INTEVAC

INTEVAC oDLC™

PROTECTION FOR DISPLAY COVER PANEL

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Revision Number: 1

Mobile communications and computing devices have proliferated extensively throughout our daily lives. Smartphones, Mobile Computing (Tablet, Laptop), Auto-Infotainment Systems and Smartwatches have become ubiquitous. With the proliferation of electronics in our daily lives, our dependence to these devices has grown ever greater. This dependence requires our devices to operate at all times and withstand extensive handling and abuse.

oDLC Performance

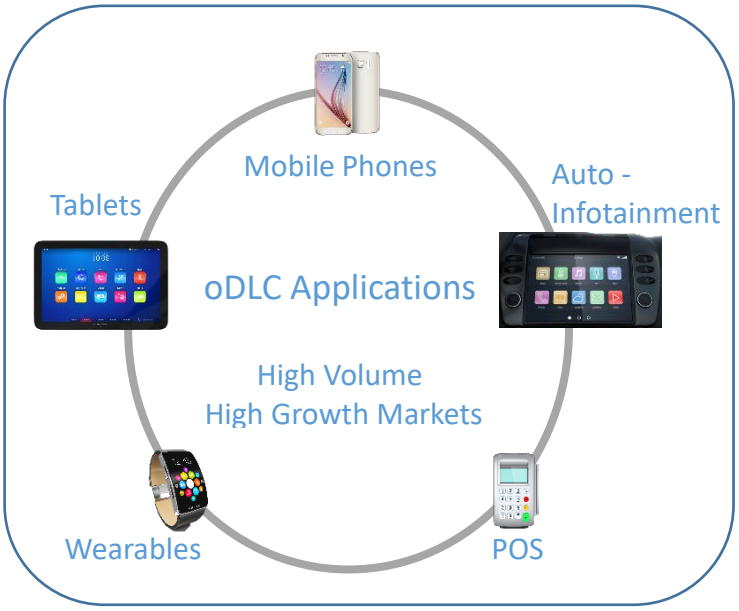
+ 20x Increased Scratch Resistance
+ 20% Increased Breakage Strength
~ 10x Haze Improvement
> 91% Light Transmission

The most vulnerable component of our mobile devices? It's the glass display. Subject to constant handing, the display acts as the primary MMI (Man-Machine Interface).

As our devices have grown in size and weight, the display has become larger and, unfortunately, ever more susceptible to damage.

Intevac, Inc., has created a complete ultra-thin-film protective coating solution designed to provide substantial scratch and breakage protection for display cover panels – making the display system physically stronger, while maximizing light transmission. The coating is called oDLC™, for optical Diamond-Like-Carbon, and this paper describes the coating itself, as well as testing results demonstrating its various benefits.

Applications

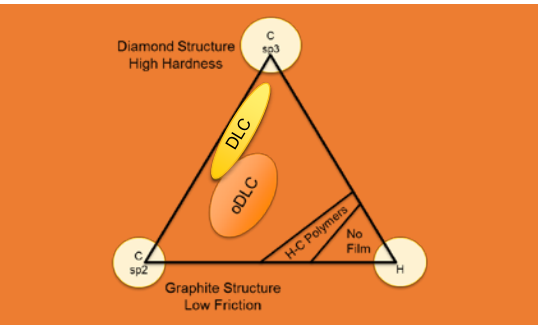


Various Applicable Product Markets

Mobile Phone Applications

What is Intevac oDLC (Optical Diamond-Like Carbon)?

Intevac has developed an ultra-thin-film protective coating targeting the electronic display cover market. The film – oDLC, or optical Diamond-Like-Carbon, provides significant scratch and breakage protection for the glass-based display covers used on mobile smartphones, mobile computing, wearables, auto-infotainment systems, and much more.



Diamond-Like-Carbon (DLC) technology is a well-understood and trusted technology – DLC has been used for decades to reduce wear on contact surfaces in a variety of commercial applications. With its excellent adhesion and friction properties, DLC films are found today in products ranging from high-end medical implants to disposable razor blades, from industrial gears and machine tools to Hard Disk Drive (HDD) Media. Conventional DLC – a class of amorphous carbon generally comprised of ***sp^3*** and ***sp^2*** bonded carbon – is typically used in applications where optical transparency is not required due to conventional DLC's inherent opacity.

Intevac, as the established thin-film equipment leader for the Hard Disk Drive Media industry, supports an installed equipment base on which ~60% of all Hard Disk Drive Media is manufactured annually, equating to over 500 Million individual disks per year. Intevac's DLC technology is an integral part of the thin-film stack used in HDD media, providing wear and anti-corrosion protection to the thin films below it.

Building on our success with conventional DLC, Intevac leveraged decades of experience in HDD media to develop ***oDLC – optically transparent Diamond-Like-Carbon***. The company has invested thousands of man hours and millions of dollars since 2011 to develop, manufacture, test and perfect a complete solution that includes the deposition system (Intevac VERTEX™) as well as the film (oDLC) itself.

The breakthrough from this effort is this: development of an optically clear DLC that is stable, cost effective, and provides significant protective mechanical properties.

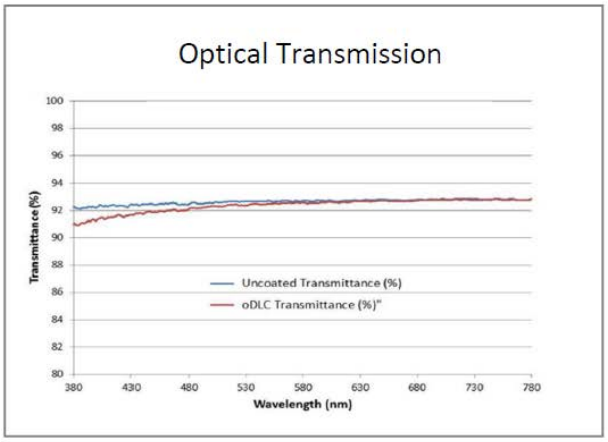
oDLC Performance

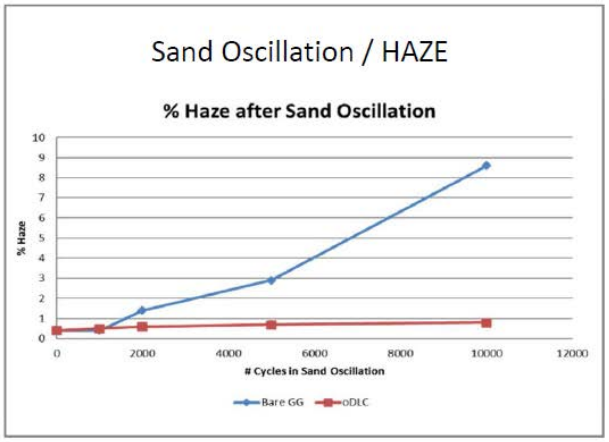
In its quest to develop and commercialize oDLC, Intevac has performed extensive industry-standardized testing to prove the capability and durability of the oDLC coating. Testing has shown oDLC provides extensive scratch and breakage performance improvement when applied to both aluminosilicate and soda-lime glass substrates – the two most prevalent glass materials used today in electronic displays.

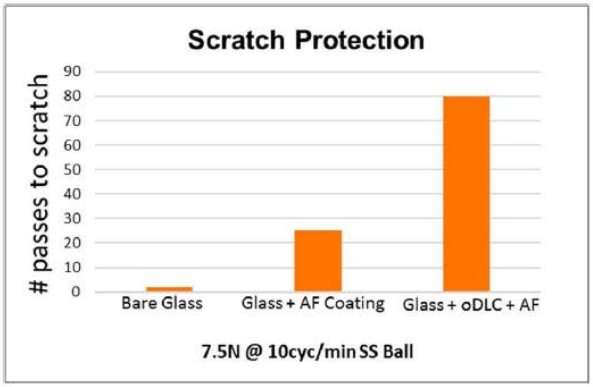
With respect to aluminosilicate glass, the coating improves overall scratch resistance by 20 times over non-coated substrates. Glass breakage strength improves by roughly 20% when coated with oDLC. Lastly, oDLC significantly reduces small or light scratches that cause hazing. Under standardized oscillating sand testing, oDLC coated glass reduces hazing by approximately 10 times.

Attribute / Test	SL-Glass	A-Glass	SL-Glass + oDLC	A-Glass + oDLC
Scratch (Taber Passes)	0	1	60+	80+
Breakage Resistance (Ring-on-Ring)	Baseline	Baseline	~ +20%	~ +20%
Haze Reduction (Sand Oscillation)	Baseline	Baseline	~ 10x	~10x
Optical Clarity (Transmittance)	91.8%	92.5%	91.3%	91.8%

SL-Glass = Soda Lime Glass
A-Glass = Aluminosilicate Glass (e.g., Corning Inc.'s Gorilla Glass™)







oDLC Testing

Intevac, along with its industry partners, has performed extensive mechanical testing to prove the effectiveness of the oDLC film. Below is a description of these tests, with results.

1. **Sand Oscillation Test**
   Based on an ASTM industry standard test, Intevac developed a sand oscillation test that mimics and accelerates the light scratches that develop on display glass over time from everyday handling of the surface. For this test, we tape glass to an aluminum weight (to simulate the weight of a phone) and place it upside down in a bed of silica and vigorously oscillate the bed (10K cycles).

   Sand oscillation testing shows a 10x reduction in hazing (light scratches) of glass coated with oDLC versus non-coated glass.

2. **Scratch Test**
   Based on an ASTM industry standard test, Intevac developed an accelerated wear test that imparts scratches onto the surface of the display glass. The scratch test was developed to measure the resistance of the glass surface, as well as a coated surface, to a specific force using a known scratching material.

   Scratch testing shows a 20x improvement in scratch resistance of glass coated with oDLC versus non-coated glass.

3. **Breakage Test**
   Intevac has tested glass substrates (coated and uncoated), that were first abraded and then subjected to a Ring-on-Ring (RoR) flexure test. The test evaluates the breakage strength of the glass substrate over time.

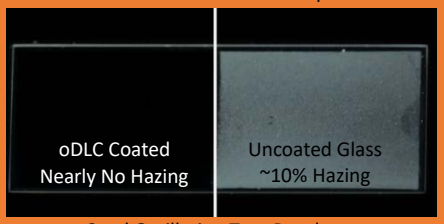
   Breakage testing shows ~ 20% improvement in breakage resistance of glass coated with oDLC versus non-coated glass.

4. **Optical Clarity**
   A critical factor for any protective film is its ability to allow the transmission of light from the display to the viewer's eye. A delicate balance must be maintained in providing substantial protective benefits while maintaining optical clarity. Intevac has taken great effort to achieve the ideal balance between protection and clarity, as shown in our optical clarity test.

   Optical clarity testing shows > 91% light transmission (or roughly 0.5% light transmission loss) of oDLC coated glass.

Sand Oscillation Testing

Sand Oscillation Test Set-up

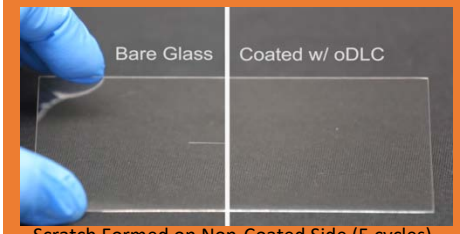


Sand Oscillation Test Results

Scratch Testing

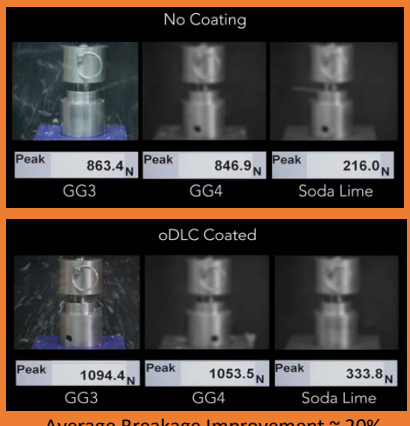
Tester


Glass Under Test



Scratch Formed on Non-Coated Side (5 cycles)
No Scratch on oDLC Coated Side

Breakage Testing



Average Breakage Improvement ~ 20%

Trends Driving Need for oDLC

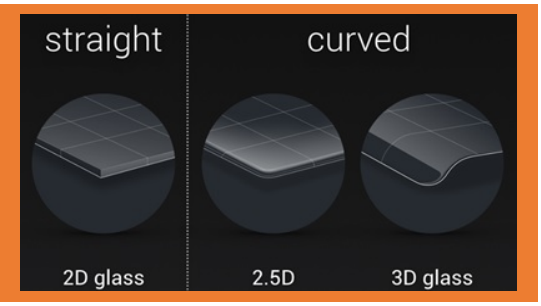
Several Consumer Electronics (CE) industry trends are driving the need for a highly durable and cost-effective protective coating solution for display cover panels.

1. **Higher Breakage Strength = Softer Surface**
   The CE industry has been on a continual quest to deliver breakage-free / scratch-free display cover panels. Since the early days of mobile phones, manufacturers have sought to use plastics in place of glass due to its superior breakage characteristics. Unfortunately, the very characteristic that enables plastic to absorb more force than glass – softness – is also its weakness, as plastic is extremely easy to scratch. To date, glass provides the best available mix of breakage strength, scratch resistance and optical clarity. However, the number one complaint consumers have with their mobile electronics (especially mobile phones) is with breakage or damage to the display cover. In fact, over 70% of all reported issues with mobile phones are directly related to display issues.

   Corning Incorporated, with its Gorilla Glass (GG) product, the de-facto industry cover glass standard, has developed successive generations of product (from GG1 to GG5)[1] with the intent to improve breakage strength. Throughout this succession, it has been observed that as the glass breakage strength improves, the surface toughness – the ability of the surface to resist scratches, has decreased.

   Intevac oDLC has been demonstrated to augment and improve Gorilla Glass breakage performance by providing greater scratch resistance, thereby providing a more robust overall solution than uncoated GG alone.

2. **Protecting the Proud Edge**
   Another trend within the consumer electronics industry is the move to 2.5D and 3D cover glass. In the past, manufacturers used what is known as 2D glass, which describes the edges at the ends of the glass; the display image area stopped at or before the sharp corner (A protective bezel around the cover panel ensured the edges of the glass were not exposed).



Over the past few years, for ergonomic and aesthetic reasons, CE manufactures have been moving to 2.5D and 3D cover panels. As the reader can see from the graphic, the 2.5D glass is a cover panel where the edges have been rounded. It is now quite commonplace to find mid to high-end phones with 2.5D cover panels. 3D cover panels describe a glass that has significant curvature - essentially a curved cover panel, with a display image possibly wrapping around the side (see left graphic).

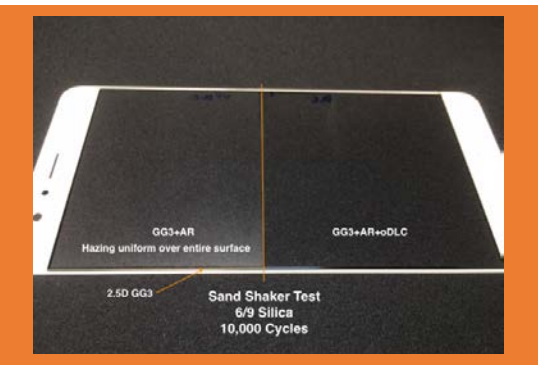
[1]*All versions of Gorilla Glass are trademarks of Corning Incorporated*

Both 2.5D and 3D glass lack the protective bezel found in 2D cover panels; in fact, they both have what is known as a "proud edge" – this means the edge of the glass is exposed. As a result, it is a well-known issue within CE circles that 2.5D and 3D glass suffer from higher rates of scratches (especially at the edges) as well as higher breakage rates. oDLC has been proven to provide effective scratch protection to 2.5D and 3D cover panels (see graphic on right – oDLC coated on bottom half of glass –glass exposed to 10,000 cycles of sand oscillation – hazing only on non-coated half – oDLC coated surface and edges are virtually haze-free).

10K Cycles Sand Oscillation

3. Protecting Anti-Reflective Coatings

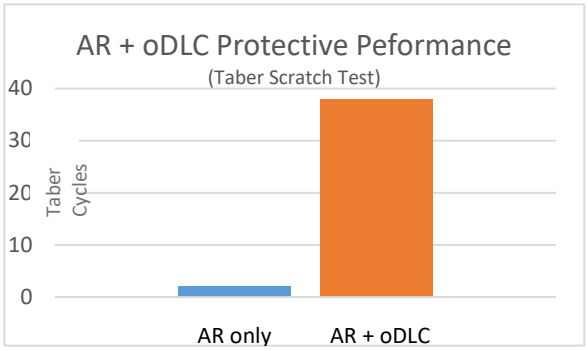
Ever been outdoors under bright sun and tried to view your mobile phone? Difficult to view, wasn't it? This next trend in mobility will be music to your ears (or a feast for your eyes) – the CE industry is adopting the use of Anti-Reflective (AR) Coatings.



AR coatings are intended to significantly reduce the amount of reflected light – the same light that prevents you from viewing your electronic display in bright sunlight. For reference, today's average mobile phone display has roughly 4% reflection. With AR coatings, this number may be reduced to as low as 0.5%!

But there is one important issue to contend with regarding AR coatings: they are easily scratched. While consumers tolerate light scratches on non-AR coated display glass – scratched AR glass is very noticeable and quite distracting, defeating the purpose of adding AR coatings. Mobile phones and other display-based consumer electronic devices that use the display as their main interface are likely to scratch at some point, even with careful use. In this case, the benefits of AR (better readability) may not outweigh the negatives (distracting scratches), and mobile phone manufacturers remain cautious with regards to the use of AR coatings.

With Intevac oDLC, CE manufacturers have gained a powerful tool to protect "soft coatings", such as AR, from damage.



Conclusion

With the growing use of electronic systems (and subsequent handling) coupled with the functionality and aesthetic beauty enabled by glass, the use of and the requirement for, stronger, more scratch-resistant glass increases daily. A prime example of this trend is the implementation of glass as a replacement for aluminum and plastic in the rear-cover panels of high-end mobile phones (phones costing > US$400). A specific example - starting with the Samsung S6 (introduced in 2015), glass replaced the plastic back-cover panel and has continued through successive generations. It is projected that glass will be used as the back-cover panel for the majority of high-end mobile phones by 2018.

Intevac's oDLC thin-film coating, as has been demonstrated, enhances the strength and scratch resistance for *all* glass surfaces found on consumer electronic devices (such as mobile phones, tablet computers, kiosks, wearables and automotive instrumentation) while enabling new technologies such as anti-reflective coatings. The requirement for glass enhancing solutions such as oDLC are set to grow.

To learn more, please contact Intevac Inc. at equipment@intevac.com or call +1.408.986.9888.

Glossary

- MMI: Man-machine interface
- oDLC: Optical Diamond-like Carbon film
- HDD: Hard Disk Drive
- AR: Anti-reflective film
- AF: Anti-fingerprint film
- GG1-GG5: Gorilla Glass Generations
- RoR: Ring-on-Ring Test
- CE: Consumer electronics
- SL-Glass: Soda-lime Glass
- A-Glass: Alumino-silicate Glass
- 2D Glass: Straight edge glass
- 2.5D and 3D Glass: Curved edge glass