



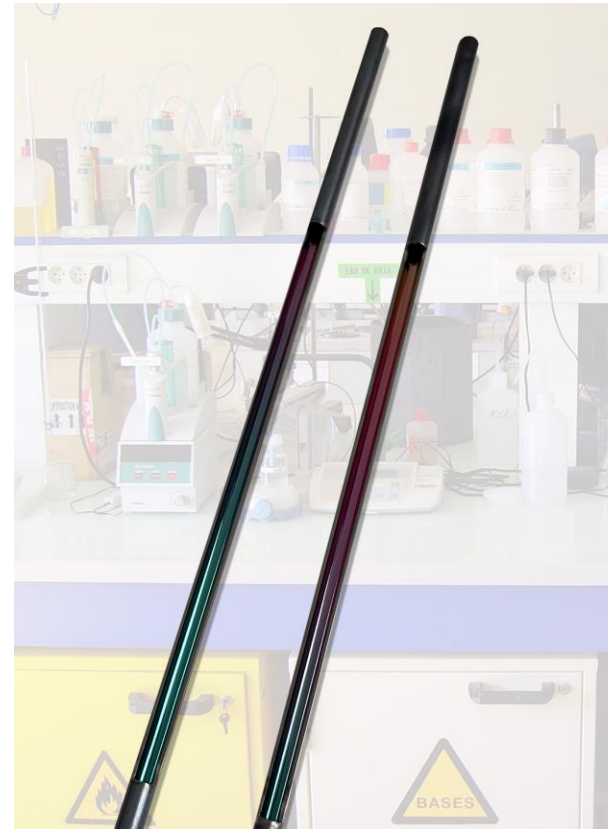
Siltride®

SilcoTek's most protective and versatile coating technology.



Overview

- ▶ History and corporate overview of SilcoTek
- ▶ CVD coating technology and process
- ▶ What is Siltride?
- ▶ Siltride uses in real world applications
- ▶ Game changing surface improvements
 - ▶ Corrosion
 - ▶ Electrical resistance
 - ▶ Hydrophilicity
 - ▶ High temperature protection
 - ▶ Durability and wear resistance
 - ▶ Expanded substrate capability
- ▶ Questions



History and Corporate Overview

- ▶ 1987: Restek invents *SilcoSteel* to make metal GC capillaries inert like glass.
- ▶ 1990 – 2000: *Restek Performance Coatings (RPC)* team is formed, dedicated to CVD coatings and exploring new areas where the technology can help solve customers' problems.
- ▶ 2009: Demand of RPC grows to a point where a separate company is necessary for continued growth, SilcoTek is born.
- ▶ 2013: A 36,000 square foot coating facility is built to grow SilcoTek's coating capabilities.
- ▶ 2023: After new additions, SilcoTek has expanded into a 70,000 square foot facility with over 65 employees.



History and Corporate Overview

- ▶ Vision: A better world through SilcoTek coatings.
- ▶ Mission: To provide game-changing coatings.
- ▶ Target markets:
 - ▶ Semiconductor
 - ▶ Analytical
 - ▶ Life Sciences
 - ▶ Energy, both carbon-based and emerging technologies
 - ▶ Many more
- ▶ SilcoTek's **ZIP** Code guides the conduct we follow every day.
 - ▶ **Zero** disappointments – We strive for a perfect coating process, from quote to shipping, every time.
 - ▶ **Integrity** in all we do – We are open, honest, and admit mistakes.
 - ▶ **Plus 1** customer service – We aim to go above and beyond every time you interact with us.



CVD Coating Technology

- ▶ Like all SilcoTek coatings, Siltride is applied using a proprietary chemical vapor deposition (CVD) technology.
 - ▶ The CVD process is commercialized and scalable for growth.
 - ▶ Expect non-line-of-sight, 3D deposition for reliable and even coverage of complex geometries and high-aspect ratios, adhering to a range of substrates.
 - ▶ No impact on design tolerances, sealing surfaces, or threads.
 - ▶ Covalent bonding between CVD coatings and substrate surfaces allows for excellent adhesion without fear of flaking off.



CVD Coating Process



SilcoTek receives customer parts to our warehouse.



Preliminary condition and material inspection.



Surface preparation to remove unwanted residues.



Parts go into the CVD oven chambers for coating.



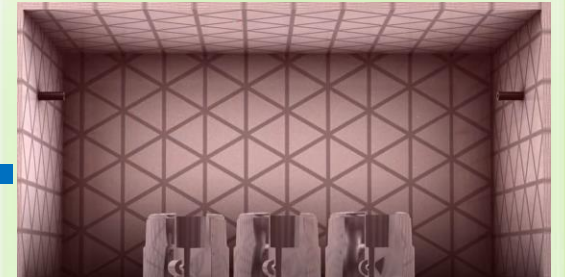
SilcoTek ships parts back to our customers.



Post-coating inspection.



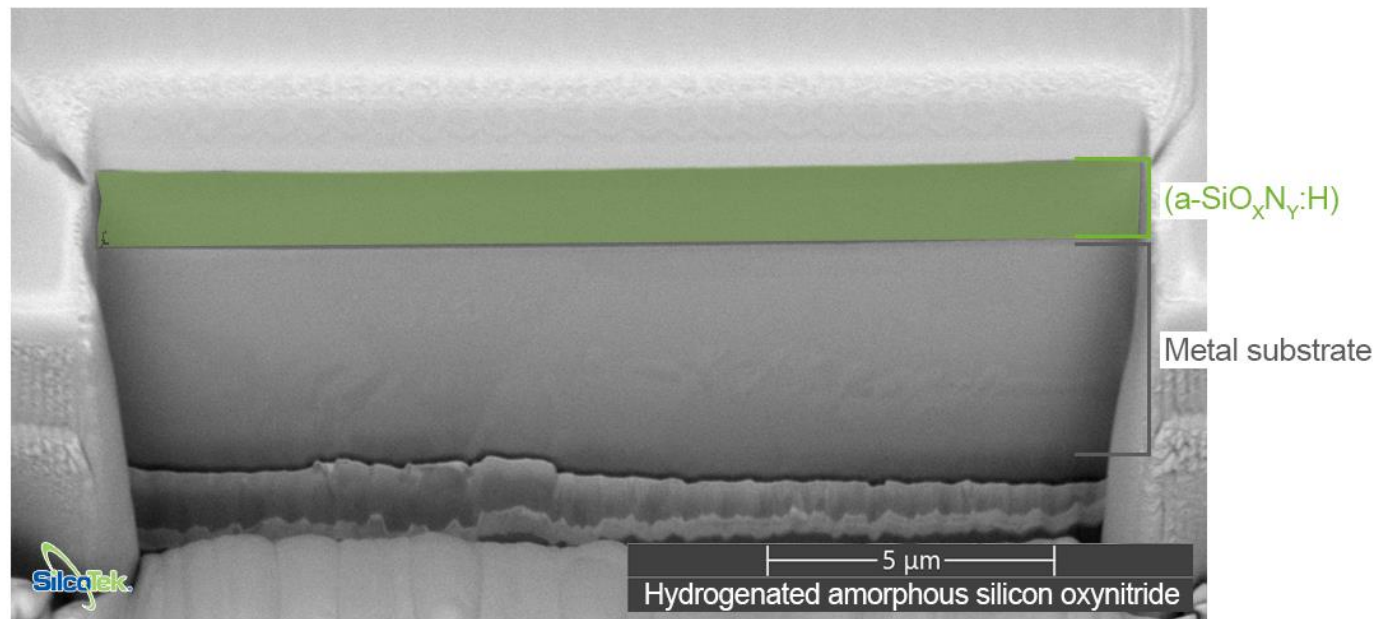
Parts leave oven with a thin uniform protective coating.



Gases are heated and deposited via CVD onto parts.

What is Siltride?

- ▶ Siltride is a hydrogenated amorphous silicon oxynitride coating ($\text{a-SiO}_x\text{N}_y\text{:H}$)
 - ▶ Typical thickness on a flat surface is 500 – 2000 nm.



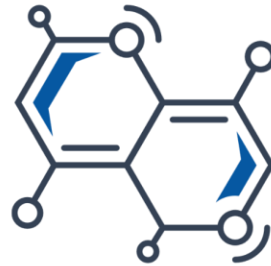
What is Siltride?

- ▶ The Siltride coating process deposits a chemically protective barrier of hydrogenated amorphous silicon oxynitride that is excellent for improved corrosion, dielectric, and durability performance.



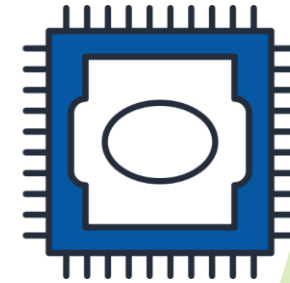
Life Sciences

Optimize the surface properties of critical parts to improve performance and achieve desired results.



Energy and Chemical Processing

Increase process uptime and reduce costs by preventing corrosion, fouling, and frequent maintenance.



Semiconductor Manufacturing

Reduce maintenance costs and environmental footprint with a highly corrosion resistant barrier.

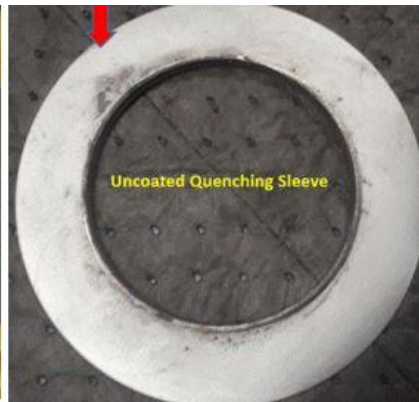
Game-changing surface improvements

- ▶ Siltride was developed in order to propel surface performance in harsh corrosion and high-temperature environments, expanding on silicon-based chemistry to overcome known weaknesses of existing coatings.
- ▶ Siltride allows customer to improve their surface performance in the following categories:
 - ▶ Corrosion resistance
 - ▶ Electrical resistance
 - ▶ Hydrophilicity
 - ▶ High-temperature protections
 - ▶ Durability and wear resistance
 - ▶ Expanded substrate compatibility

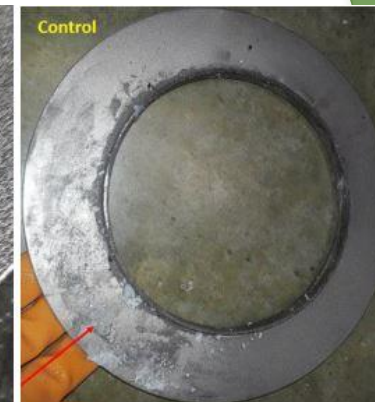
Real World Applications

- ▶ Samsung determined that the high cost of corrosion of the components in their scrubbers, particularly quenching sleeves and gas distribution rings in the combustion column, was becoming a limiting factor in their production efficiency. Instead of stopping production to constantly replace these parts, Samsung came to SilcoTek for a coating that would slow the corrosion, increase efficiency, and maintain the integrity of the wafers being processed.
- ▶ The silicon nitride composition creates an excellent barrier against the highly corrosive environment of a scrubber system.
- ▶ See the following images of the control part (uncoated metal) and the Siltride coated metal part over the course of a 70 day testing cycle.

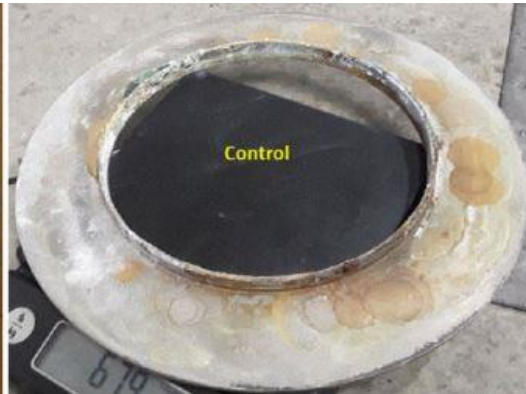
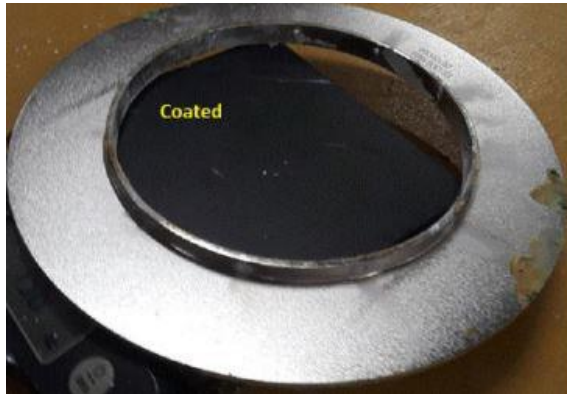




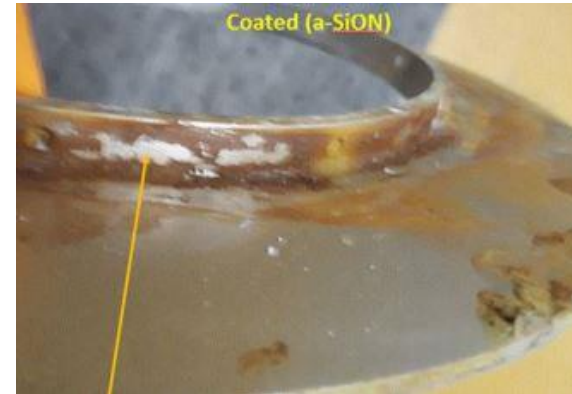
14 days



28 days



42 days



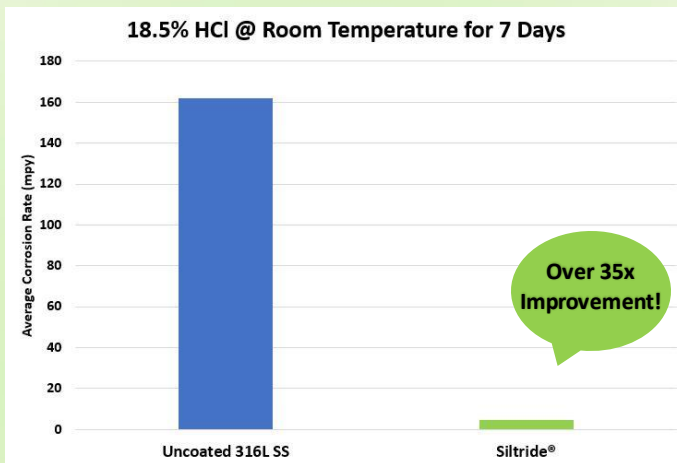
70 days

"The joint evaluation with SilcoTek is a good example of a productive collaboration. SilcoTek a-SiON (Siltride) coating performed better than 300% for uncoated, control parts, as our results show in the paper. This improvement significantly reduces the environmental footprint of semiconductor manufacturing."

-Cesar Garza, Staff Engineer at Samsung Austin Semiconductor

Corrosion Resistance

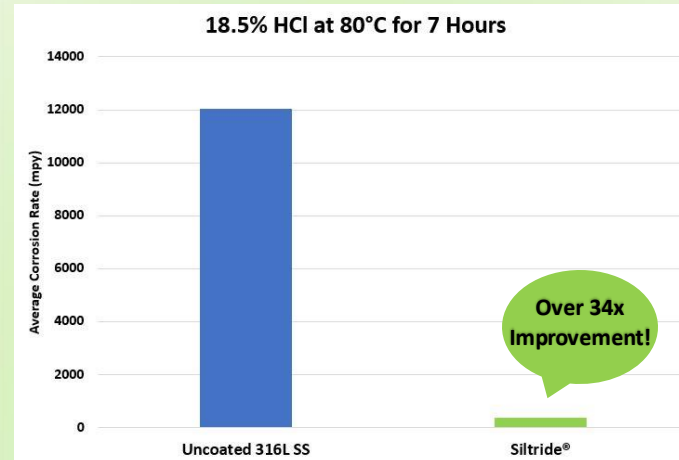
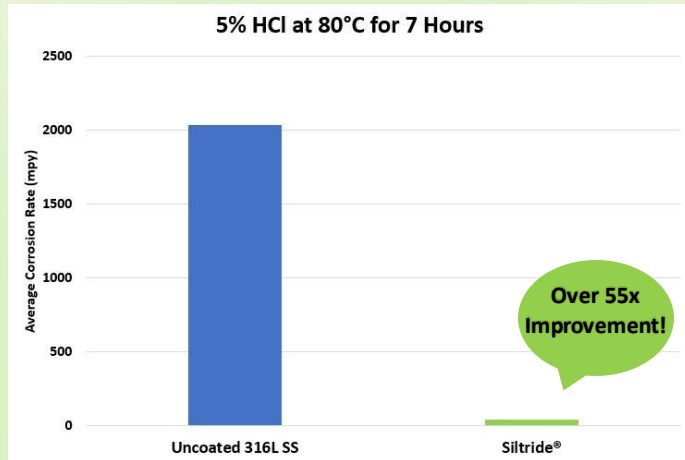
Hydrochloric Acid



- ▶ Coupons were immersed in 18.5% HCl for 7 days at room temp. (ASTM G31). This trial shows an aggressive environment testing the limits of Siltride. In these conditions, Siltride performed well with minimal corrosion while considerably outperforming uncoated 316L SS.

Corrosion Resistance

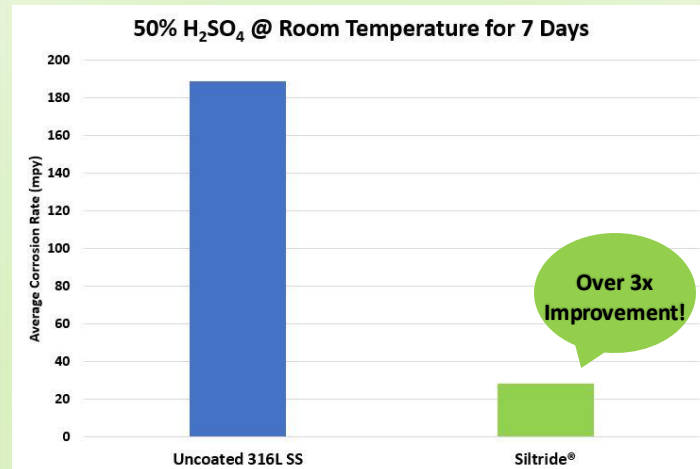
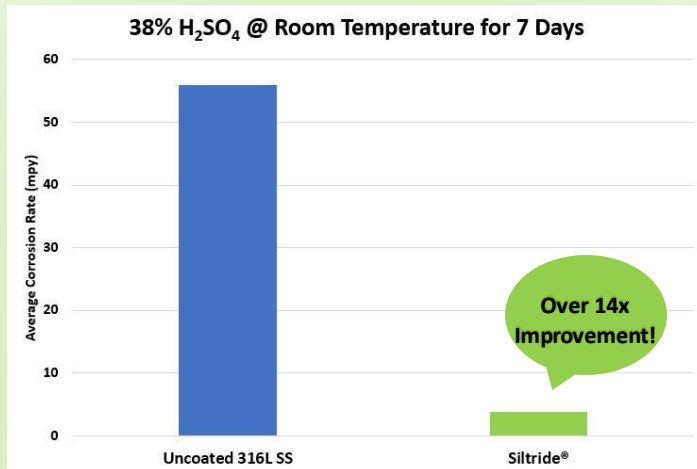
Hydrochloric Acid @ 80°C for 7 Hours



- Coupons were immersed in 5% and 18.5% HCl at an elevated temp. of 80°C for 7 hours. This aggressive test shows a major improvement over the uncoated SS, with Siltride allowing only minor pitting and corrosion.

Corrosion Resistance

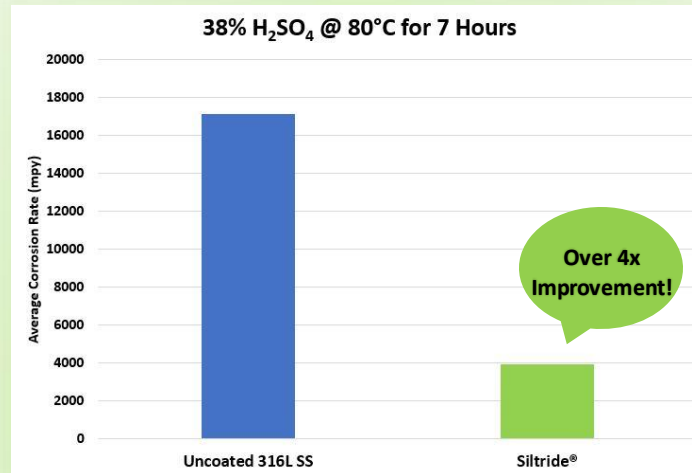
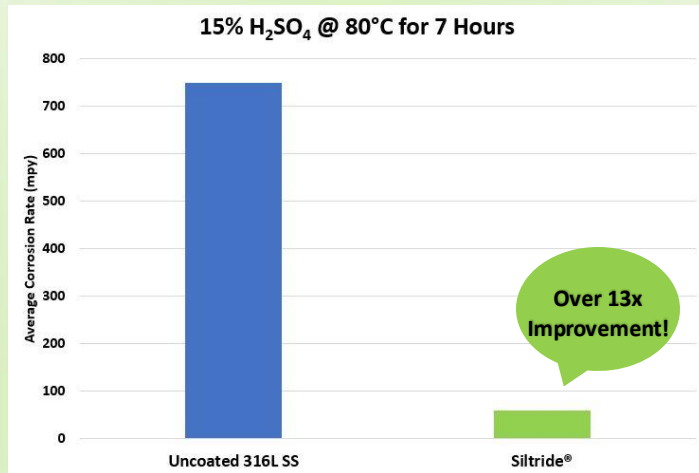
Sulfuric Acid @ Room Temperature for 7 Days



- ▶ Coupons were immersed in 38% and 50% H₂SO₄ at room temp. for 7 days. The SS coupons are nearly unrecognizable, while Siltride maintains much of the integrity of the coating, protecting the substrate underneath.

Corrosion Resistance

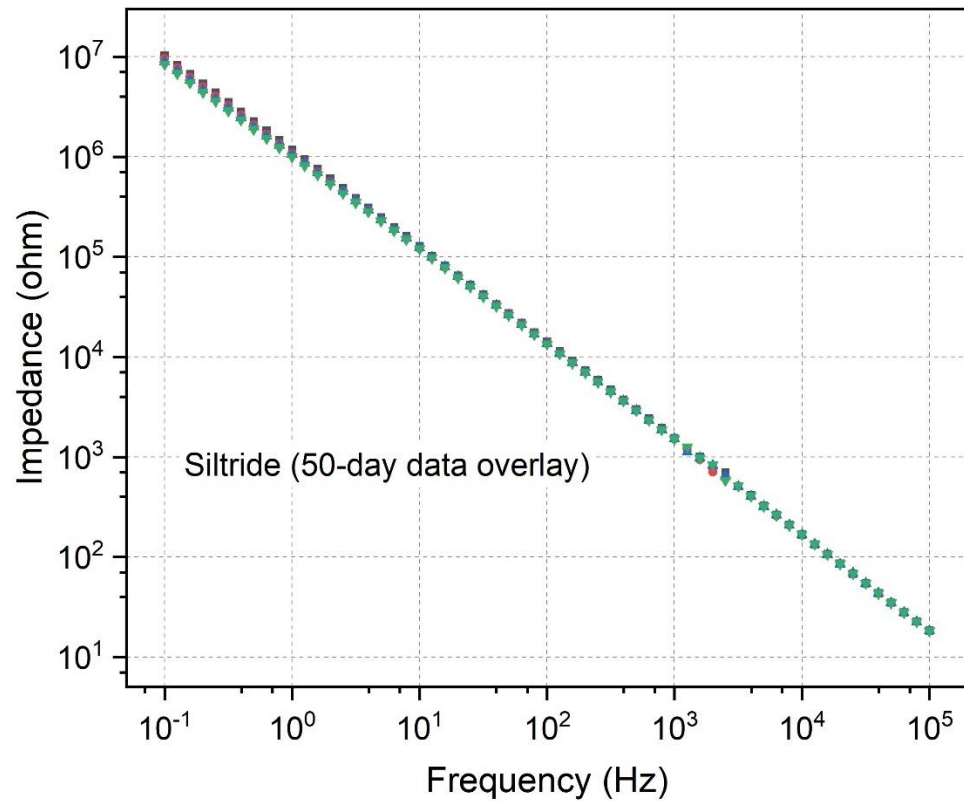
Sulfuric Acid @ 80°C for 7 Hours



- Coupons were immersed in 15% and 38% H₂SO₄ at an elevated temp. of 80°C for 7 hours. In one of the most corrosive testing environments, Siltride still significantly outperforms the uncoated SS.

Corrosion Resistance

EIS in 5% NaCl



- ▶ Coupons were exposed to 5% NaCl solution at room temp. for 50 days and monitored by Electrical Impedance Spectroscopy (EIS)(ASTM G106).
- ▶ Siltride shows a high impedance value at low frequencies, maintaining excellent stability and protection in the salt solution over time.

Electrical Resistance

Comparing SilcoTek Coatings

- ▶ Improved electrical resistivity will help to insulate substrates, further preventing corrosion and creating an excellent dielectric barrier.
- ▶ Siltride and Dursan both have good dielectric breakdown strengths.
- ▶ Siltride has the highest electrical resistivity and lowest dielectric loss (i.e. leakage) of any SilcoTek coating.

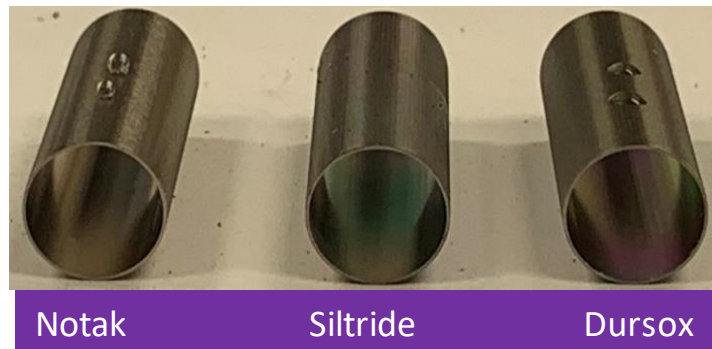
	Bulk resistivity ($\Omega\cdot\text{cm}$)	Relative permittivity (error)	Dielectric loss $\tan \delta$ (error)	Breakdown field 1 (MV/cm)	Breakdown field 2 (MV/cm)	Weibull Modulus
Silcolloy	10^8	18.9 (2.3)	0.4 (0.04)	0.09 – 0.1	0.15 -0.2	4.3
Dursan	10^{12}	6.9 (1.2)	0.6 (0.6)	N.A.	5.9 – 9.6	4.6
Siltride	10^{13}	8.3 (0.6)	0.04 (0.05)	4.2	6.6 – 7.7	14.6



Water Contact Angle

Siltride is Hydrophilic

- ▶ Siltride 1000 is hydrophilic with a water contact angle of $<40^\circ$.
- ▶ Siltride can also be customized to create a hydrophobic surface as customers' applications require, referred to as Siltride 1010.
 - ▶ The water contact angle of Siltride 1000 is closer to $10^\circ - 20^\circ$ but will gradually rise over time in an open air environment.
 - ▶ Hydrophilic surfaces have high surface energies and will easily attract particles and VOC molecules from the environment, making it less hydrophilic as particles accumulate.
 - ▶ To restore Siltride 1000 hydrophilicity, parts can be baked for a few hours (around 400°C) or dipped in a 5% NaOH solution for 5 minutes.



High Temperature Stable

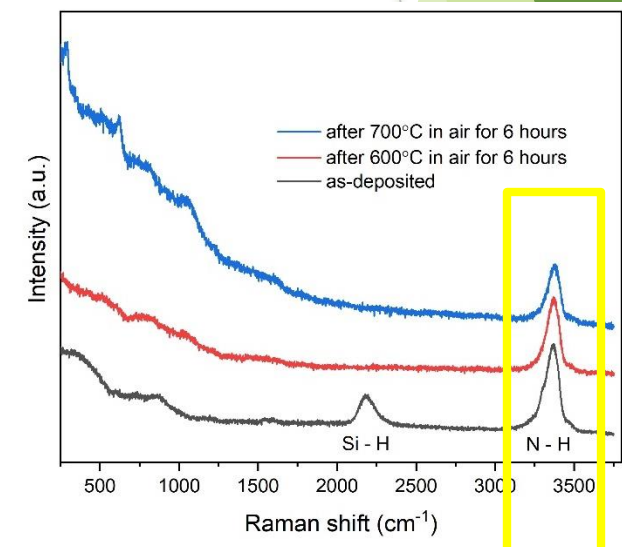
- ▶ Siltride protects substrates from oxidation at temperatures up to 700°C.
 - ▶ EDS analysis performed after uncoated and Siltride coupons were exposed in air to 700°C for 6 hours.
 - ▶ Results show the uncoated SS turned blue due to metal oxide formation and measured ~8 % by weight oxygen
 - ▶ Siltride coating was stripped from the metal to perform EDS to reveal a shiny metallic surface and measure under the EDS detectable limit (0.1%).
- ▶ Raman shows Siltride remains amorphous after 700°C thermal exposure.
 - ▶ Even after 7 hours in 700°C, hydrogen from the N-H bonds remain proving a strong oxidation resistance.



Uncoated 700°C
Oxygen ~8%



Siltride 700°C
Oxygen < 0.1%

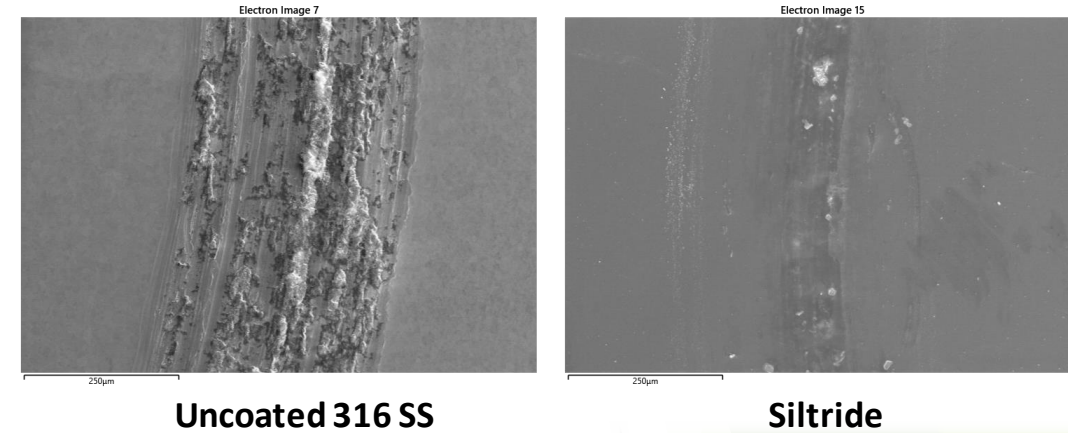


Durability & Wear Resistance

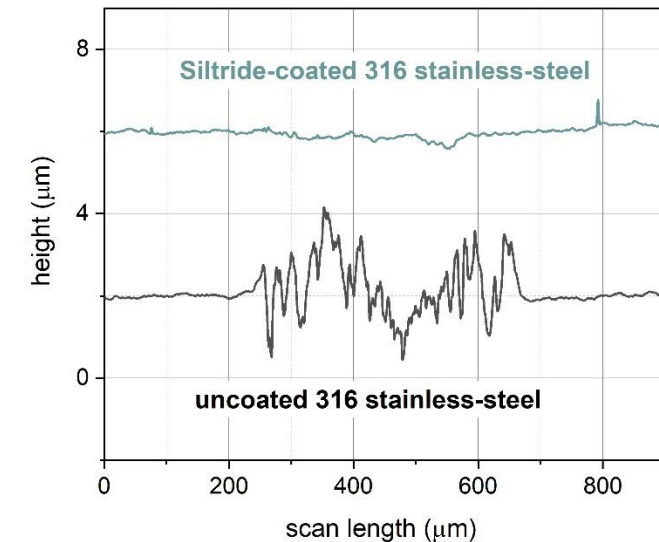
- Wear track SEM images (both taken at 500x) of uncoated SS and Siltride after pin-on-disk (1N and 15 minutes) test (top right) and wear track cross sectional profiles (bottom right) show Siltride is a more wear resistant surface than the uncoated SS.

	Pin-on-disk (1N and 15 minutes)	
Surface	Bare 316 SS	Siltride
Wear track cross section (μm^2)	113.132	44.411
Wear rate x 10^{-5} (mm^3/Nm)	9.428	3.701
Hardness (Gpa)	4-6	10

Wear track SEM images (500x)



Cross sectional profiles



Substrate Compatibility

- ▶ Siltride is compatible with a variety of substrates. The full list can be found on our website.
 - ▶ The most common substrates Siltride is applied to include: stainless steel, Inconel, Hastelloy, aluminum, glass, and carbon steel.
- ▶ SilcoTek has expanded the substrate compatibility for Siltride to include Monel (or nickel 400 alloy in general).

Common Questions & Answers

- ▶ What does Siltride look like?
 - ▶ Siltride coatings have a rainbow finish with green, yellow, and purple colors depending on the thickness of the coating deposited. Coating becomes less colorful and more matte as coating thickness increases.
- ▶ What is the lead time for Siltride?
 - ▶ The current lead time for Siltride is 15 days or fewer. Orders can be expedited in accordance with SilcoTek's Expedite Program.
- ▶ How should a part treated with Siltride be cleaned?
 - ▶ Mild sonication with solvent for 2-3 minutes, or longer as needed. Avoid abrasion as much as possible.
- ▶ How can I tell if Siltride has been damaged or removed?
 - ▶ Color deterioration and loss of hydrophilicity (surface should be more hydrophilic than SS) indicated coating may need to be reapplied.

Questions?

- ▶ Contact SilcoTek via the following:
 - ▶ Online at www.SilcoTek.com
 - ▶ Via email at TechService@SilcoTek.com
 - ▶ Via telephone at +1 (814) 353-1778

