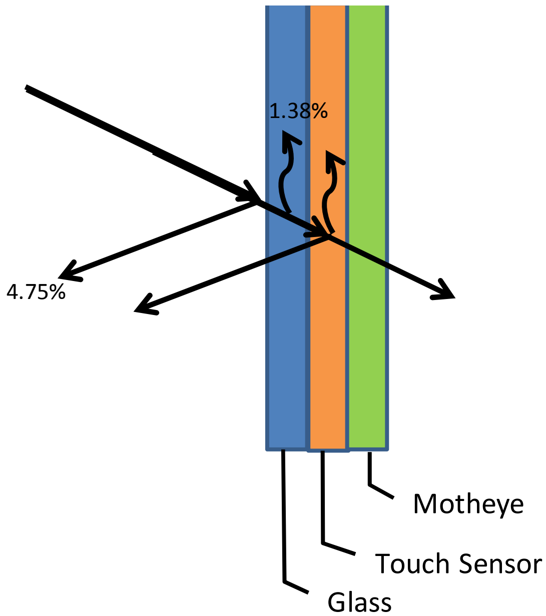

Figure 3-3. Simplified Sample Model

Using the simplified model of Figure 3-3, Equations 3-3 and 3-4 may be written for the lumped model where:

- A is the touch sensor absorption.
- R is the touch sensor reflectance
- TT is the total sample transmittance (measured)
- RT is the total sample reflectance (measured)

It should be noted that Equation 3-3 is a first order approximation since the A*R cross term of the more precise equation of (1-A)(1-R) is negligible and the use of Equation 3-3 greatly simplifies the mathematics.

$$TT \cong 0.9525(1-0.0138)(1-A-R) \\ = 0.9394(1-A-R) \qquad \text{Eq 3-3}$$

Similarly the reflectance Equation 3-4 may be constructed.

$$RT \cong 0.0475 + 0.9525^2(1-A_G)^2 R \\ = 0.0475 + 0.8824R \qquad \text{Eq 3-4}$$

Equation 3-4 may be rewritten as Equation 3-5 to solve for the sensor reflectance, R.

$$R \cong \frac{RT - 0.0475}{0.8824} \qquad \text{Eq 3-5}$$

Equation 3-5 may then be substituted into Equation 3-3 to yield the touch sensor absorption A in terms of measured sample transmission TT and refection RT per Equation 3-6.

$$A \cong 1 + \frac{0.0475}{0.8824} - \frac{TT}{0.9394} - \frac{RT}{0.8824} \qquad \text{Eq 3-6}$$

The transmission T of just the touch sensor element may then be described per Equation 3-7.

$$T \cong 1 - A - R \qquad \text{Eq 3-7}$$

The optical configuration for each test sample is described in Figures 3-4 through 3-11.

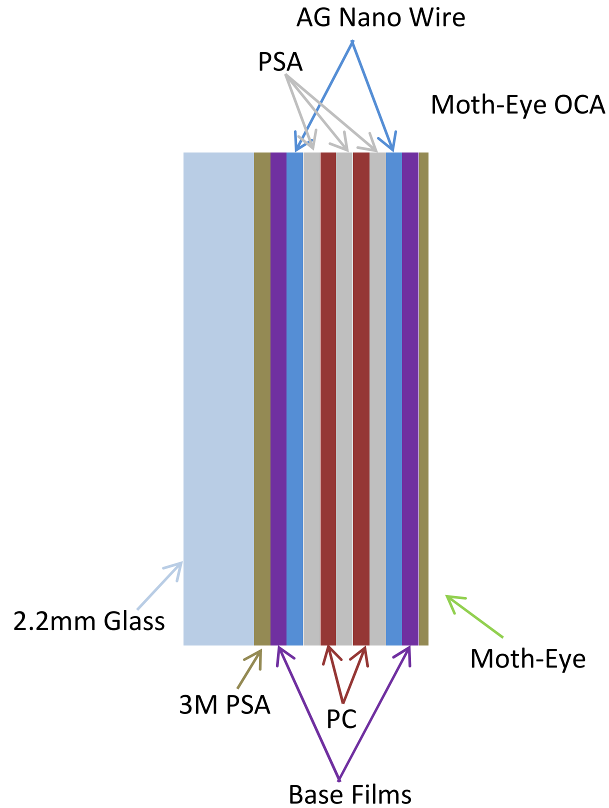

Figure 3-4. Silver Nanowire (Touch Panel)

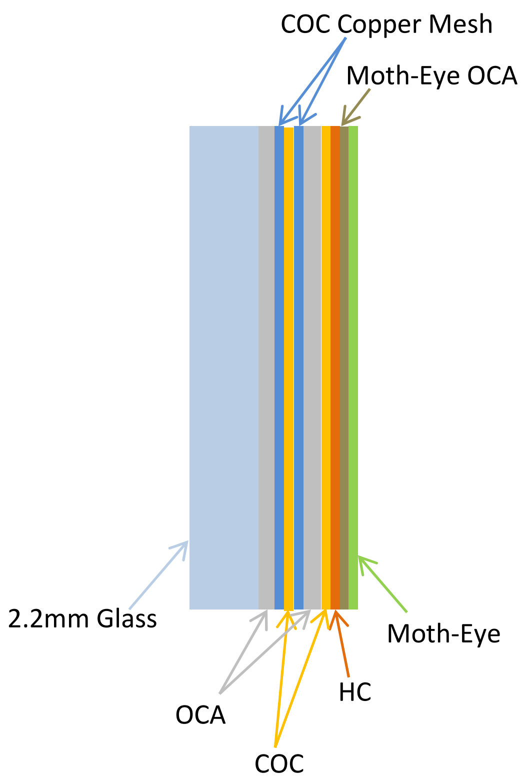

Figure 3-5. COC Copper Mesh (Touch Panel)

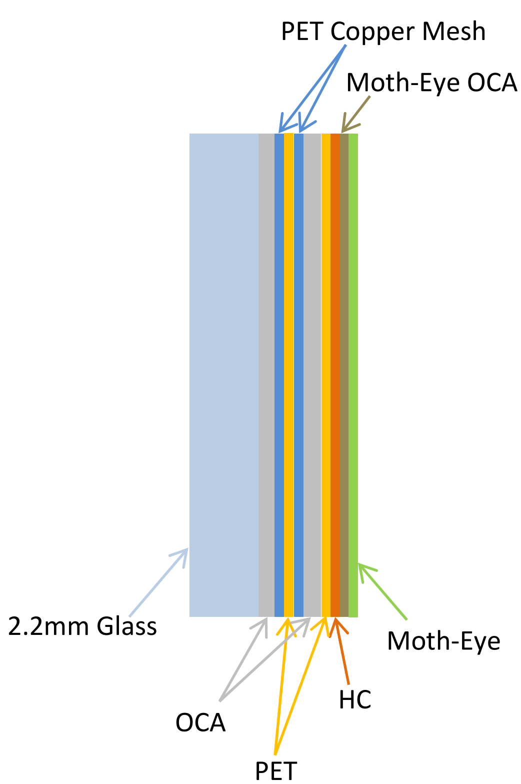

Figure 3-6. PET Copper Mesh (Touch Panel)

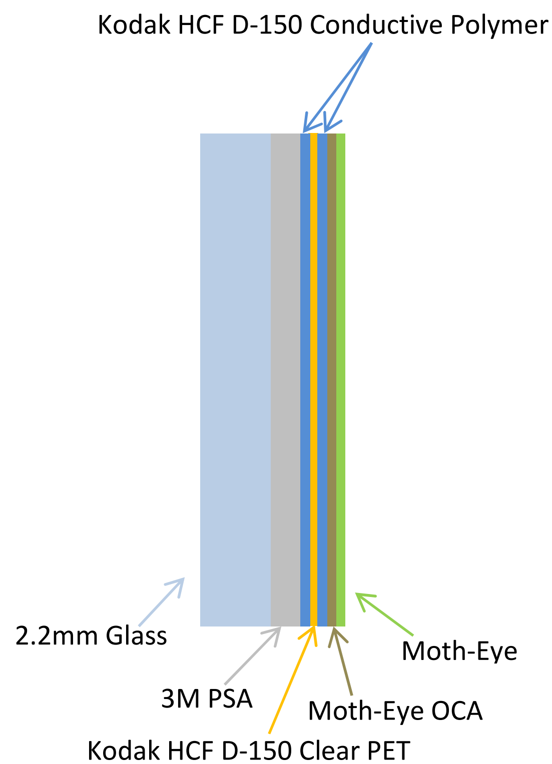

Figure 3-7. Kodak HCF D-150 (not pattered for touch sensor)

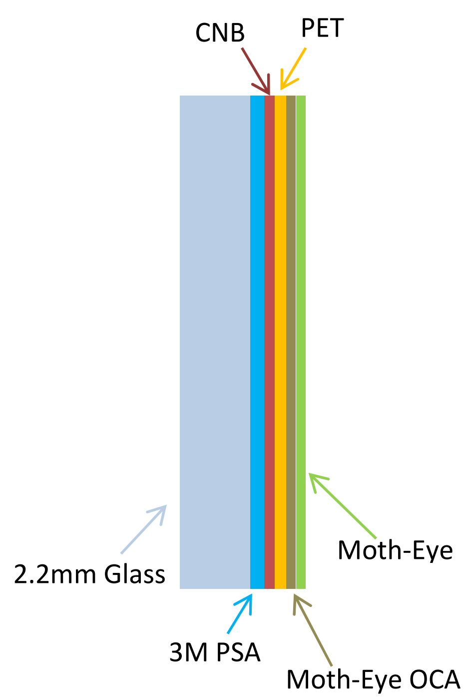

Figure 3-8. Carbon Nanotube (not patterned for touch sensor)

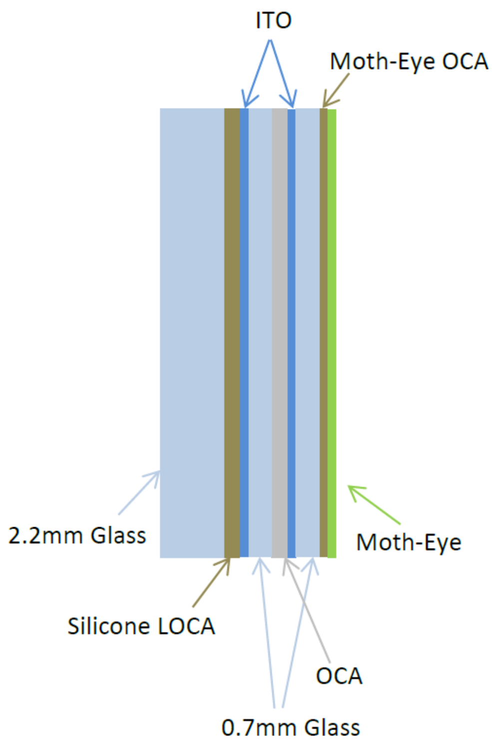

Figure 3-9. ITO on Glass Touch Sensor

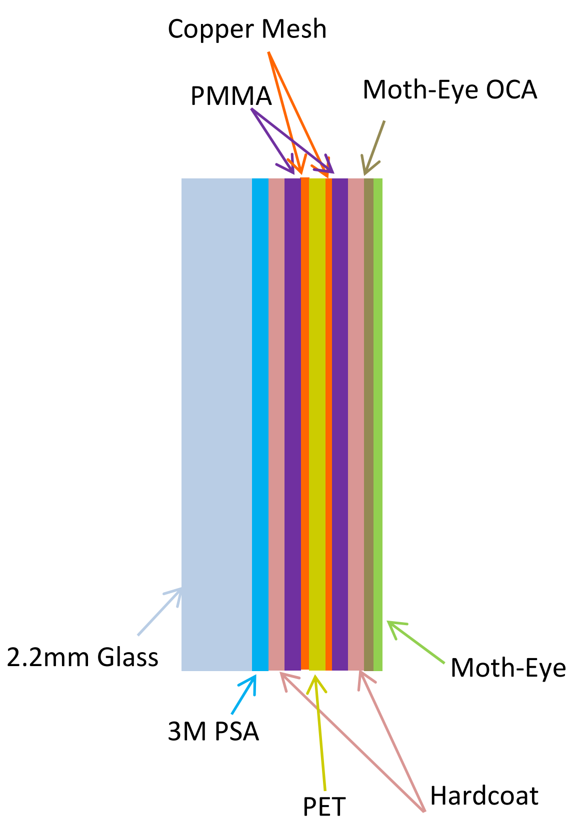

Figure 3-10. Unipixel XTouch™ Hybrid-Metal Copper
Mesh

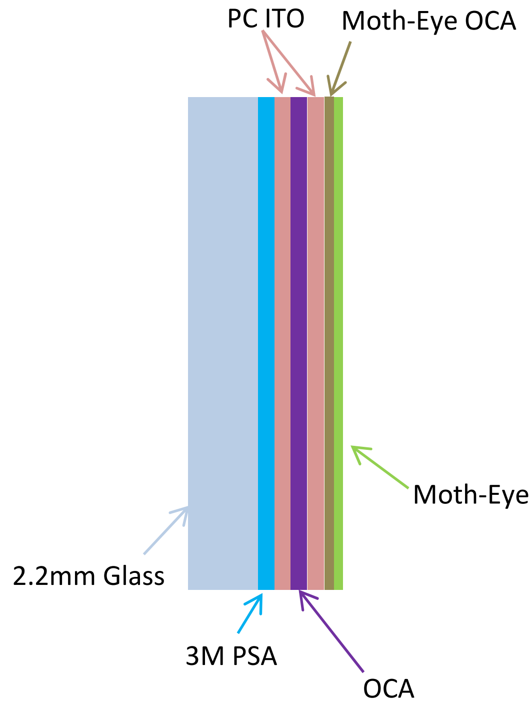

Figure 3-11. ITO on PC Touch Sensor

Figure 3-12. Hunter Lab Ultrascan Spectrophotometer

The data for each sample configuration was measured as shown in Table 3-2 by utilizing a Hunter Lab Ultrascan and shown in Figure 3-12.

Equations 3-5, 3-6 and 3-7 may be utilized to extract the absorption, reflectance and transmittance data associated with the touch sensor materials except for the PEDOT as summarized in Table 3-3. Since the PEDOT sample was not a patterned touch sensor and had two full unpatterned layers, a different set of equations must be utilized to extract the equivalent one layer performance. Figure 3-13 shows the simplified model that must be analyzed. For a patterned sensor, there is an equivalent of one layer because the X and Y patterns generally do not overlap.

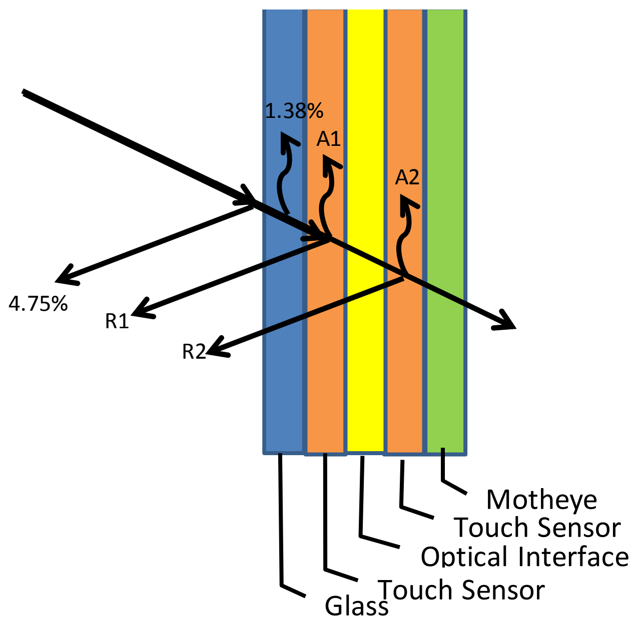

Figure 3-13. Dual Layer Optical Analysis Model

For the two layer PEDOT sample, Equations 3-8 and 3-9 may be devised.

$$TT \cong 0.9525(1-A_G)(1-A_1-R_1)(1-A_2-R_2)$$ Eq 3-8

$$RT \cong 0.0475 + 0.9525^2(1-A_G)^2 R_1 + 0.9525^2(1-A_G)^2(1-A_1-R_1)^2 R_2$$ Eq 3-9

Since $A_1=A_2$ and $R_1=R_2$, Equation 3-8 may be rearranged to produce Equation 3-10.

$$(1-A_1-R_1)^2 \cong \frac{TT}{0.9525(1-A_G)}$$ Eq 3-10

Substituting Equation 3-10 into Equation 3-9 yields Equation 3-11.

$$RT \cong 0.0475 + 0.9525^2(1-A_G)^2 R_1 + 0.9525 R_1(1-A_G)TT$$ Eq 3-11

Solving Equation 3-11 for R_1 results in Equation 3-12.

$$R_1 \cong \frac{RT - 0.0475}{0.9525^2(1-A_G)^2 + 0.9525(1-A_G)TT}$$ Eq 3-12

Substituting Equation 3-12 into Equation 3-10 yields Equation 3-13. Using the relationships developed in Equations 3-12 and 3-13, the single layer equivalent reflectance and absorption may be determined from the dual layer PEDOT measurements.

$$A_1 = 1 - \frac{RT - 0.0475}{0.9525^2(1-A_G)^2 + 0.9525(1-A_G)TT} - \sqrt{\frac{TT}{0.9525(1-A_G)}}$$ Eq 3-13

SCI Data							
ID	**Y**	**x**	**y**	**L***	**a***	**b***	
Glass	8.1	0.308	0.3257	34.2	-0.37	-0.94	
Silver Nanowire/PC (Touch Panel)	6.26	0.2992	0.3118	30.05	0.64	-3.69	
IM ITO/Glass (Touch Panel)	4.87	0.3044	0.3191	26.35	0.22	-1.98	
ITO/PC (Touch Panel)	5.59	0.3079	0.3201	28.36	0.76	-1.68	
Copper Mesh/COC (Touch Panel)	5.3	0.3167	0.3258	27.58	1.42	-0.2	
Copper Mesh/PET (Touch Panel)	5.38	0.3073	0.3214	27.8	0.39	-1.5	
Hybrid Copper Mesh/PET (XTouch™ Touch Panel)	4.95	0.3077	.0.3242	25.58	-0.09	-1.02	
Carbon Nanotube/PET-105Ω/□ (Non-Touch, 1 layer)	4.85	0.307	0.3242	26.31	-0.21	-1.07	
Carbon Nanotube/PET-166Ω/□ (Non-Touch, 1 layer)	4.85	0.3067	0.3232	25.29	0.1	-1.23	
Kodak HCF D-150 PEDOT/PET (Non-Touch, 2 layer)	4.81	0.3051	0.3214	26.2	-0.08	-1.6	
SCE							
ID	**Y**	**x**	**y**	**L***	**a***	**b***	
Glass	0.03	0.2779	0.335	0.31	-0.17	-0.03	
Silver Nanowire/PC (Touch Panel)	0.99	0.2726	0.2681	8.94	2.46	-7.02	
IM ITO/Glass (Touch Panel)	0.04	0.2775	0.3246	0.38	-0.17	-0.08	
ITO/PC (Touch Panel)	0.06	0.2392	0.2299	0.5	0.2	-0.97	
Copper Mesh/COC (Touch Panel)	0.4	0.4118	0.3564	3.61	3.35	2.5	
Copper Mesh/PET (Touch Panel)	0.2	0.3099	0.2822	1.83	1.23	-1.03	
Hybrid Copper Mesh/PET (XTouch™ Touch Panel)	0.23	0.3113	0.3263	2.04	0.03	-0.07	
Carbon Nanotube/PET-105Ω/□ (Non-Touch, 1 layer)	0.19	0.2599	0.2591	1.75	0.42	-2.13	
Carbon Nanotube/PET-166Ω/□ (Non-Touch, 1 layer)	0.19	0.2492	0.2566	1.7	0.16	-2.25	
Kodak HCF D-150 PEDOT/PET (Non-Touch, 2 layer)	0.08	0.2448	0.2588	0.74	-0.01	-0.97	
TRAN							
ID	**Y**	**x**	**y**	**L***	**a***	**b***	**Haze %**
Air	100	0.3127	0.3291	100	-0.01	0.02	0
Glass	90.43	0.3123	0.3298	96.17	-0.59	0.24	0.1
Silver Nanowire/PC (Touch Panel)	88.98	0.3158	0.3351	95.57	-1.35	2.81	1.5
IM ITO/Glass (Touch Panel)	92.62	0.3128	0.3314	97.07	-1.14	0.91	0.4
ITO/PC (Touch Panel)	91.62	0.314	0.3326	96.66	-1.08	1.59	0.2
Copper Mesh/COC (Touch Panel)	86.18	0.3132	0.3312	94.39	-0.84	0.89	0.8
Copper Mesh/PET (Touch Panel)	89.61	0.3135	0.3316	95.83	-0.86	1.09	1
Hybrid Copper Mesh/PET (XTouch™ Touch Panel)	89.18	0.3134	0.3318	95.65	-0.97	1.16	1
Carbon Nanotube/PET-105Ω/□ (Non-Touch, 1 layer)	86.28	0.3148	0.3323	94.43	-0.51	1.59	0.4
Carbon Nanotube/PET-166Ω/□ (Non-Touch, 1 layer)	88.22	0.3142	0.3319	95.25	-0.64	1.34	0.4
Kodak HCF D-150 PEDOT/PET (Non-Touch, 2 layer)	80.53	0.3063	0.3264	91.92	-2	-2.06	0.3

Table 3-2. Raw Data

ID	Ω/□	RT%	TT%	R%	A%	T%	Haze%
Silver Nanowire/PC (Touch Panel)	80	6.26	88.98	1.711242	3.568724	94.72003	1.5
IM ITO/Glass (Touch Panel)	150	4.87	92.62	0.135993	1.269159	98.59485	0.4
ITO/PC (Touch Panel)	150	5.59	91.62	0.951949	1.517712	97.53034	0.2
Copper Mesh/COC (Touch Panel)	10	5.3	86.18	0.6233	7.637292	91.73941	0.8
Copper Mesh/PET (Touch Panel)	10	5.38	89.61	0.713962	3.895363	95.39067	1
Hybrid Copper Mesh/PET (XTouch™ Touch Panel)	10	4.95	89.18	0.226655	4.84041	94.93294	1
Carbon Nanotube/PET 105Ω (Non-Touch, 1 layer)	105	4.85	86.28	0.113327	8.040814	91.84586	0.4
Carbon Nanotube/PET 166Ω (Non-Touch, 1 layer)	166	4.85	88.22	0.113327	5.975666	93.91101	0.4
Kodak HCF D-150 PEDOT/PET (Non-Touch, 2 layer)	150	4.81	80.53	0.036611	7.373437	92.58995	0.3

Table 3-3. Performance Summary

Each parameter is compared in Figures 3-14 through 3-17.

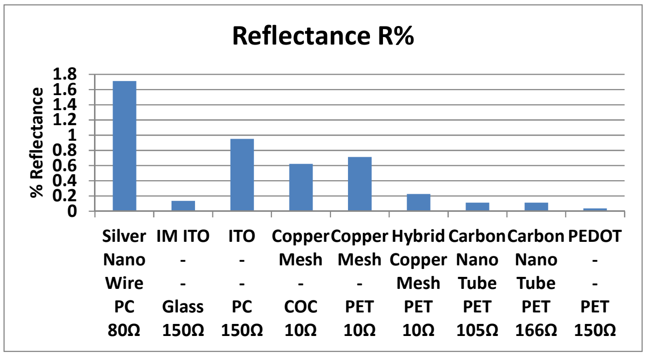

Figure 3-14. % Reflectance

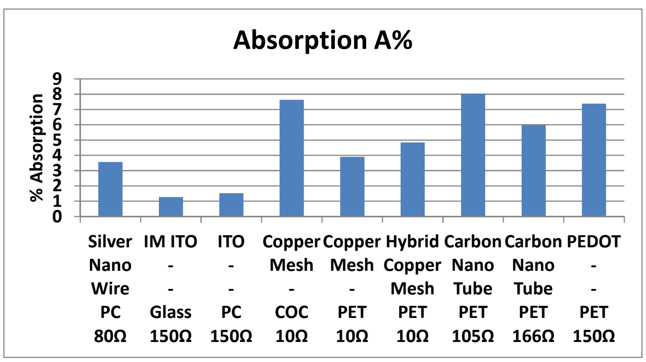

Figure 3-15. % Absorption

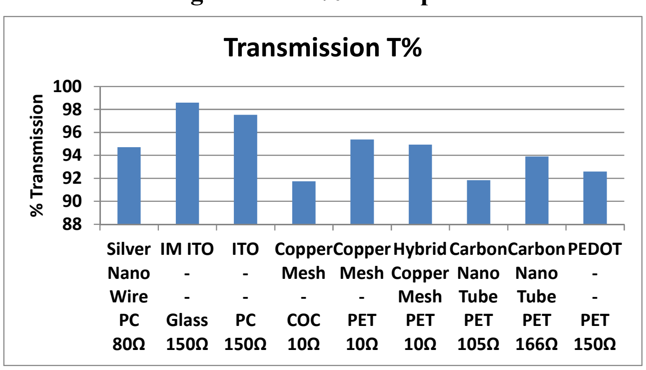

Figure 3-16. % Transmission

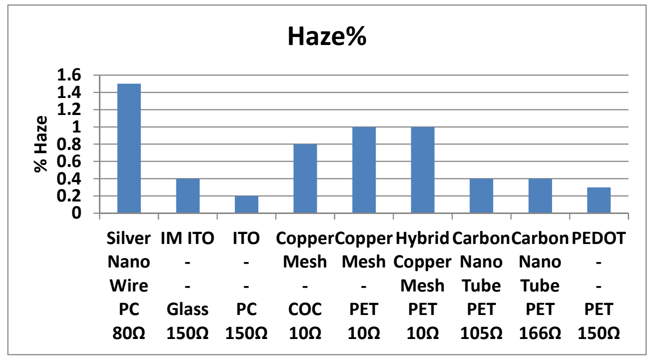

Figure 3-17. % Haze

In the automotive application, reflectance performance is the most important parameter due to high ambient daytime lighting conditions. In addition, low haze means superior clarity performance. Therefore it appears that hybrid copper mesh, carbon nanotube and PEDOT are possibly good candidates for automotive applications from an optical aspect. Due to the carbon nanotube stretchability per Figure 2.2-1, it may be a possible candidate for automotive 3D touch screens. In addition, the next generations of Carbon NanoBud® will have higher transmission per Figure 2.2-3 which was not as good as ITO transmission.

4. Additional Carbon Nanotube Investigation

Due to the attractive nature of the carbon nanotube system for 3D formed touch screens, additional samples were constructed to discover the carbon nanotube layer reflectance since the supplier, Canatu, asserts that there is no reflectance from the carbon nanotubes (CNT). Additional samples per Figures 4-1 and 4-2 were prepared that included clear PET film with no CNT deposition from the same substrate that the CNT samples were prepared from. The measurement results are shown in Table 4-1.

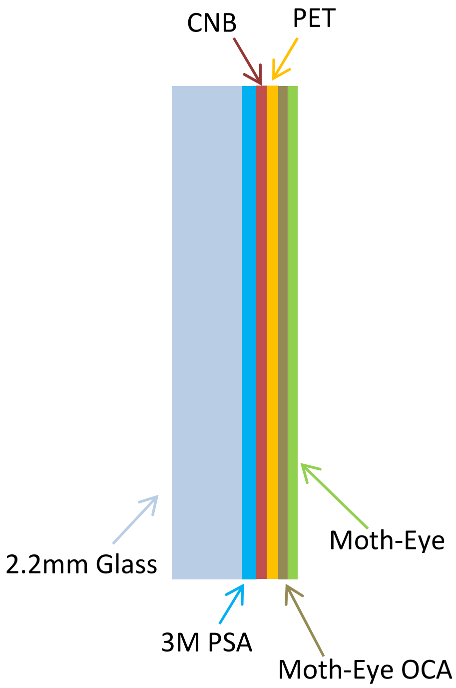

Figure 4-1. CNB towards Front

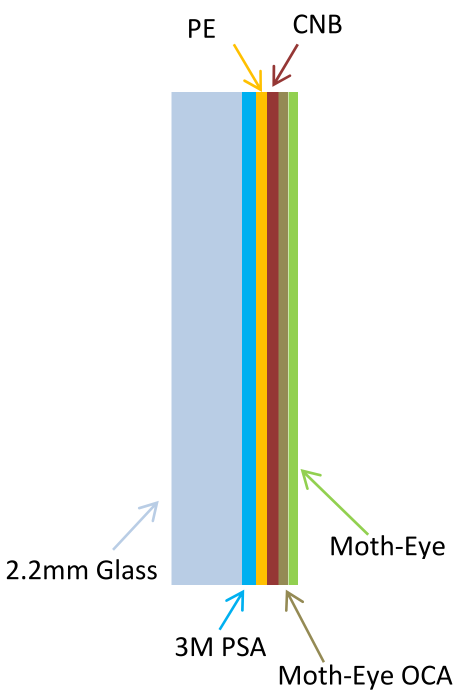

Figure 4-2. CNB towards Rear

ID	SCE
Glass	0.03
Canatu 166Ω/□ CNB → Rear Fig 4-2	0.19
Canatu PET Only	0.2
Canatu 166Ω/□ CNB → Front Fig 4-1	0.19

ID	**SCI**
Glass	8.12
Canatu 166Ω/□ CNB → Rear Fig 4-2	4.86
Canatu PET Only	4.98
Canatu 166Ω/□ CNB → Front Fig 4-1	4.98

ID	**Trans**	**Haze %**
0.87% Haze Standard	91.67	0.9
Canatu 166Ω/□ CNB → Rear Fig 4-2	88.15	0.4
Canatu PET Only	92.92	0.3
Canatu 166Ω/□ CNB → Front Fig 4-1	88.52	0.3

Table 4-1. With and Without CNT

The first thing to notice is that the reflectance with and without the CNT is almost identical at 4.98% and this result shows that all of the substrate interface and moth-eye plus the front glass surface reflectance is 4.98% and the CNB has little no reflectance component. Rounding the 4.98% to 5% and recognizing that the CNB has 0% reflectance yields Equations 4-1 and 4-2.

$$0.8852 = 0.95(1 - A_{W/CNT} - 0) \qquad \text{Eq 4-1}$$

$$0.9299 = 0.95(1 - A_{W/OCNT} - 0) \qquad \text{Eq 4-2}$$

Solving Equations 4-1 and 4-2 yields Equations 4-3 and 4-4.

$$A_{W/CNT} = 0.068211 = 6.8211\% \qquad \text{Eq 4-3}$$

$$A_{W/OCNT} = 0.021158 = 2.1158\% \qquad \text{Eq 4-4}$$

Equation 4-4 shows that the rest of the substrates are absorbing a significant amount of light at 2.11%. The difference between Equations 4-3 and 4-4 is the amount that the CNT is absorbing per Equation 4-5.

$$A_{CNT} = 0.047053 = 4.7053\% \qquad \text{Eq 4-5}$$

Note that this result is identical to that reported by Canatu.

The transmission of the CNT layer may then be determined from Equation 4-6.

$$T = 1 - A - R$$
$$= 1 - 0.047053 - 0 = 0.952947 \quad \text{Eq 4-6}$$

Further analysis may be performed to determine the reflectance and absorption of the PET substrate by utilizing the earlier results from section 3.0. Figures 4-3 and 4-4 may be utilized to discover the PET performance characteristics in the optical stack.

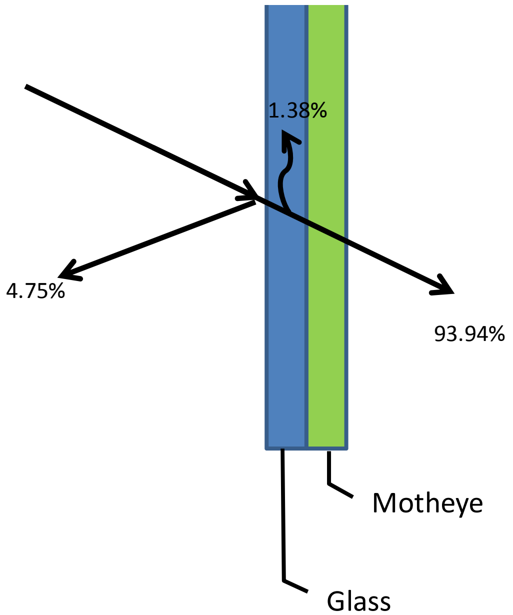

Figure 4-3. Glass + Moth-eye Performance

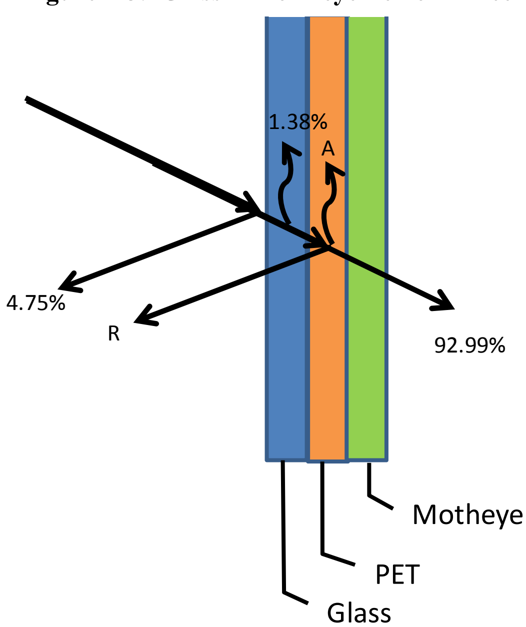

Figure 4-4. Glass+PET+Moth-Eye Performance

Using Figure 4-4, Equation 4-7 may be constructed to determine the reflection component from the PET film.

$$RT = 0.0498 \cong 0.0475 + (1 - 0.0475)^2 (1 - 0.0138)^2 R \quad \text{Eq 4-1}$$

Solving Equation 4-7 provides the 0.26% reflectance for the PET component in the optical stack per Figure 4-4. Note that this is high reflectance result indicates that the PET utilized has an index of refraction more towards the upper range of 1.57 to 1.65.

$$R \cong \frac{0.0498 - 0.0475}{(1 - 0.0475)^2 (1 - 0.0138)^2} = 0.0026 = 0.26\% \quad \text{Eq 4-7}$$

Similarly, Equation 4-8 may be constructed to determine the absorption of the PET component.

$$TT \cong (1 - 0.0475)(1 - 0.0138)(1 - 0.0026)(1 - A) \quad \text{Eq 4-8}$$

Equation 4-9 solves for the absorption, A, of 0.75% for the PET substrate which is a rather high value.

$$A \cong 1 - \frac{0.9299}{(1 - 0.0475)(1 - 0.0138)(1 - 0.0026)} \quad \text{Eq 4-9}$$
$$= 0.0075 = 0.75\%$$

The results of this additional study indicate that the optical properties and selection of the touch sensor substrate materials should be considered in determining the optical performance. More suitable candidates such as Cyclic Olefin Copolymer (COC) may provide better optical performance due superior birefringence performance and index of refraction matching.

An additional item of interest is the haze floor of the sample substrate without carbon nanotubes of 0.3% and therefore the carbon nanotubes do not have any measurable haze component.

5. Conclusion

From the optical test data, competing transparent technologies on plastic substrates are approaching and in some aspects exceeding ITO on glass performance. From an optical aspect, hybrid copper mesh, carbon nanotube and PEDOT are possibly good candidates for automotive applications requiring low reflectance performance.

For 3D touch screens, the carbon nanotube system may be a good candidate for automotive applications due to low reflectance and lowest resistance change when stretched (formed).

For 2.5D curved touch screens, PEDOT, carbon nanotube and hybrid copper mesh may be good candidates for automotive applications. Not considering the almighty cost aspects, each candidate may be technically more suitable depending on the application requirements.

- PEDOT – lowest reflectance and haze
- Carbon Nanotube – low reflectance and haze with the potential for lower resistivities
- Hybrid Copper Mesh – reasonably low reflectance and haze with higher transmission. In addition provides thin tracking borders, integrated tail, and the lowest resistivity for superior touch performance

6. References

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[2] PEDOT Principles and Applications of an Intrinsically Conductive Polymer by A. Elschner, S. Kirchmeyer, W. Lovenich, U. Merker and K. Rueter CRC Press

[3] Chandrakant Bhat, David P. Brown, Clement Chen, Bjørn F. Mikladal,Liam Ó Súilleabháin, Erkki L. Soininen, Dewei Tian, Ilkka Varjos, Xiaowei Zhan, Canatu, Helsinki, Finland, LITE-ON TECHNOLOGY CORPORATION, Taipei, Taiwan, R.O.C, 68.3 Curved Mobile Phone Cover with Carbon NanoBud Touch, SID 2015 Proceedings

[4] 2015 SID Symposium, Session 68.3, Power Point Presentation

[5] https://www.fusionuv.com/UV_In_The_News_Fall_2010.aspx

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