SBIR: Polymer Based Starshade Contamination Control
Novel First Contact Polymers and Procedures

James P. Hamilton, PhD
Wisconsin Distinguished Professor
Founder
Photonic Cleaning Technologies, LLC
Xolve, Inc.

Department of Chemistry, University of Wisconsin-Platteville
Director, UW System Nanotechnology Center for Collaborative R&D, NCCRD
Mechanical & Plastics Engineering, Darmstadt University of Applied Sciences, Germany

LIGO-Nobel Prize Physics Oct 2017

Laser Gravity Wave Interferometer
Protecting and Cleaning Precision Surfaces

Outline of Presentation:

• Background: For Orientation
• Show (quickly) Examples in Use - Success
• We have the data: Mirrors, CCD’s, Laser Optics, Space Surfaces
• SBIR Phase II Results so Far (1.25 Qtr’s)
• Conclusions and Future Work
First Contact Polymer End Game: Routinely Maintain Mirrors at Max Reflectivity, Extend Coating & Optic Lifetime, Eliminate Scatter, & make Zero Defect Coatings.

Keck, Gemini, CFHT – Hawaii
Chile - ESO
LAMOST- China
LIGO - Caltech/MIT
DES CAM – Fermilab/LBNL
CDMS – Stanford/Fermilab
GTC– Canary Islands
NASA GSFC
NASA JPL

NASA-JPL Starshade
LIGO-USA
JWST Mirror
Typical Methods of Cleaning Precision Surfaces like Optics

Cotton applicator Drag Wipe

Blowing Clean

Alcohol/Acetone Drag Wipe

CO₂ Snow Cleaning

Historical Methods of Cleaning Optics. Welcome to the future.
Our top 20 photonics stories of 2016—LIGO leads the list

- Photonics guides remotely piloted aircraft  PAGE 23
- Galvo scanners support ultrafast laser micromachining  PAGE 41
A No Residue Strip Coating
Protect & Clean

1/20\textsuperscript{th} the adhesion of Scotch Tape on Aluminum - SAFE

First Contact vs Scotch Tape (810) Peel from Borofloat Glass First Surface Aluminum Mirror
“THE Protection and Cleaning Solution”

“Cleaning and Protecting Precision Surfaces in Manufacturing, Assembly, Shipping, Coating and Storage”

Value Propositions:
1. Asset is ready when it is needed.
3. Clean in situ – No Realignment
4. Cleanroom clean without the Cleanroom.
5. Clean the Uncleanable-Easily: Sensors, CCD’s, FPA’s, Gratings
6. Eliminate Diffraction Rings from Dust: Laser Patterning, Holography
7. Zero Defect Coatings: Cleaning before coating
8. No Residue, Vacuum compatible
9. Simple, Green, Easy, Reproducible

• Easy to use – No special training needed.
  No mixing. Doesn’t tear.
  No thinning. Safe in Coating Chambers.
  No Residue Removes Fingerprints.
Contamination Control & Surface Protection

Problem I: Reduced Performance

Some surfaces are “uncleanable”.

Nanoparticles & Residue very hard to remove.


Problem II: Destruction

Cleaning before coating.

Enabling Zero Defect Coatings.

Laser Induced Damage: Optics & Optical Coatings
Contamination Control & Surface Protection

Problem III: Uncleanable

Sensors & Focal Plane Arrays

Zero Dust Tolerance - Literally.

Problem IV: Zero Dust Tolerance

Cleanroom Clean without the cleanroom.
A massive sandstorm blowing off the northwest African desert has blanketed the area with a thick layer of sand, similar to the Sahara Dust that travels across the Atlantic Ocean. The sandstorm is estimated to have covered thousands of square miles of the desert, with the thick layer of sand extending up to several thousand feet. The sandstorm is expected to have a significant impact on the region, potentially causing disruptions to local ecosystems and human activities.
Volcanic Dust on Keck

Sahara Dust on GTC

Backlit Keck Mirror
Acid Cleaning before washing.

8.2m Mirror driven for cleaning & recoating: Atacama desert in Chile.

Pour or Spray

Spread

Peel
**First Contact Polymer Trials - Gran Canarias Telescopia: 2/2/16**

<table>
<thead>
<tr>
<th>Color</th>
<th>λ nm</th>
<th>Before</th>
<th>After</th>
<th>Orig. %</th>
<th>% Gain</th>
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<tr>
<td>Blue</td>
<td>470</td>
<td>81</td>
<td>90</td>
<td>92</td>
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<td>Near IR</td>
<td>880</td>
<td>77</td>
<td>87</td>
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<td>10</td>
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**Total Integrated Scattering, 670 nm**

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<th>Before</th>
<th>After</th>
<th>Improv.</th>
<th>Original</th>
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<td>7.63</td>
<td>0.88</td>
<td>6.75</td>
<td>0.2†</td>
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</table>

This mirror had light dust, water marks, some pinholes, insects marks, bugs & some microscratches.

Primary Mirror Segment Installed 3/27/2015, removed January 2016

What this data proves, is that regular maintenance of mirror surfaces with First Contact Polymer can maintain reflectivity indefinitely and prevent damage.

Cleaning aluminum coating on dirty, 3 year old mirror segment.

**First Contact Polymer Trials - Gran Canarias Telescopia: 2/2/16**

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<td>470</td>
<td>72</td>
<td>88</td>
<td>91</td>
<td>16</td>
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<td>Green</td>
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<tr>
<td>Near IR</td>
<td>880</td>
<td>67</td>
<td>85</td>
<td>87</td>
<td>19</td>
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<th>Improv.</th>
<th>Original</th>
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<tbody>
<tr>
<td></td>
<td>10.29*</td>
<td>2.38</td>
<td>7.92</td>
<td>0.2†</td>
</tr>
</tbody>
</table>

This mirror had thick Saharan dust, water marks, pinholes, insects marks, bugs & microscratches from CO₂ cleaning due to dust.

Primary Mirror Segment Installed 3/27/2012, removed January 2016

*essentially offscale reading on TIS instrument. †Regular cleaning over the years resulted in roughness causing 0.1 TIS moving to 0.2 baseline.

Using First Contact Polymer on a regular basis can avoid such degradation.

Flashlight through 3 year old Al Mirror Coating on Keck Primary Mirror Segment.
The End Game for Massive Telescopes:
Routinely Maintain Mirrors at Maximum Reflectivity
Dramatically (Indefinitely?) Extend Coating Lifetimes
W.M. Keck Telescope Segments with First Contact Polymer

Photo Credit: James Hamilton

Photo Credit: Steve Doyle
Vandenberg AFB Western Range Depot Optics Group

Removing the Protective Polymer Coating

Worth Repeating: This Environmentally-Friendly process leaves no hazardous waste!

- Repeated applications can be used to remove difficult contamination.
- Polymer solution dissolves itself to remove any fragments.
- Multiple applications will create a strong, thick polymer film.
  Protect the optical surface indefinitely from salt fog, particulate contamination, fingerprints, and incidental contact.
Before

During

After

First Contact Polymer

"No touch, One step, Cleaning process"

Actual Customer Photos - Takahashi Coated CaF₂ Lense
Cleaning the Uncleanable.

Nomarski Microscopy Images, PCT
How to determine Optical Surface Cleanliness

Metrology: Mechanical, Optical, Electron
- Mass of Residue
- Differential Interference (DIC) Microscopy
- Scanning Electron Microscopy (SEM), Surfscan (KLA)
- Total Incident Scattering, Laser Induced Damage Testing
- Electron Spectroscopy (XPS, ESCA, Auger)
- Atomic Force Microscopy (AFM)
- Spectroscopy
- Polymer Properties

Our Surface Research:
A progression geared towards demonstrating atomic level cleanliness.
Signals in synchrony

When shifted by 0.007 seconds, the signal from LIGO’s observatory in Washington (red) neatly matches the signal from the one in Louisiana (blue).

- LIGO Hanford data (shifted)
- LIGO Livingston data

First Contact Polymer

LIGO PRL Feb 2016
Advantages of cleaning optics with Red First Contact

Garilynn Billingsley, Margot Phelps

Distribution of this document:
LIGO Scientific Collaboration

This is an internal working note of the LIGO Laboratory.

California Institute of Technology
LIGO Project – MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW22-295
185 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu
"Bidirectional Reflectance Distribution Function."

BRDF = Reflectance of a target as a function of illumination geometry and viewing geometry.

“Not only did cleaning with First Contact leave no residue, it also removed nearly all the residue left by the methanol. -LIGO Internal Report T1000137-v3
Apply. Peel. Repeat as/if needed.

“A highlight of the BRDF tests shows that repeated applications of FC only improves optical surfaces”

-LIGO Laboratory, California Institute of Technology, 1200 E. California Blvd., Pasadena, CA
Atomically Clean after: Before and after XPS Spectra on Glass

In fact, First Contact™ polymers actually removed previously existing carbon contamination present on the Si & glass surfaces.

Integrated peak area: 4 monolayers removed.

Prep for vacuum. Remove water, organics.

Only First Contact™ didn’t leave residue…
High Power Laser Damage Threshold (LIDT) – 355nm

Clean, New Laser Optic

Polymer Cleaned

No Change in LIDT = No residue = No Damage
Cleaning & Protecting is a Balance of Adhesion and Release
Calibration, Precision & Accuracy

![Graph showing adhesion values for different tapes](image)

- **Blue Scotch**
- **Green Scotch**
- **Red Scotch**
- **Ultra 1110**
- **Ultra 1153**

![Graph showing peel force vs. peeled length](image)
Before Phase II SBIR

![Graph 1: First Contact vs Scotch Tape (810) Peel from Borofloat Glass First Surface Aluminum Mirror](image1)

![Graph 2: Adhesion Graph](image2)
Compliance with Planetary Protection requirements is mandatory for NASA missions per NASA Policy Directive (NPD) 8020.7G: Biological Contamination Control for Outbound and Inbound Planetary Spacecraft.

Spores, Bacteria, RNA, DNA, Prions?

Mars Viking Lander: Heat Sterilization 1976
SEM Images of E. Coli and Substrates

E. coli rods in Luria Broth

E. coli pooling in a drop of Luria Broth
First Contact Removes *E. coli* from Brass Surface

<table>
<thead>
<tr>
<th>First Contact Formulation</th>
<th>Growth</th>
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<tbody>
<tr>
<td></td>
<td>Aluminum</td>
</tr>
<tr>
<td>None</td>
<td>+</td>
</tr>
<tr>
<td>L Class</td>
<td>+</td>
</tr>
<tr>
<td>R Class</td>
<td>+</td>
</tr>
</tbody>
</table>
Siliconizing Glass Improves First Contact: DNA Binding on Glass

- Siliconized Glass does not degrade DNA (Lane 13)
- All polymers adhere to DNA on siliconized glass (Lanes 2, 6, 10)
- Additional formulations may remove DNA from untreated glass (to be tested)
- PCR controls confirm no contamination (Lanes 16, 17)
**Cumulative DNA Removal: First Contact on Brass**

<table>
<thead>
<tr>
<th>Rounds of Removal</th>
<th>1x</th>
<th>1x</th>
<th>2x</th>
<th>1x</th>
<th>2x</th>
<th>1x</th>
<th>2x</th>
<th>1x</th>
<th>2x</th>
<th>PCR Controls</th>
</tr>
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<tbody>
<tr>
<td>DNA</td>
<td>-</td>
<td>10 ng</td>
<td>50 ng</td>
<td>100 ng</td>
<td>500 ng</td>
<td>+</td>
<td>-</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

- Polymer removes DNA completely from untreated Brass (Lanes 2-5, 7)
- Additional rounds of polymer treatment remove additional DNA (Lanes 6/7, 8/9)
The End Game for Massive Telescopes:
Routinely Maintain Mirrors at Maximum Reflectivity
Dramatically (Indefinitely?) Extend Coating Lifetimes
Protecting and Cleaning Precision Surfaces

Summary

- Cleanroom Clean without a Cleanroom
- Assets will be Mission Ready: Just Peel
- UHV & Space Compatible
- Extend life of Coatings and Laser Optics
- Create Zero Defect High Power Laser Optics (R&D)
- Critical Surfaces Protected & Clean after peel.
- Decontaminate Critical Surfaces
- Clean the Uncleanable
- Reduce Downtime

hamiltonj@photoniccleaning.com
Dark Energy Survey Camera

3 sq. deg. Field of View
Each image will contain:
  ~ 20 Galaxy clusters
  ~ 200,000 Galaxies
Each night ~ 300 GB
Entire survey ~ 1 PB

520 Mpixel!!

Total DOE cost $24M
Plan first light Oct. 2010

El Blanco
Chile

DES Focal Plane

62 2kx4k Image CCDs
82kx2k focus, alignment CCDs
4 2kx2k guide CCDs
The Dark Energy Survey Camera: DECam

3 sq. deg. Field of View
Each image contains:
  ~ 20 Galaxy clusters
  ~ 200,000 Galaxies
Each night ~ 300 GB
Entire survey ~ 1 PB
El Blanco - Chile

520 Mpixel!!

62 2kx4k Image CCDs
4 2kx2k guide CCDs
82kx2k focus, alignment CCDs

Static Sensitive!!!
Average of Impedance between 100-300 MHz for SWNT doped films. These films were used to protect and clean Dark Matter sensors and astronomical CCD detectors on DESCAM built at Fermilab on the following slides.

Quantum Efficiency
DES Backlit CCD
Before and after using First Contact polymer.

Relative QE for pb-22-01, After Cleaning

Quantum Efficiency
DES Backlit CCD
Before and after using First Contact polymer.

520 Mpixel!!
Dark Energy Survey Camera
This was a BRAND NEW CCD fabbed at LBL and sent directly to the Fermilab Cleanroom.

“Surface cleaning of CCD imagers using a electrostatic dissipative nanotube doped formulation of First Contact”
G. Derylo, J. Estrada, B. Flaugher, J. Hamilton, D. Kubik, K. Kuk, V. Sparpine,)
doi:10.1117/12.789654