SURFACE PROTECTION OF OPTICAL FILMS AND GLASS DURING AND AFTER ASSEMBLY

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Introduction

For a society infatuated with information, the rapid deployment of various display devices, from TVs to mobile phones to tablets to electronic store graphics to electronic tattoos, continues to drive the evolution of optical films, polarizers, diffusers, ITO coated glass, and different filter media. This paper will examine the use of low and ultra low adhesion protective films as either primary carriers of delicate components through the shipping, handling, storage, and manufacturing of the OEM device, or post manufacturing storage, handling, and throughout the consumer marketplace.

Low Adhesion Protective Film Applications

The electronic devices that have become so common and are required to exist in today's modern society demand special precautions to prevent damage to the display screens and multi-layer constructions. Any of the multitude of surfaces used in the construction of a laptop, tablet, or smart phone should be free of scratches, marks, abrasion or damage, lest the high definition image be deformed. Surface protection of the materials is required to protect the delicate and highly valued surfaces during routine handling, whether it be during shipment, storage, or post-production consumer handling.

Figure 1. (L) Typical Smart Phone Construction, including Touch Screen Panel, which by itself can consist of (R) 3-5 layers of Glass/Plastic constructions.

For touch enabled smart phones, tablets, PCs, or other touch enabled consumer interface devices, the capacitive type touch screen panel is leading the technology, primarily through the use of Indium Tin Oxide (ITO) grids applied onto the sensor glass, which can identify the location of the user's finger(s) and plot movement, location, and speed. Due to the nature of the sensor glass with its sensitive ITO coating on the surface, these sensor glass panels may need to be protected during handling and shipment

to the final manufacturing site, as well as during storage. Protection of these layers is paramount to the high resolution needed before and during the fabrication of these devices.

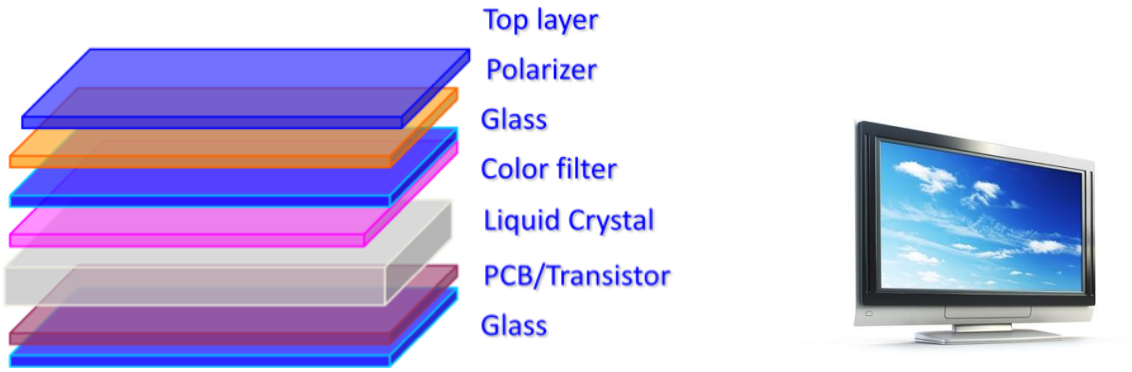


Figure 2. Typical LCD TV construction showing multi-layer construction, comprising but not limited to cover lens, glass, filters, polarizers, the display itself, and backlights.

Application Requirements for a protective covering

- Adhesion (Ranging from ultra low adhesion of 1-3 grams to low adhesion of 20-200 grams)
- Little to No adhesion build during the usable life of the component
- No Migration or leachables onto the surface that can impact subsequent laminating steps
- Good Anchorage of the protective PSA to the carrier film
- Good wetting of the PSA to the surface being protected

One approach to creating a protective film has been to modify traditional silicone PSAs to achieve the desired level of adhesion and low tack through the modification of silicone resin (tackifier) chemistry, silicone polymer construction, ratio of resin to polymer, and crosslinking system.

Adhesive Application Types

• Ultra Low Adhesion	0.5-4 grams/inch	Cover lens, Protective Tapes for Display mfg process, Mobile & Display surfaces
• Very Low Adhesion	5-10 grams/inch	Processing Tape in Mobile Assembly
• Low Adhesion	20-100 grams/inch	Masking tape for F-PCB, Casting
• Moderate Adhesion	100-300 grams/inch	Removal tape
• High Adhesion	300-2000 grams/inch	Bonding tape, Masking tape for PCB

The application types listed above reflect different needs for different substrates at different times within the process and fabrication of the electronic display. Ultra Low and Very Low adhesion types can be used as protection for delicate filmic substrates used in the fabrication of the device, and are suitable for easy machine removal of the protective film during high speed lamination applications during the construction stage. Low to Moderate adhesion protective films can be used post manufacturing to apply

a more durable protection for film, or to increase the device modulus for shipment or process treatment. Low to Moderate adhesion films can be used as aftermarket films for consumers to apply as a screen protector to the display, sold through the local grocery store or electronics shop. Typical peeling force depends on size or width, and so large screen panels generally target less adhesion.

Figure 3. Consumer level screen protector film to reduce surface scratches

Market Growth

The continued emergence of TFT-LCD (Thin Film Transistor Liquid Crystal Displays) into smartphones, gaming consoles, and portable readers like the Nook and Kindle drive a lot of the growth in the display manufacturers. While growth from the glass cover lens fabricators has slowed over the last few years due to a slow marketplace and from an excess of inventory in 2010, demand is expected to recover in 2012. Strengthened cover glass, allowing for thinner, more flexible, but scratch resistant cover lens for smart phones and tablet PC's, provides additional durability to the electronic device, and is seeing rapid growth. In 2011, 755 million devices will ship with cover glass, for a year/year growth of 146%. Mobile phones account for 84.4% of the shipments.[3]

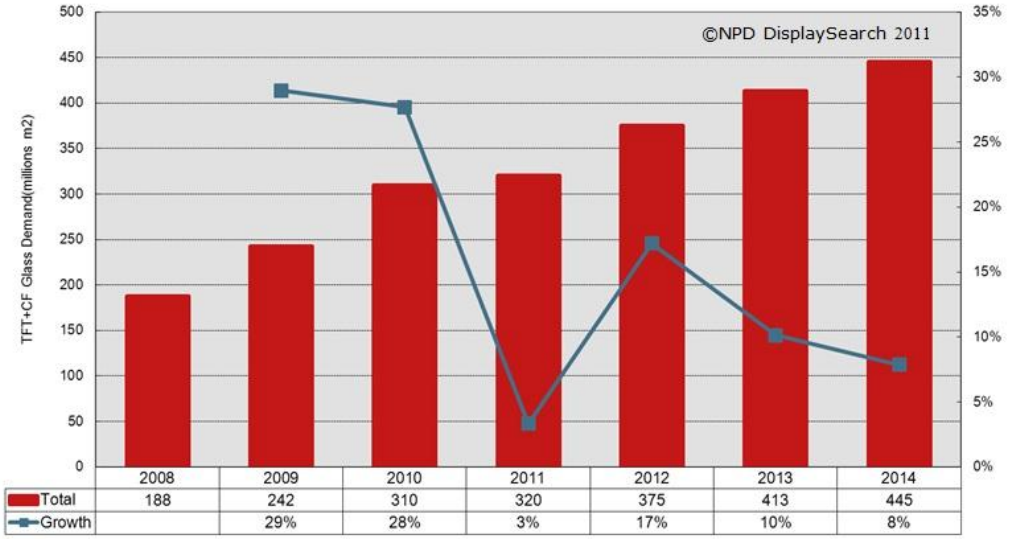


Figure 4. Demand for glass substrates grew rapidly over the past few years as TFT-LCD manufacturers expanded TV panel production, but due to an overstock from 2010 inventories and the slow economy,market growth slowed in 2011, and is expected to continue to do so.
Source: NPD DisplaySearch *Quarterly LCD Glass Substrate Report*

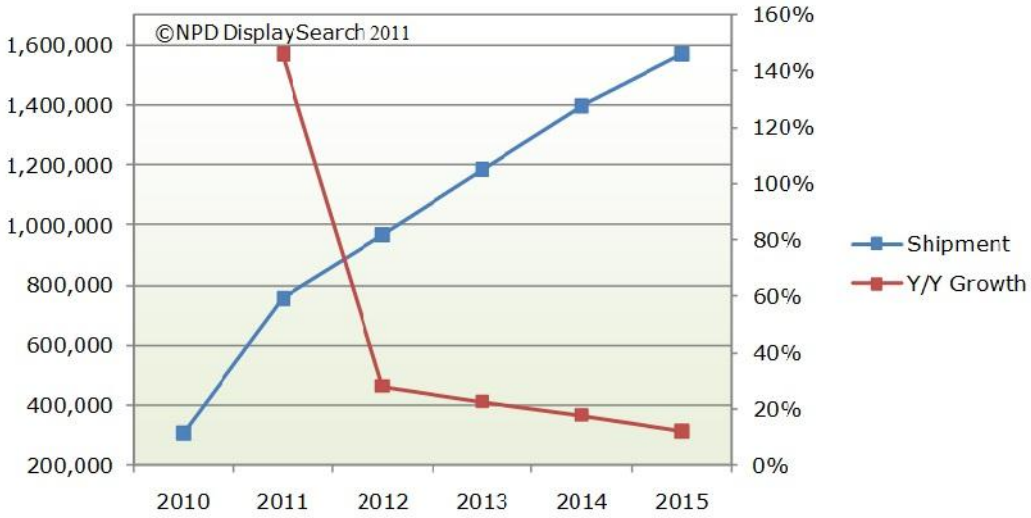


Figure 5. Growth in smartphone and tablet PCs has provided a substantial increase in growth for the strengthened cover glass market, which will be in 755 million devices in 2011. Source: NPD DisplaySearch *Cover Glass Technology and Market Forecast Report.*

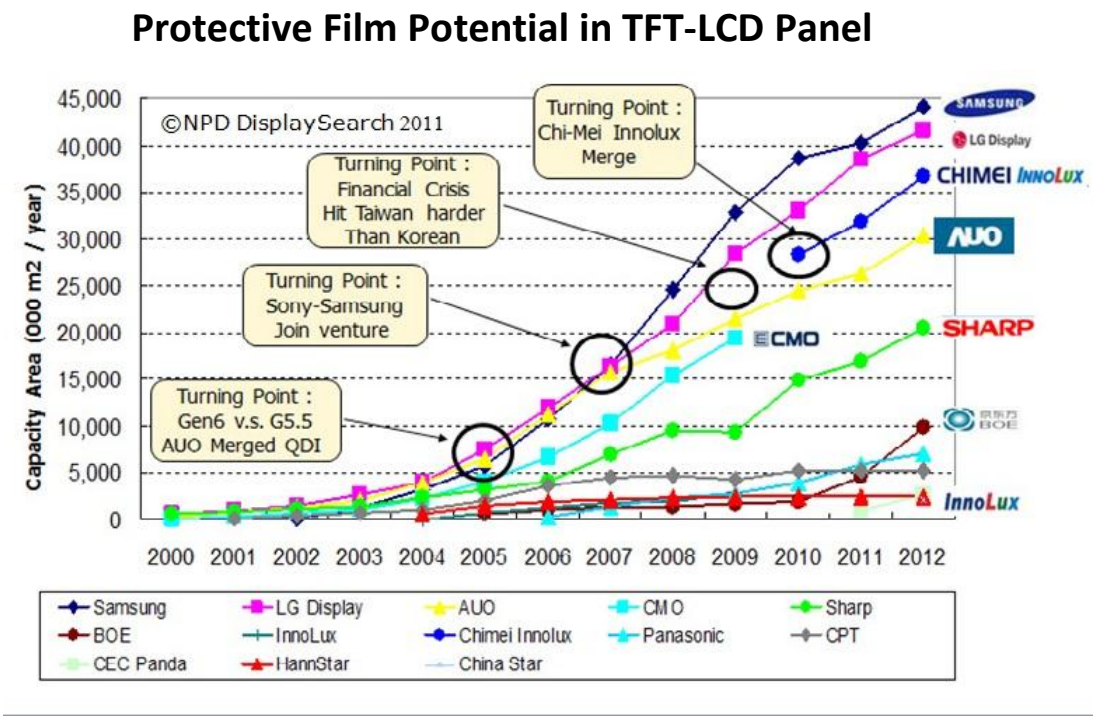


Figure 6. Historical growth of TFT-LCD panel manufacturing by capacity area by top manufacturers. Source: NPD DisplaySearch *Quarterly Large Area Production Strategy Report*

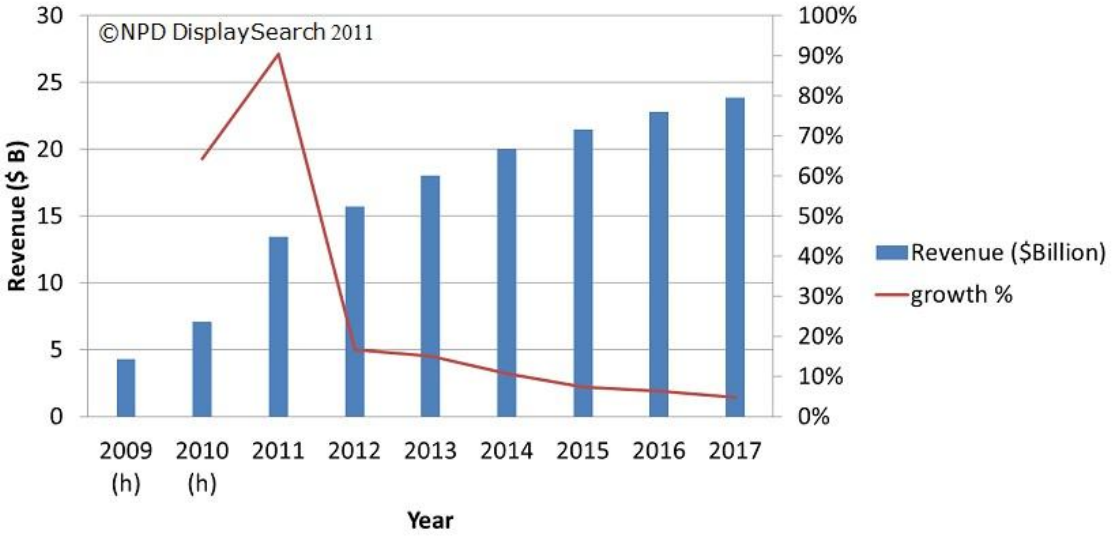


Figure 7. Touch screen module revenue was $4.3 billion in 2009, and grew to $7.1 billion in 2010. NPD DisplaySearch forecasts that touch screen module revenue will grow 90% and reach $13.4 billion in 2011, and nearly double in six years, reaching $23.9 billion by 2017.
Source: NPD DisplaySearch 2011 *Touch Panel Market Analysis*

Silicone Protective Films

Silicone Protective Films are being specified into applications for various reasons over traditional acrylic type protective films, primarily due to:

- Variable tuning of adhesion through blending to achieve optimal adhesion
- Consistent adhesion upon aging with little to no adhesion build
- Ability to reach Ultra low and Very low adhesion levels of 1-28 grams (0-1 oz)
- Self Wetting ability to substrate surface

Variable tuning of the adhesion levels through blending of a high or moderate adhesion PSA and a low adhesion PSA can be achieved by following a blending curve as shown below.

	Adhesion	Tack
Si PSA Type 1 (Moderate Adh)	200-300 grams/inch	90 grams
Si PSA Type 2 (Very Low Adh)	5-10 grams/inch	72 grams
Si PSA Type 3 (Ultra Low Adh)	3-4 grams/inch	50-75 grams
Si PSA Type 4 (High Adhesion)	800-1000 grams/inch	1140 grams

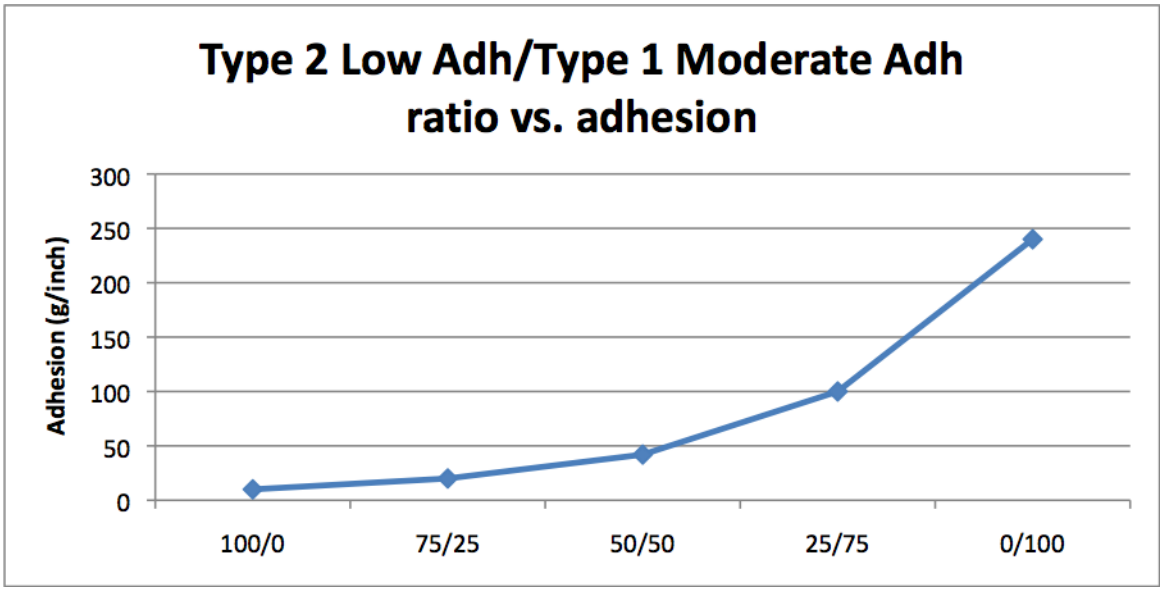


Figure 8. Blending Protective PSA Type 1 (Moderate adhesion) with a Type 2 (Low Adhesion) PSA can result in a customized adhesion level designed to suit the needs of the application.

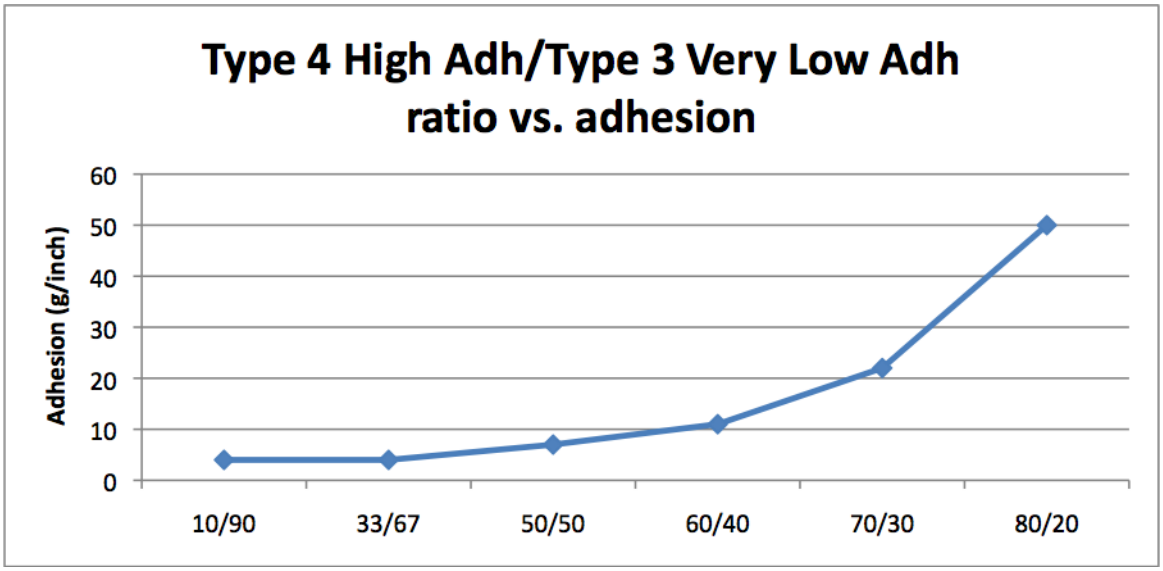
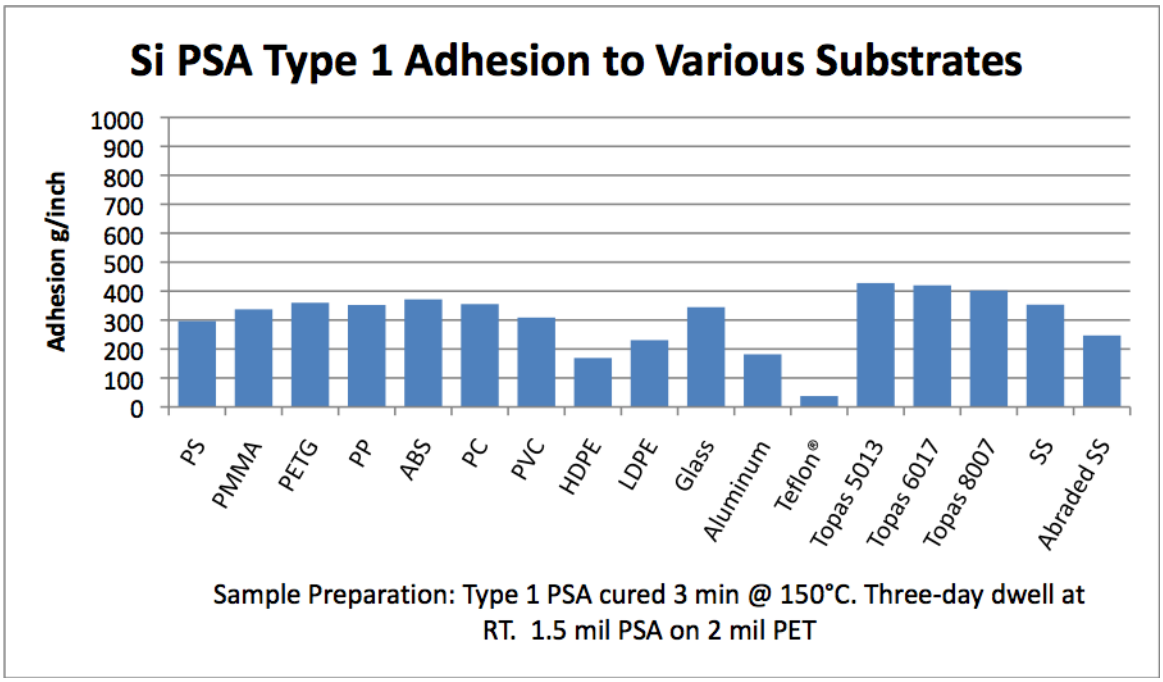
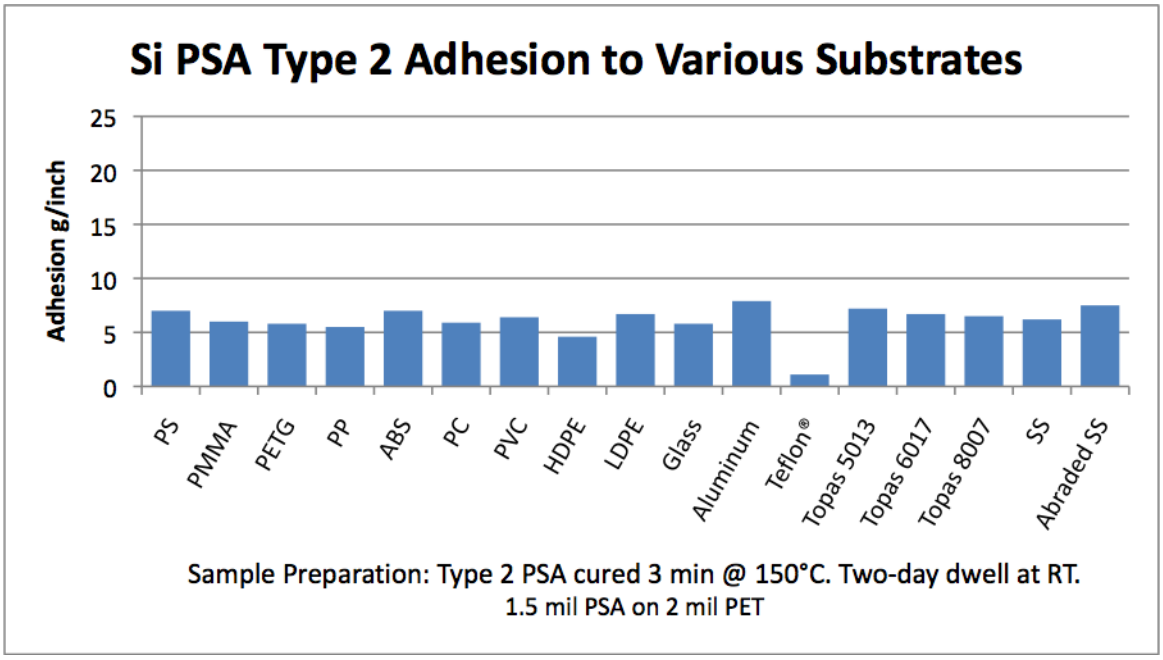


Figure 9. Blending High Adhesion PSA Type 4 with a Type 3 Very Low Adhesion PSA can also result in a customized adhesion level designed to suit the needs of the application.

Testing indicates that adhesion levels vary slightly by substrate, depending on surface energy. The following graphs depict protective films manufactured with Si PSA type 1, 2, and 3. Each construction had a target coat weight of 1.5 mil, onto an unprimed, untreated 2 mil PET film. Protective Film type 1 was designed to target the moderate adhesion level, while type 2 was designed to target slightly higher than 5 grams, and type 3 was targeting slightly lower than 5 grams.





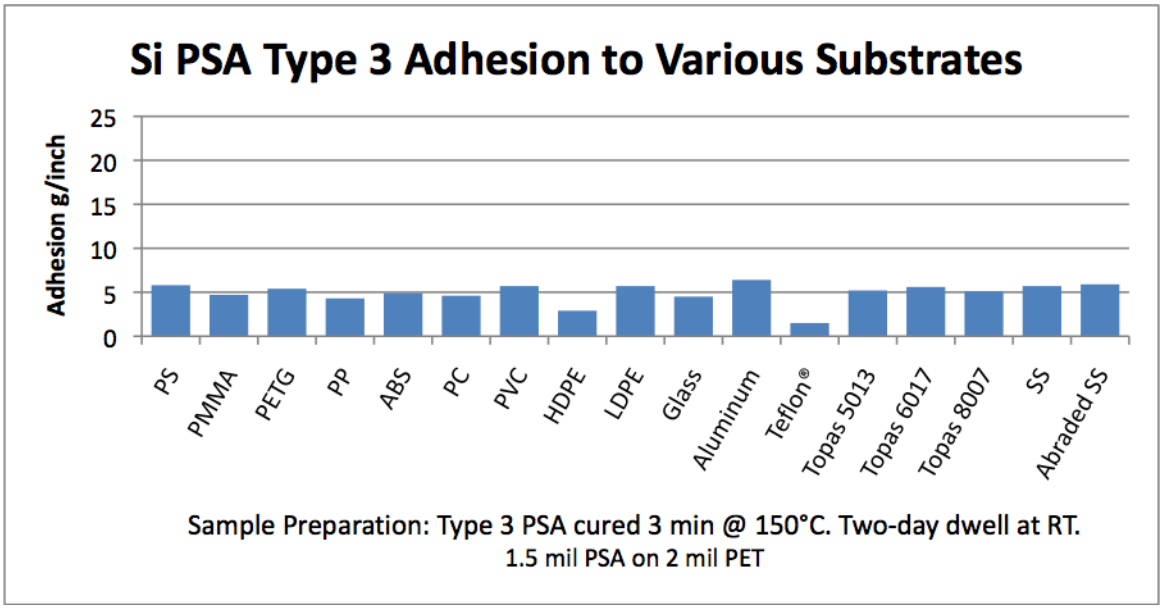
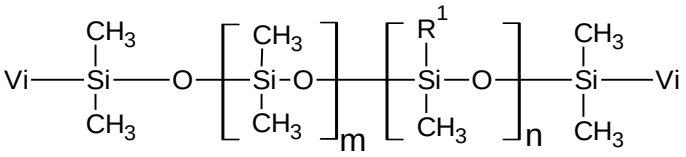


Figure 10, 11, & 12. Adhesion of Protective Pressure Sensitive Adhesives Type 1, 2, & 3 to various substrates targeting moderate (100-300 grams) adhesion, very low (5-10 grams) and ultra low (0.5-4 grams) adhesion.

Silicone Chemistry

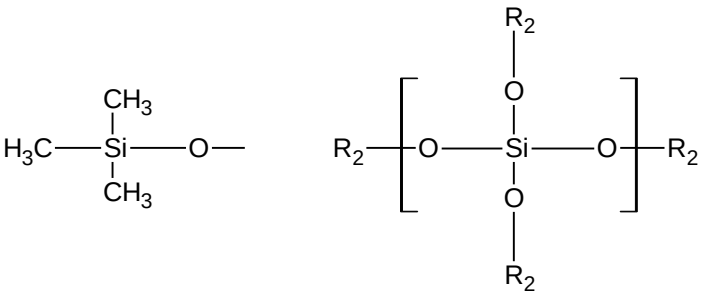
For those new to silicone pressure sensitive adhesives, the fundamental chemistries employed here derive from a solvent dispersion of vinyl-terminated silicone polymers and a silanol-functional siloxane resin. The vinyl terminated (-C=C) silicone polymer is a high molecular weight polymer with diorganosiloxane (-Si-R_2O-, also called a D unit) repeat units, with pendent vinyl groups along the

chain. The silicone polymers generally range from low viscosity polymers to high viscosity gums or semi-solids having a molecular weight (Mw) in the 600M to 1MM Dalton range.[1]



M^{Vi} -D_m - D^R_n - M^{Vi} Unit, where R1 = Me or Vi groups

Figure 13. Schematic structure of silicone polymer



M Unit Q Unit, where R2 = M, M^{OH}, or Q Unit

Figure 14. Structure units for MQ siloxane resin

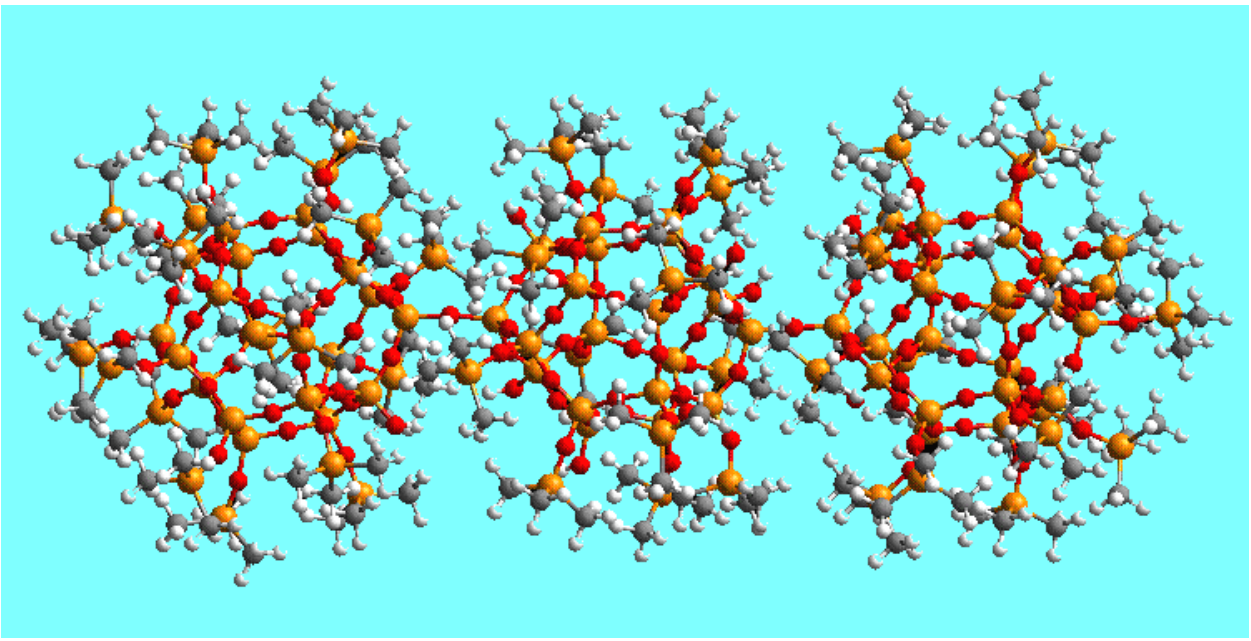


Figure 15. Computer model of postulated MQ siloxane resin structure [1]

The silanol-functional siloxane resin is also referred to as MQ resin, as it consists of trimethylsiloxy ($Me_3SiO_{½}$ or M) unit and silsesquioxane ($SiO_{4/2}$ or Q) units. Each MQ resin molecule contains multiple M and Q units, as seen in the postulated figure above. MQ resin is a highly branched, three-dimensional network, with a shell of M ($Me_3SiO_{½}$) surrounding the inner core of three-dimensional Q units. Various functionalities can be incorporated into the structure. [1]

The mixture of silicone polymer and MQ resin can be combined to yield a pressure sensitive adhesive with designer properties by the judicious choice of resin size and functionality, polymer size and functionality, and resin to polymer ratio, and a host of other variables, which can allow selective performance enhancements for specific applications.

Reinforcement or crosslinking of the polymer network yields improved low and high temperature performance. The developed products utilize a platinum-catalyzed addition cure chemistry to achieve a crosslinked network between the resin and polymer, tailored to yield low adhesion, low tack, and lower migration.

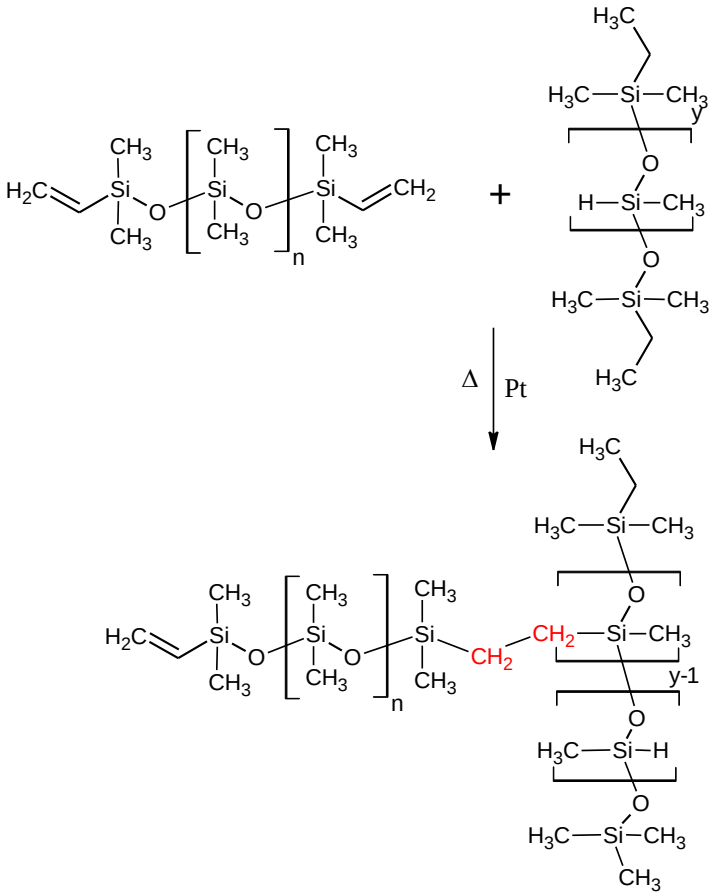


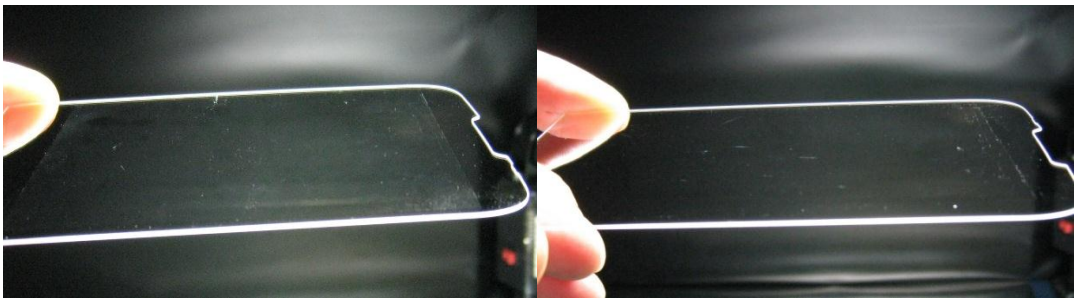
Figure 16. Addition curing reaction of vinyl and hydride reactive silicone species. The hydride crosslinker reacts across the double bond of the vinyl groups of the polymer to form an ethylene linkage[1].

The curing mechanism is more selective than the radical forming peroxide cure chemistry employed with other common silicone pressure sensitive adhesives, and does not interact with the solvent during cure. This allows the solvent to evaporate during the cure process, requiring a single zone oven as compared to a 2-zone oven required for Benzoyl peroxide type curing systems. Platinum systems can be cured with lower overall temperatures of 100-150^{o}C, but can be cured hotter if required. For consistency, most testing reported here was cured for 3 min at 150^{o}C, but this curing condition can be optimized depending on PSA formulation, coating heads and curing equipment available, processing conditions, airflow, and other equipment specific variables.

This lower curing temperature as compared to peroxide type cure systems, which require temperatures greater than 150^{o}C typically, allows for temperature sensitive substrates to be used. When optimizing the cure conditions,one should evaluate both time and temperature as variables. Evaluation of cure can be achieved in a number of ways and combinations for a given application.Optimization for the specific application can be achieved based on performance needs and processing conditions.

Migration Detection and Subsequent Bonding Impact

Manufacturers have different criteria for establishing limits for migration of any process that may impact future bonding steps in the build of electronic devices. Some companies rely on a purely visual approach, with operators trained to grade residue following protective film removal from light to moderate migration, but recognize that this is highly subjective. Some companies try to assess bond strength to these surfaces through mechanical testing in their subsequent tests (adhesion of a paint, coating, or adhesive through tensile strength, cross hatch adhesion testing, or peel testing). Some work has been done to test Subsequent Adhesion Strength (SAS) of an organic pressure sensitive adhesive against the silicone PSA, treating the silicone protective film as a release liner, but this is limited to the susceptibility of that particular organic PSA to silicone contamination and uptake, and varies with organic formulation and processing conditions.



Figures 17 (left) and 18 (right) showing moderate residue versus light residue respectively.

Some common techniques for determination of residue:

- Visual residue remaining on surface. Ideal is “No visual residue”

- Subsequent Adhesion Strength (SAS) test (modified), by applying an acrylic tape to the surface of the Si protective film (similar to a release liner test), and measuring against a known value. Note that different organic tape formulations will have different sensitivities to silicone migration or residue, so be selective in the organic tape choice.

- Solvent Extraction testing. Comparing film thickness before and after a solvent extraction can give approximate levels of cure, as measured by XRF X-Ray Fluorescence. This technique can give approximations of the quantity of uncrosslinked molecules that can be extracted by solvent, as well as an indication of anchorage (by simple observation of the film following the solvent immersion) Note: Extraction is differentfrom leachables/migration.

- Inductively Coupled Plasma spectroscopy or atomic absorption are common techniques to detect residue remaining on a surface. A solvent wash after the removal of the protective film can detect micro amounts of silicone by volume, which can then be correlated with a known sample area and coat weight.

As each application is different and unique in the combination of materials, adhesives, and pressure sensitive adhesives, the impact of migration can vary from severe to negligible. Evaluating each combination in light of this impact is needed to help ensure the durability and reliability of the end device.

Surface Wetting

Another key factor in working with silicone pressure sensitive adhesives is the ability to wet out onto the surface of the substrate. The low surface energy of a silicone system, by various measures to be in the 20-22 dyne/cm^2 range, allows the soft, flexible silicone chains to flow onto the higher surface energy (30-65+ dynes/cm^2) substrate quickly and efficiently. The customers desire the application of the protective film to wet the surface, and push any bubbles in front of it and avoiding trapping any air bubbles within the surface. If bubbles are trapped within the surface, light finger pressure should be able to move the bubble to the edge. This enables a visually pleasing and acceptable bubble-free image, yielding a high quality, aesthetically pleasing screen protector. Some applications require a silicone hard coating on the PET to limit the pick up of fingerprints or marks during the day-to-day handling of the electronic device.

Associated with surface wetting speeds and bubble formation is repositionability. Repositionability is the ability to lift up the protective film, and reapply the protective film to the same surface in the same rough proximity as originally placed. Samples with very low adhesion demonstrated an ability to be applied to the surface>20 times with no increase or decrease in adhesion (to stainless steel).

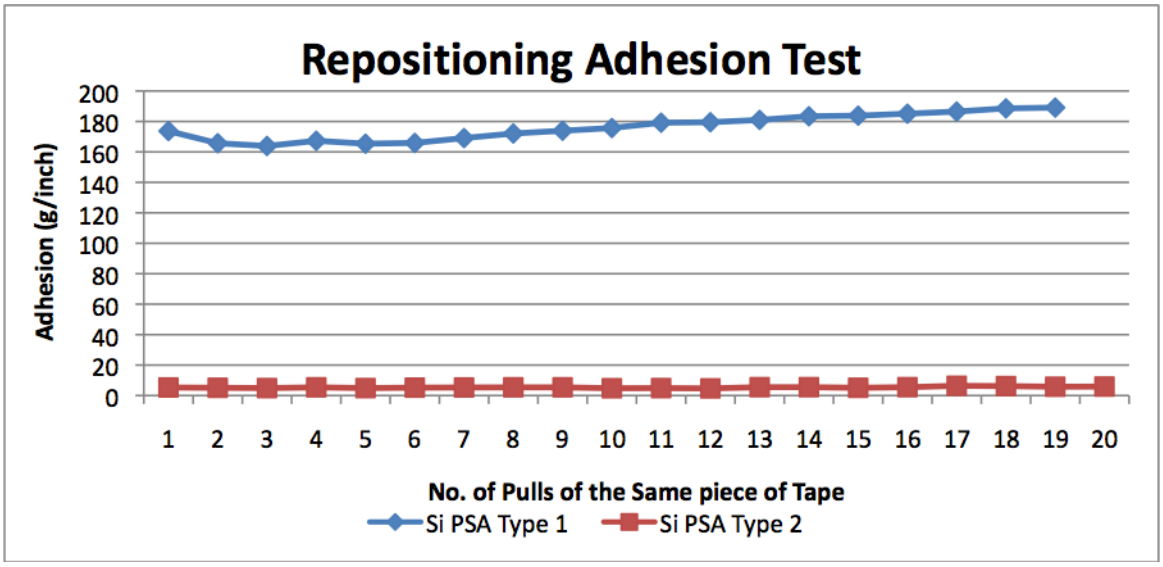


Figure 19. Very Low adhesion Si PSA Type 2 and Moderate Adhesion Si PSA Type 1 following repeated 180^{o} peel adhesion testing on the same stainless steel panel with the same piece of tape. Very low adhesion Si PSA Type 2 highlighted the ability to be reapplied and removed multiple times to the same substrate with consistent removal force.

Conclusion

The demand for glass cover sheet in electronic devices still continues to rise, along with the development of filmic type laminations that seek to displace glass as the viewing surface of handheld devices and tablets. The construction of these multilaminate components within the device continues to evolve as the imaging technology progresses. Both the inner and outer surfaces require delicate handling to avoid scratches, in order to manufacture high optical quality, high definition imaging devices and displays. The utilization of protective films can help reduce or eliminate scratches and chipping throughout the manufacturing process, as well as in the hands of the consumer.

The development of low adhesion protective films, utilizing both organic and silicone based pressure sensitive adhesive type formulations continues to evolve to meet the growing demands in the electronics world. The ability to fine tune the adhesion levels to meet the demands of the manufacturers provides the tape manufacturers with the unique ability to continue to add both standard products at low cost into their product offering, as well as add value through customized solutions.

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