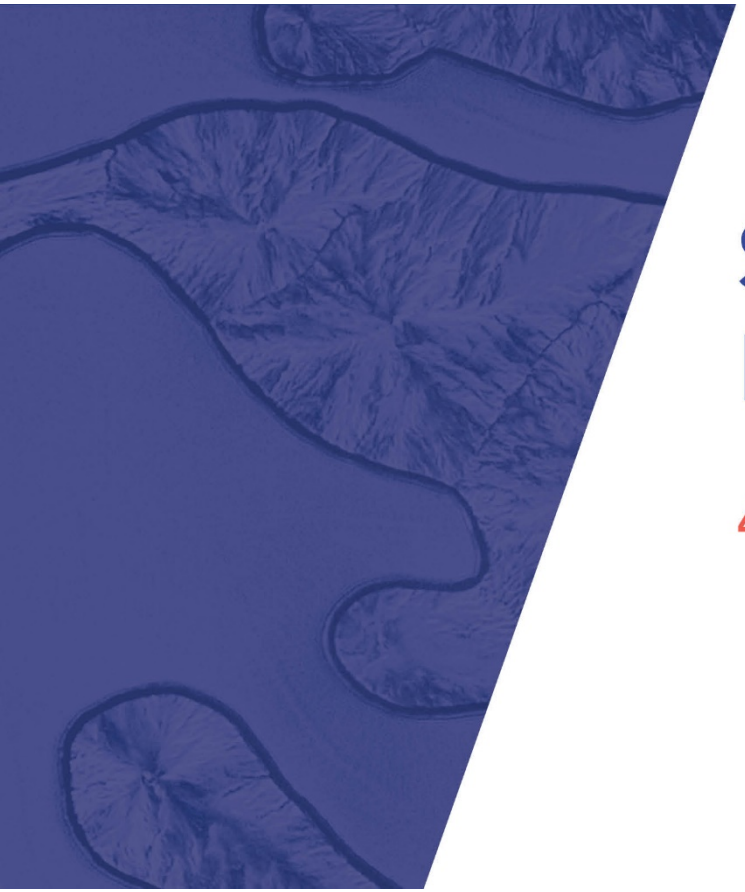

SURFACE COATINGS THAT INHIBIT INFECTION BY SARS-COV-2

4 May 2021 • 8:30 EDT (UTC -4:00)

OSA Thin Films Technical Group

OSA Technical Groups

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About the Color Technical Group

Our technical group focuses on all aspects related to the Optical thin films from fundamentals to applications

Our mission are:

- Connect the 1000+ members of our community through technical events, webinars, networking events, and social media.
- Bridge the fundamentals, the know-hows and the new developments
- Promote networking and career development through continuous learning

Our past activities have included:

- Metasurfaces: new generation building blocks for emerging optics
- Nanoscale Multilayers for EUV and X-Ray Applications
- Interface and Defect-induced Scattering in Optical Coatings

Connect with our Thin Film Technical Group

Join our online community to stay up to date on our group's activities
Please let us know if you're interested in presenting your research
You may share your ideas for technical group events

Ways to connect with us:

- OSA Technical Group Website: www.osa.org/ThinFilmsTG
- LinkedIn: www.linkedin.com/groups/4783616
- OSA – Optical Interference Coatings Conference (OIC 2022)

https://www.osa.org/en-us/meetings/topical_meetings/optical_interference_coatings/

Attendees of OIC 2019, New Mexico, USA

Scheduled 19-24 June 2022, Whistler, Canada

Today's Speaker

Dr. William Ducker

- Professor of Chemical Engineering at Virginia Tech.
- Follow of Chemical Engineering
- Ph.D. in Surface Chemistry from the Australian National University
- Research area is in the area of colloid and surface chemistry

Surface Coatings that Rapidly Inactivate SARS-CoV-2

William Ducker

Saeed Behzadinasab, Mohsen Hosseini

Dept. of Chemical Engineering and Center for Soft Matter and Biological Physics, Virginia Tech

Alex Chin and Leo Poon

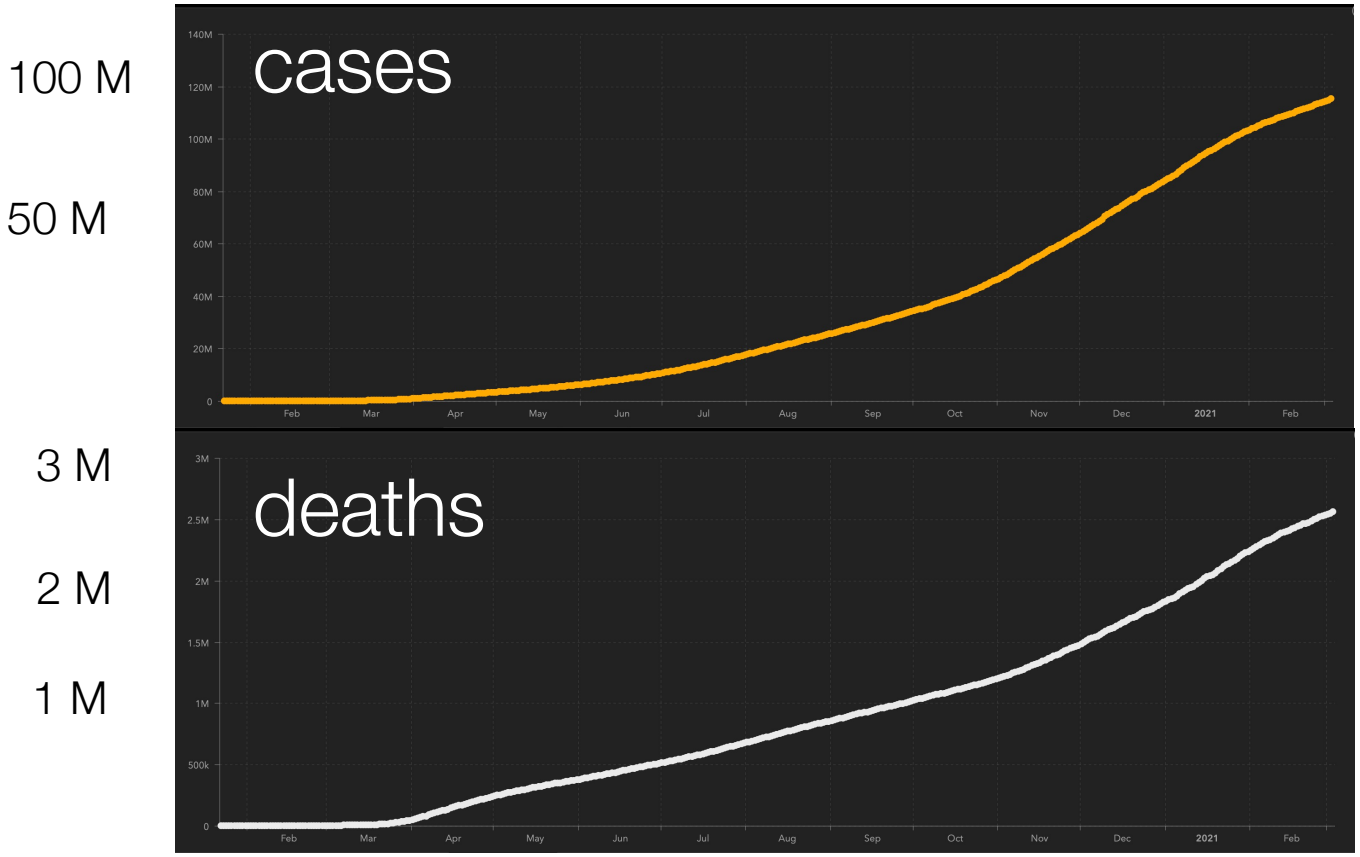
School of Public Health, LKS Faculty of Medicine, The University of Hong Kong, Hong Kong Special Administrative Region, China.

SARS-CoV-2 tests




COVID-19

- ~ 110 million people infected worldwide (WHO)
- ~ 2.5 million deaths worldwide (WHO)

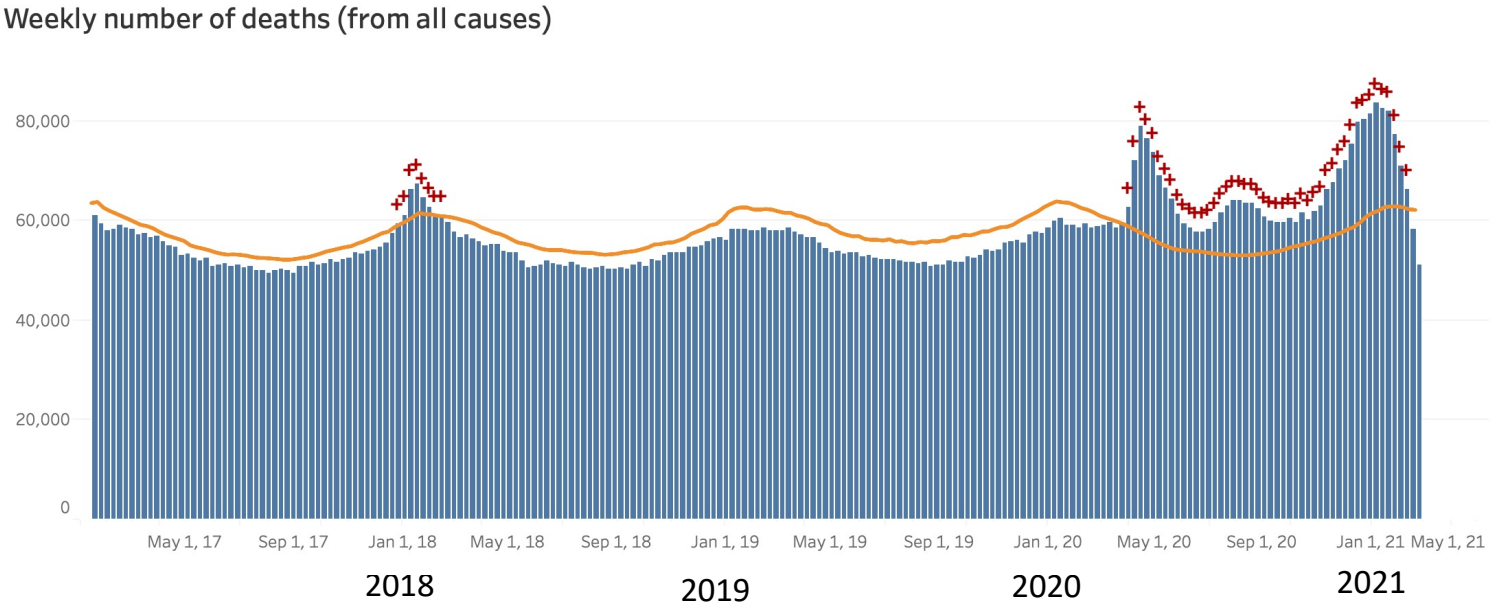


https://coronavirus.jhu.edu/map.html

USA

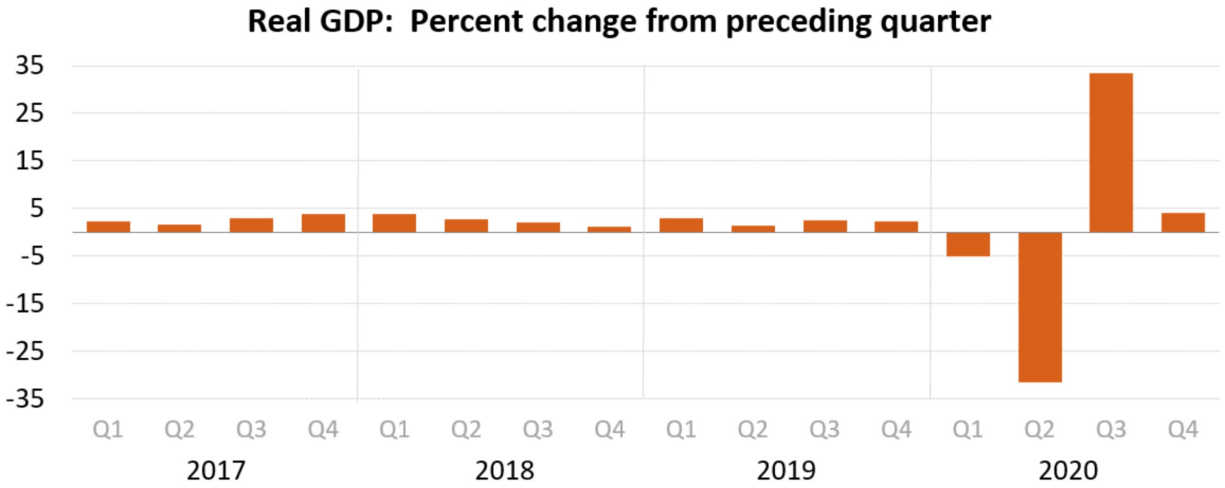
Weekly Excess Deaths, CDC

https://www.cdc.gov/nchs/nvss/vsrr/



GDP

https://www.bea.gov/data/gdp/gross-dor



Alien Invasion

Nuclear War

Climate Change World War

…

Covid-19

…

Prof. Ducker I need three more points on Q4

Alien Invasion

Nuclear War

Climate Change World War

…

Covid-19 } What can I do to help?

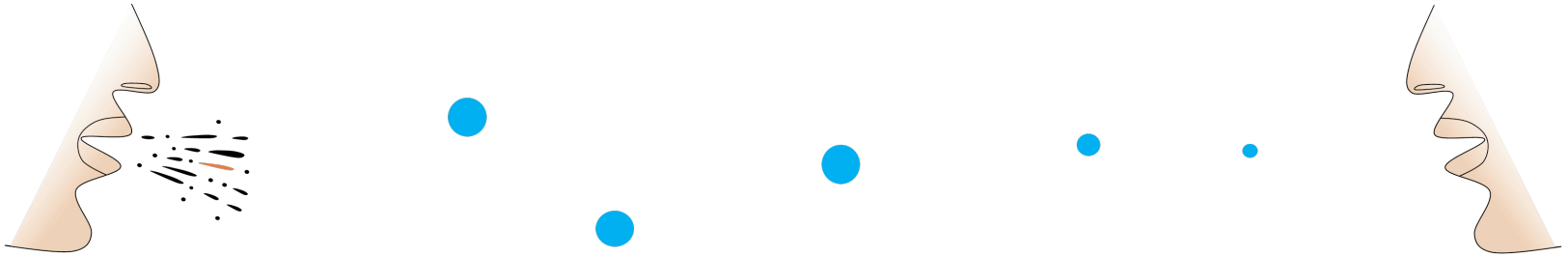
…

Prof. Ducker I need three more points on Q4

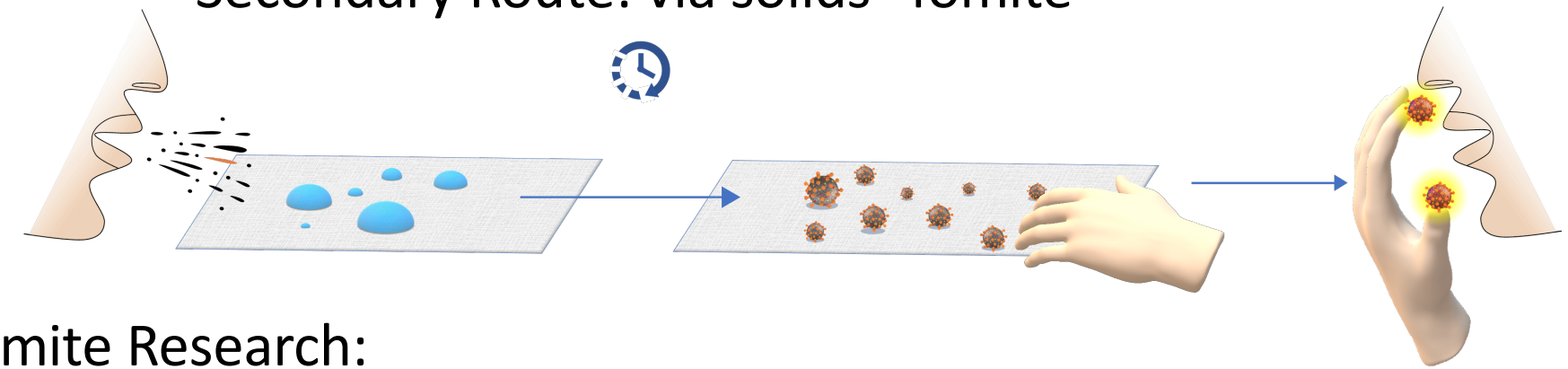
Infection Routes

Subject of Current Research

Main Route: via respiratory droplets or aerosols



Secondary Route: via solids “fomite”



Fomite Research:

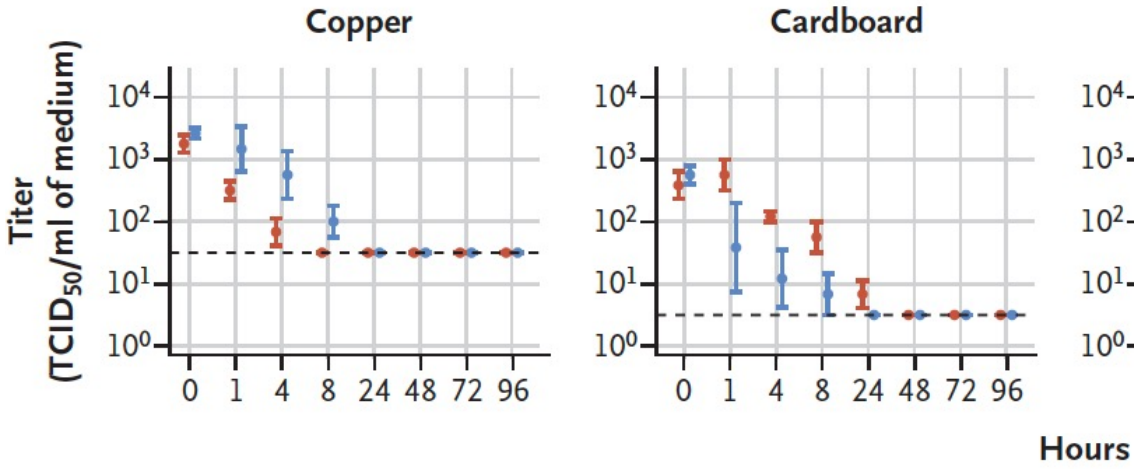
Hamster studies: Transfer via Fomites, Sia,. *Nature* **2020,**

Epidemiology: 25% via fomites, Meiksin, A. *Epidemiol. Infect.* **2020**

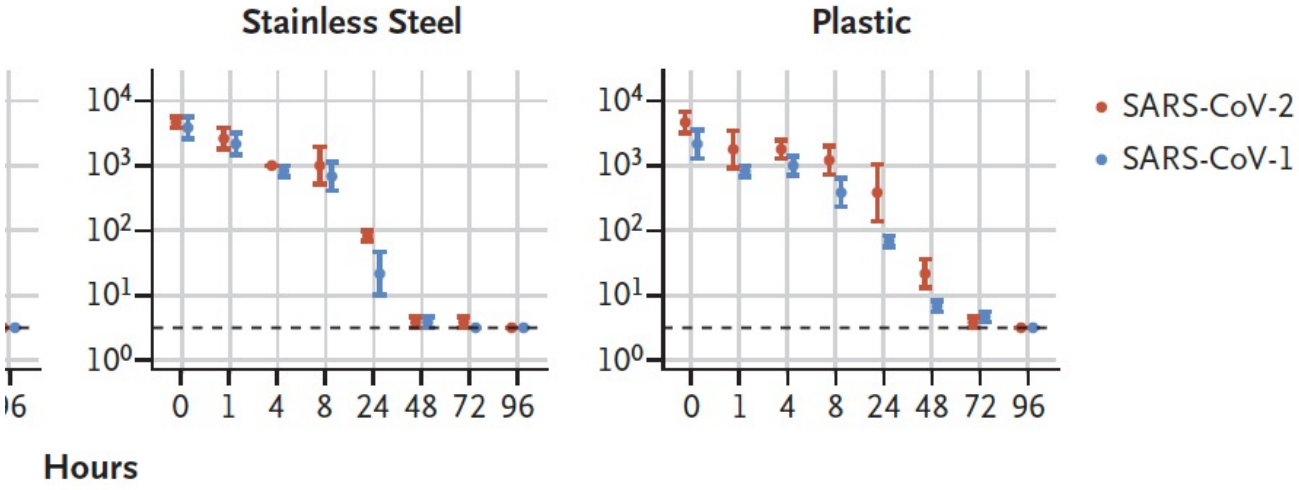
“People who come into contact with potentially infectious surfaces often also have close contact with the infectious person, making the distinction between respiratory droplet and fomite transmission difficult to discern.” WHO

Viability on a Solid

1.Van Doremalen *et al*., N Engl. J. Med., 2020 382, 1564



Higher numbers = Better at infecting cells



1.Chin *et al*., Lancet Microbe., 2020, 1, e10

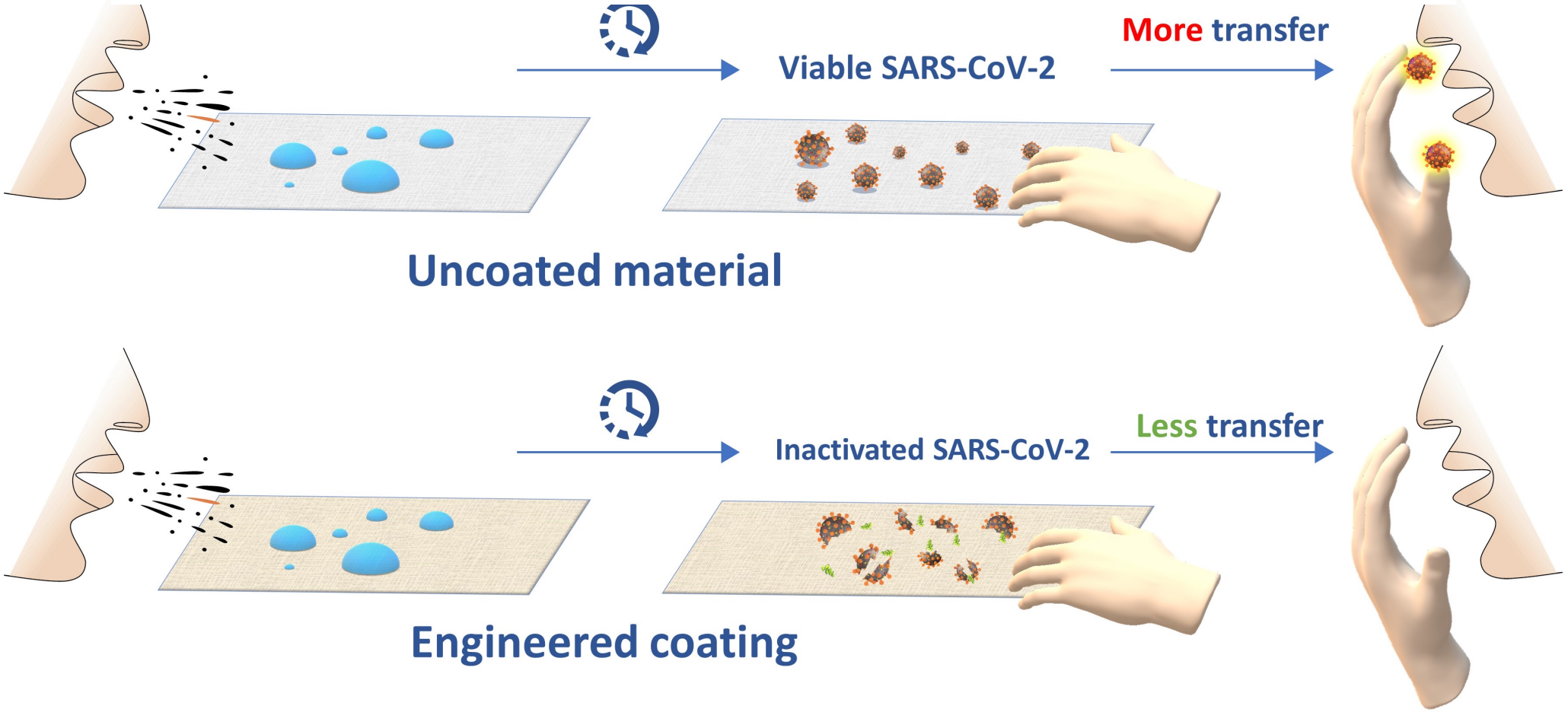
B) Surfaces*

Time	Virus titre (Log $TCID_{50}$/ml)									
	Paper		Tissue paper		Wood		Cloth		Glass	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
0 min	4.76	0.10	5.48	0.10	5.66	0.39	4.84	0.17	5.83	0.04
30 mins	2.18	0.05	2.19	0.17	3.84	0.39	2.84	0.24	5.81	0.27
3 hrs	U	-	U	-	3.41	0.26	2.21#	-	5.14	0.05
6 hrs	U	-	U	-	2.47	0.23	2.25	0.08	5.06	0.31
1 day	U	-	U	-	2.07#	-	2.07#	-	3.48	0.37
2 days	U	-	U	-	U	-	U	-	2.44	0.19
4 days	U	-	U	-	U	-	U	-	U	-
7 days	U	-	U	-	U	-	U	-	U	-

Time	Banknote		Stainless steel		Plastic		Mask, inner layer		Mask, outer layer	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
0 min	6.05	0.34	5.80	0.02	5.81	0.03	5.88	0.69	5.78	0.10
30 mins	5.83	0.29	5.23	0.05	5.83	0.04	5.84	0.18	5.75	0.08
3 hrs	4.77	0.07	5.09	0.04	5.33	0.22	5.24	0.08	5.11	0.29
6 hrs	4.04	0.29	5.24	0.08	4.68	0.10	5.01	0.50	4.97	0.51
1 day	3.29	0.60	4.85	0.20	3.89	0.33	4.21	0.08	4.73	0.05
2 days	2.47	0.23	4.44	0.20	2.76	0.10	3.16	0.07	4.20	0.07
4 days	U	-	3.26	0.10	2.27	0.09	2.47	0.28	3.71	0.50
7 days	U	-	U	-	U	-	U	-	2.79	0.46

SARS-CoV-2 viable on solids for up to one week

Research Concept



Ducker Group Research

Hypothesis

A coating can be used to speed the inactivation of SARS-CoV-2 on solids

Application

If such a coating were applied to communal objects, then this might reduce the spread of COVID-19 and other infectious diseases

Desired features of a coating

- Inactivate the novel coronavirus quickly – minutes
- Ongoing or continuous “kill”

- Applicable to everyday objects regardless of material

- High durability

- Easy to Apply

Coating Parameters

- Active material
- Support structure
- Morphology

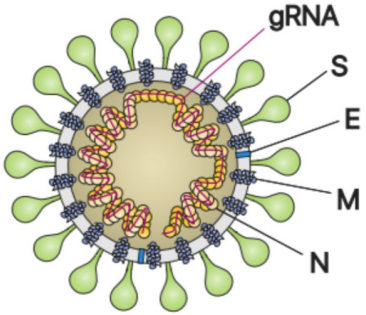
Active Material

Approaches

- Deliberate design
- Consider what works

Design

- Virus assembles spontaneously
- Change solution conditions such as assembly is no longer stable (e.g., ethanol, soap)
- Knock out a necessary function

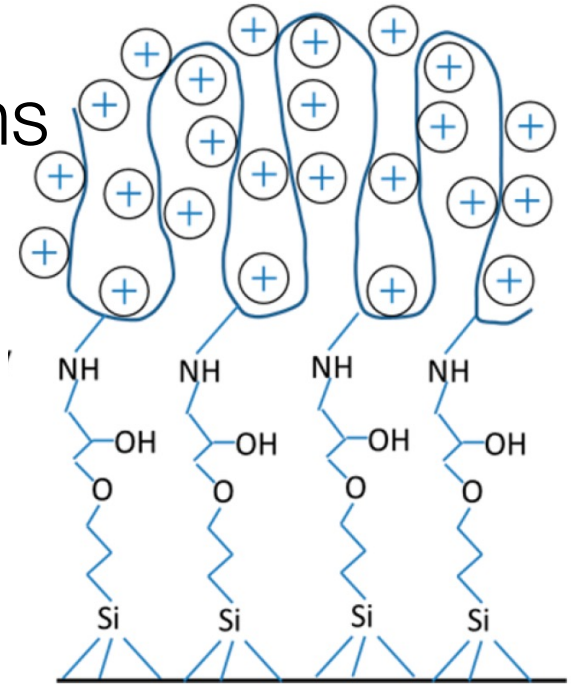


Kim et al., 2020, Cell 181, 914–921

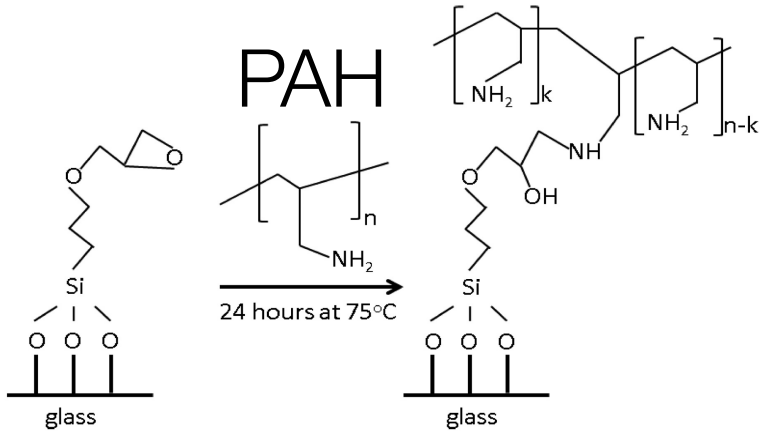
Changing the Environment

Polymer

- Highly Charged
  - Changes electrostatic interactions
- Dangles out into solution
  - Maximum contact with virus
- Tether to a solid



GOPS



This coating very effective at killing bacterial

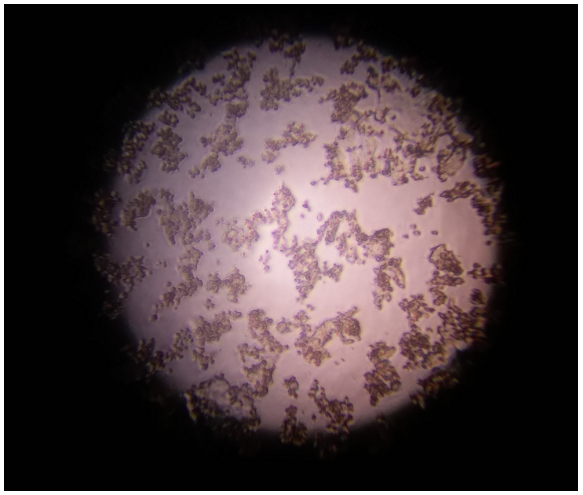
Test of Viral Activity

Use Vero E6 cells (Green Monkey kidney cells) as a proxy for human cells

Healthy Vero E6 cells

Microscope image Showing complete layer of healthy cells

Cytopathic effect (CPE)



incomplete layer of curled-up or detached cells

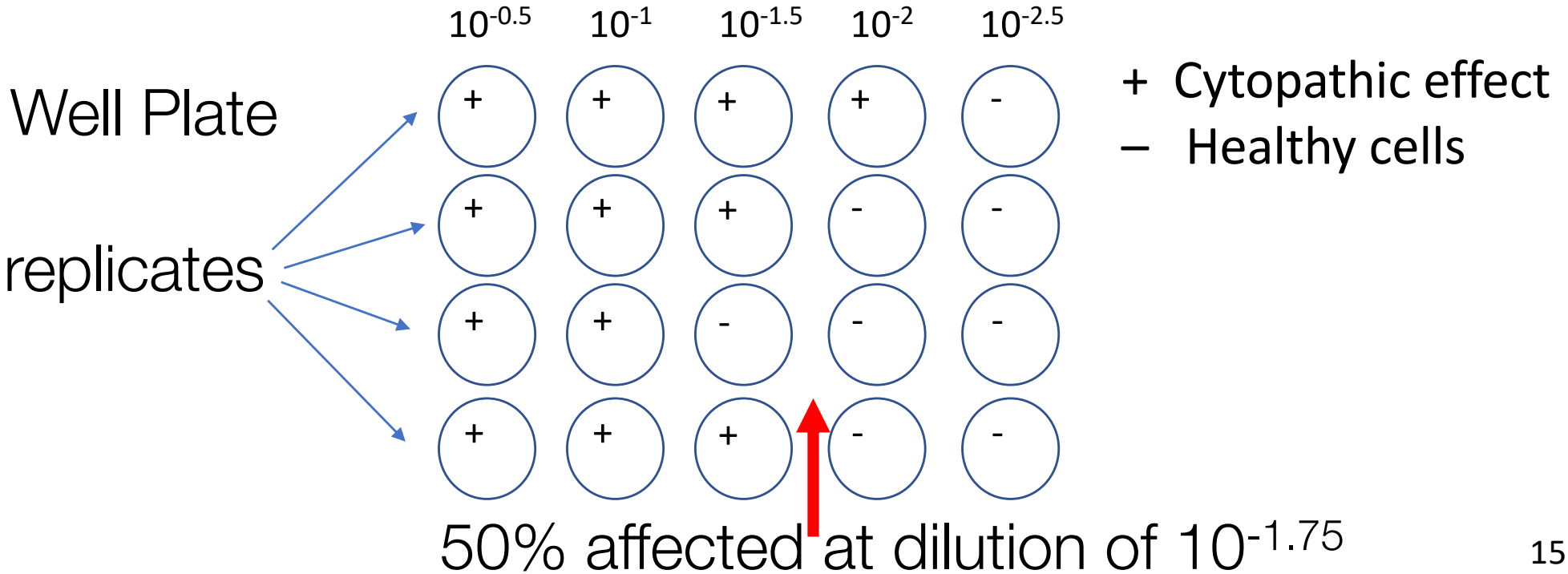
VIRGINIA TECH

$TCID_{50}$

It's the dilution necessary to see an effect

1. Grow Vero E6 cells in each of many wells in a well plate
2. Make series of dilutions of the virus after recovered from solid
3. Expose cells to virus

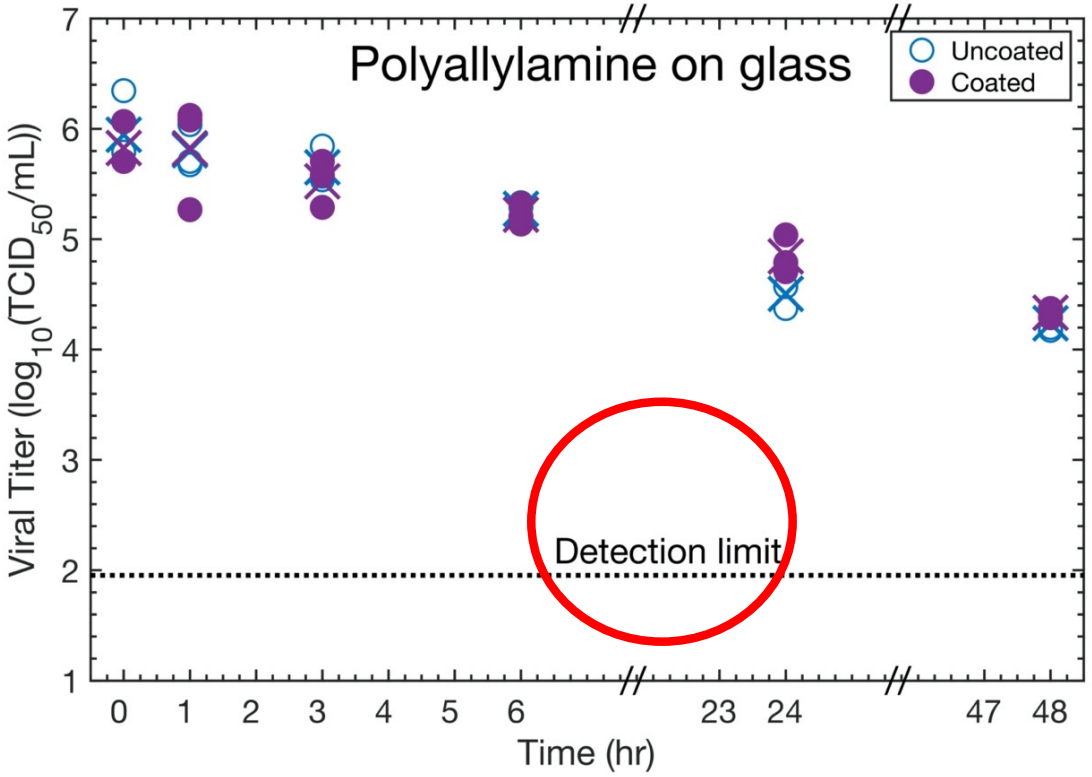
Dilution of virus after on test solid



Results: Polyallylamine Films

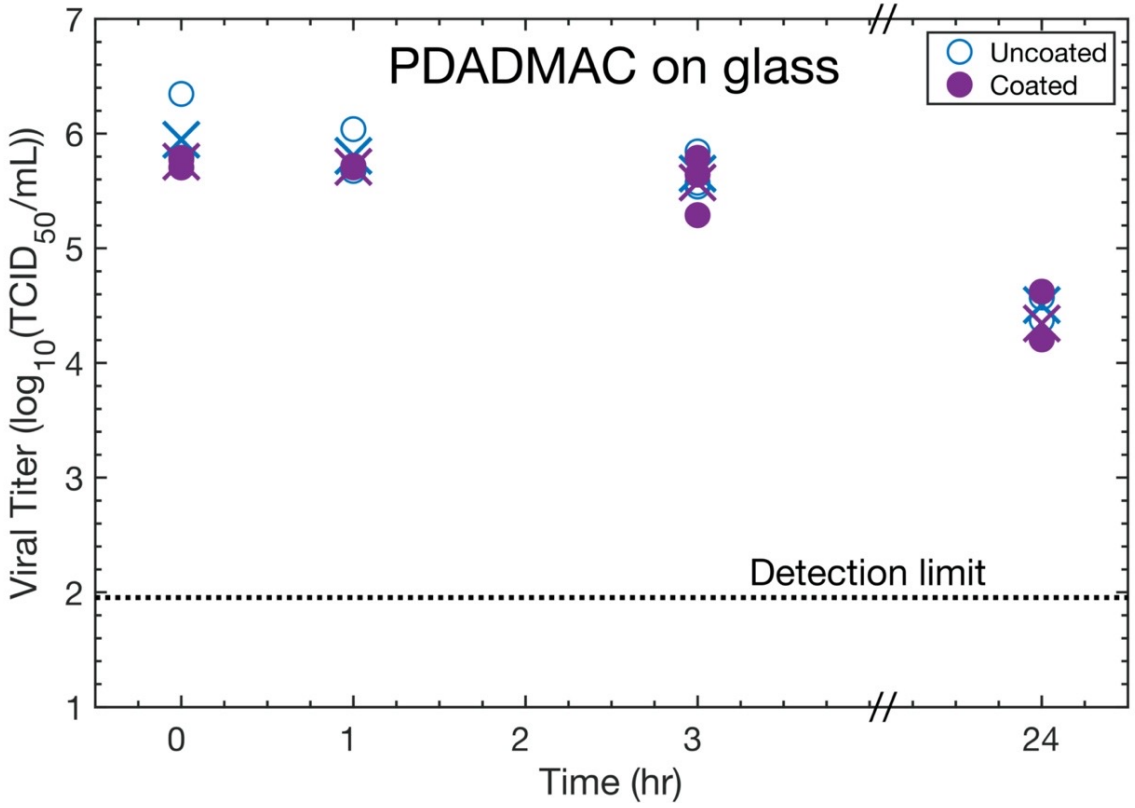
Big dilution before virus
No longer kills cells
BAD

Big dilution before virus
No longer kills cells
GOOD



Little effect on SARS-CoV-2 from the tethered cationic polymer PAA.

Results: PDADMAC Films

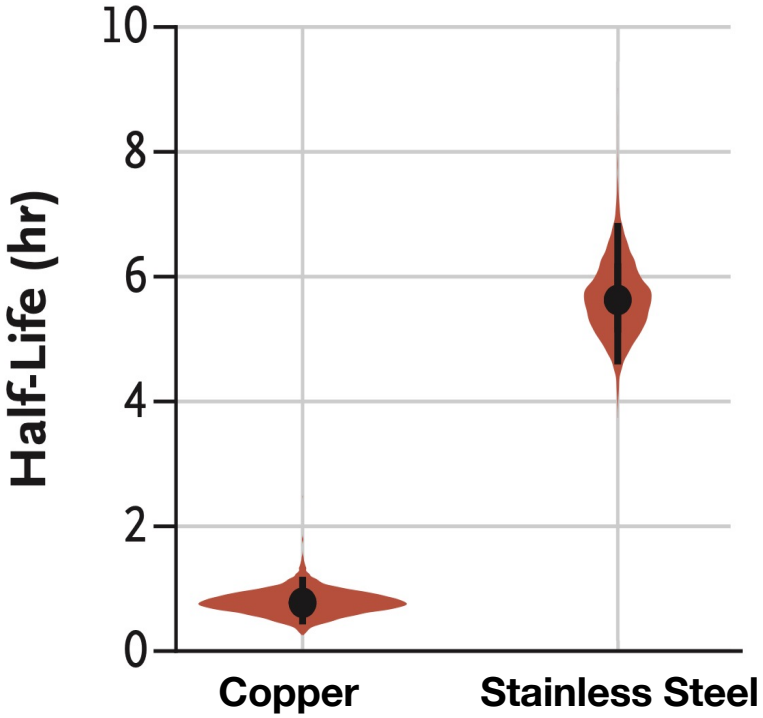


Little effect on SARS-CoV-2 from the cationic polymer PDADMAC.

Active Material

Approaches

- Deliberate design – failed so far
- Consider what works



Van Doremalen *et al.*, N Engl. J. Med., 2020 382, 1564

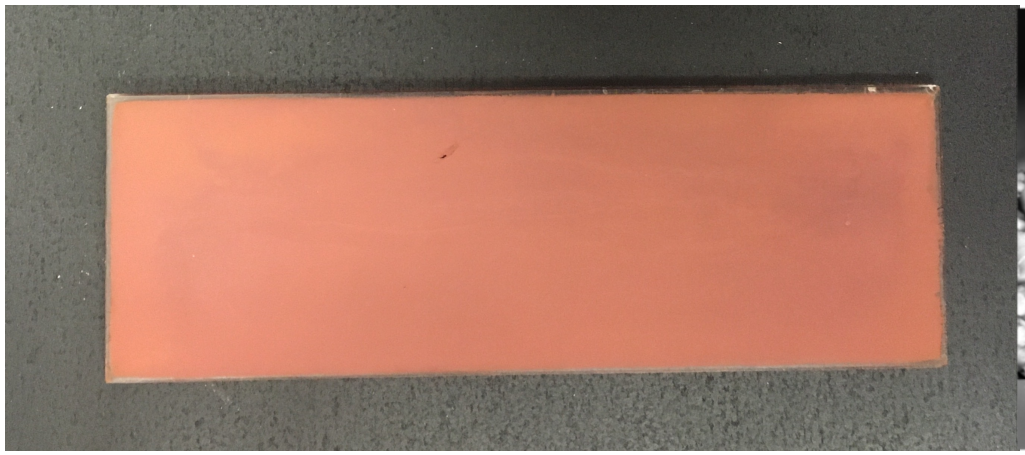
- Surface of Copper is Cu_2O
- Suspension of Cu_2O particles inactivate bacteriophage virus[2]

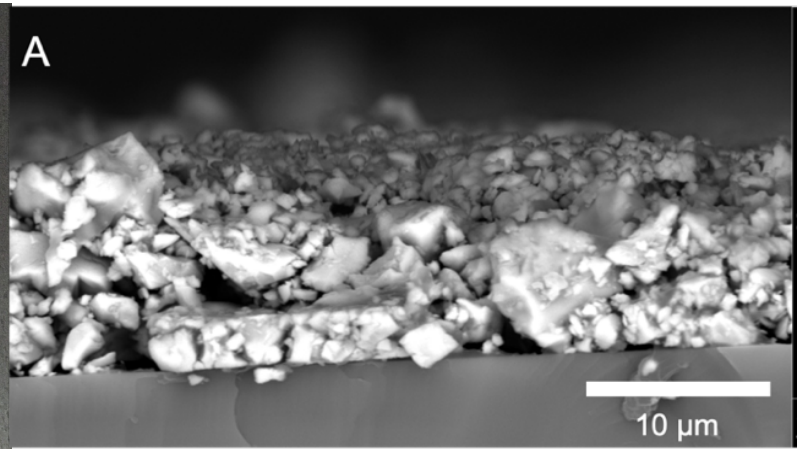
Sunada *et al.,* J. Hazard. Mat., 2012, 235, 265

- Try a surface bound layer of Cu_2O.

Methods

1. Apply a thin film of polyurethane (PU) using sponge
2. Allow for partial curing of PU
3. Cover the film with Cu_2O suspension
4. Thermally anneal the film at 120 C
5. Thoroughly wash the film
6. Ar plasma treat the surface



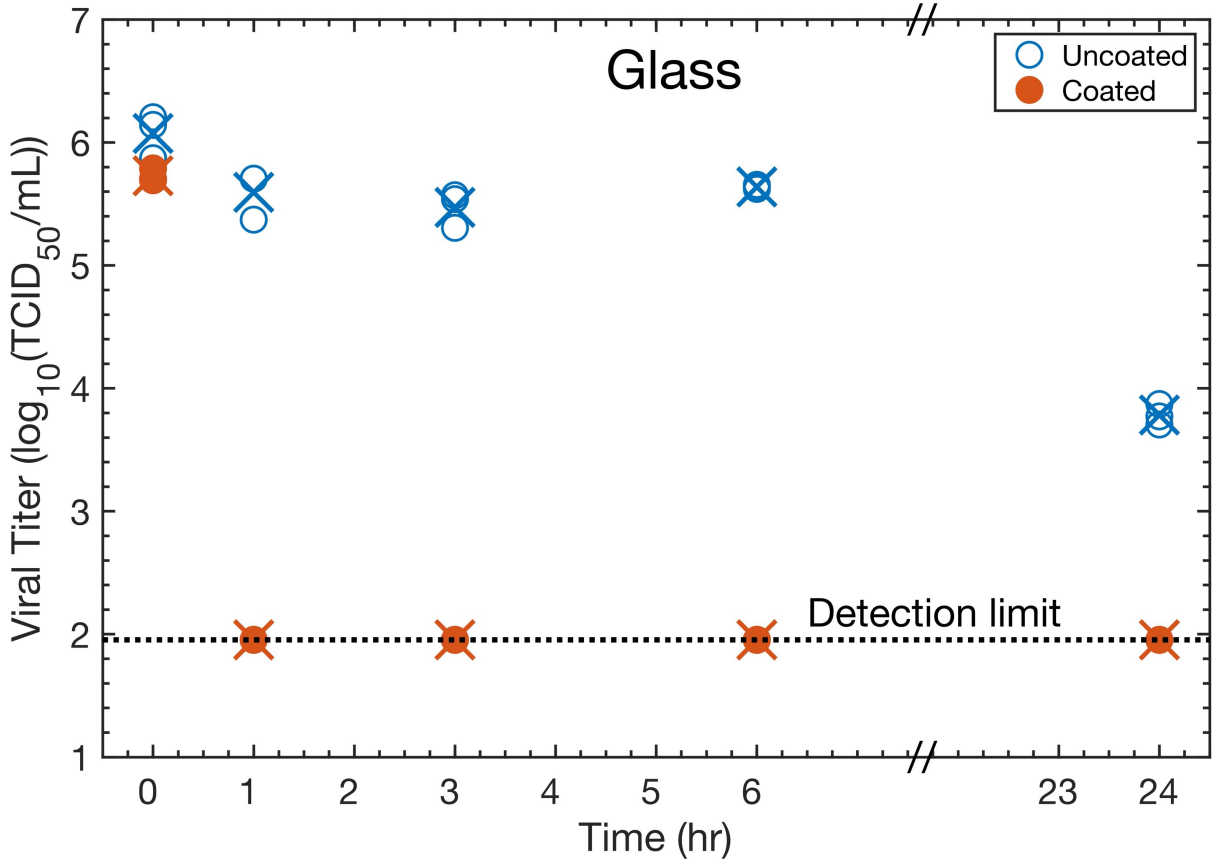


Brown, red, maroon, burgundy

Cu_2O Results on Glass

lots of active virus →

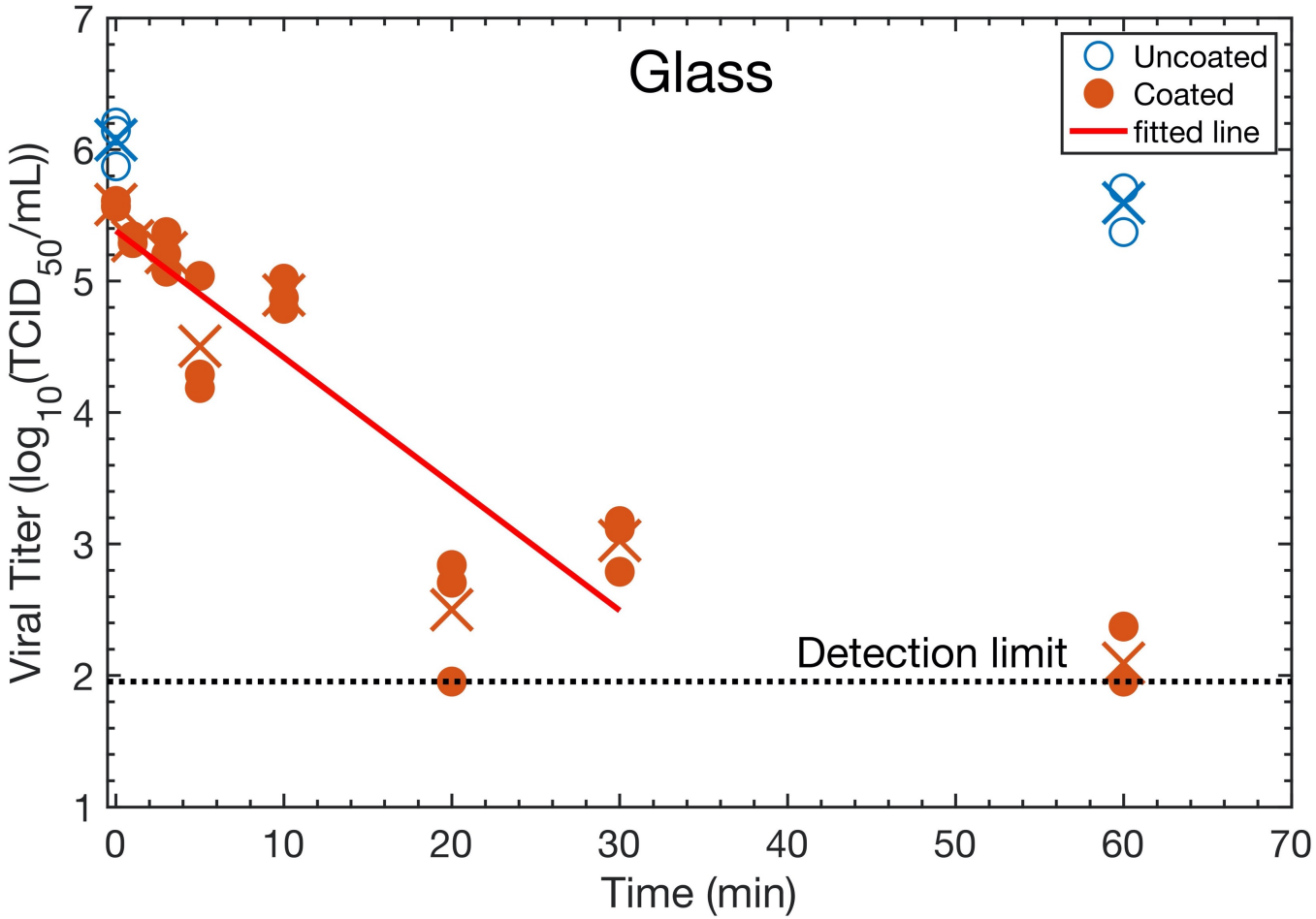
not much active virus →



- Viral reduction: >99.98% (=3.64 log, $p=5x10^{-4}$, $CI_{95\%}$=[99.95,100]) in 1 h
- Dramatic change in the SARS-CoV-2 viability in 1 hour

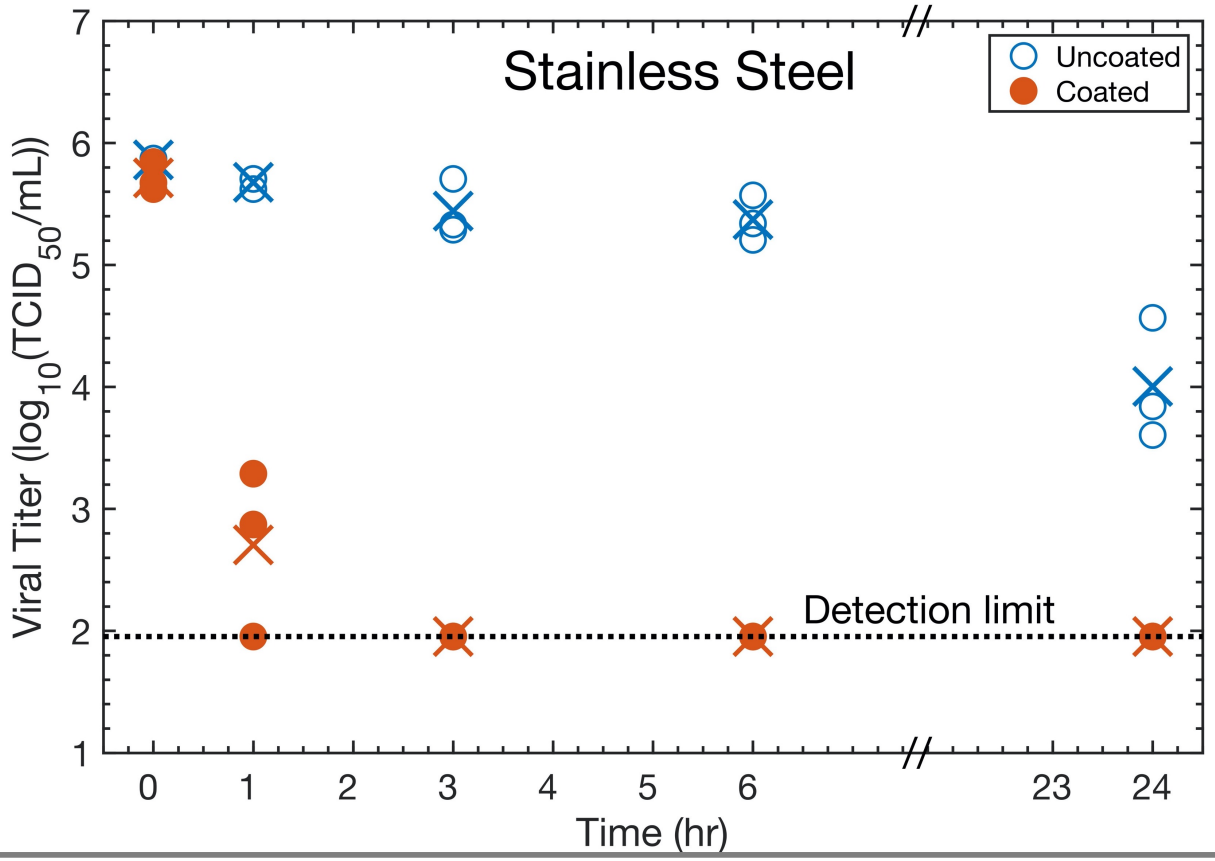
$$\log \text{reduction} = \text{mean}\left[\log_{10}\left(\frac{\text{control titer}}{\text{sample titer}}\right)\right]$$

Cu_2O on Glass: Short-term Results



- Half life = $\frac{\log(2)}{|\text{slope}|}$ = 3.5 min, 95% C.I. = [2.5, 4.2] min

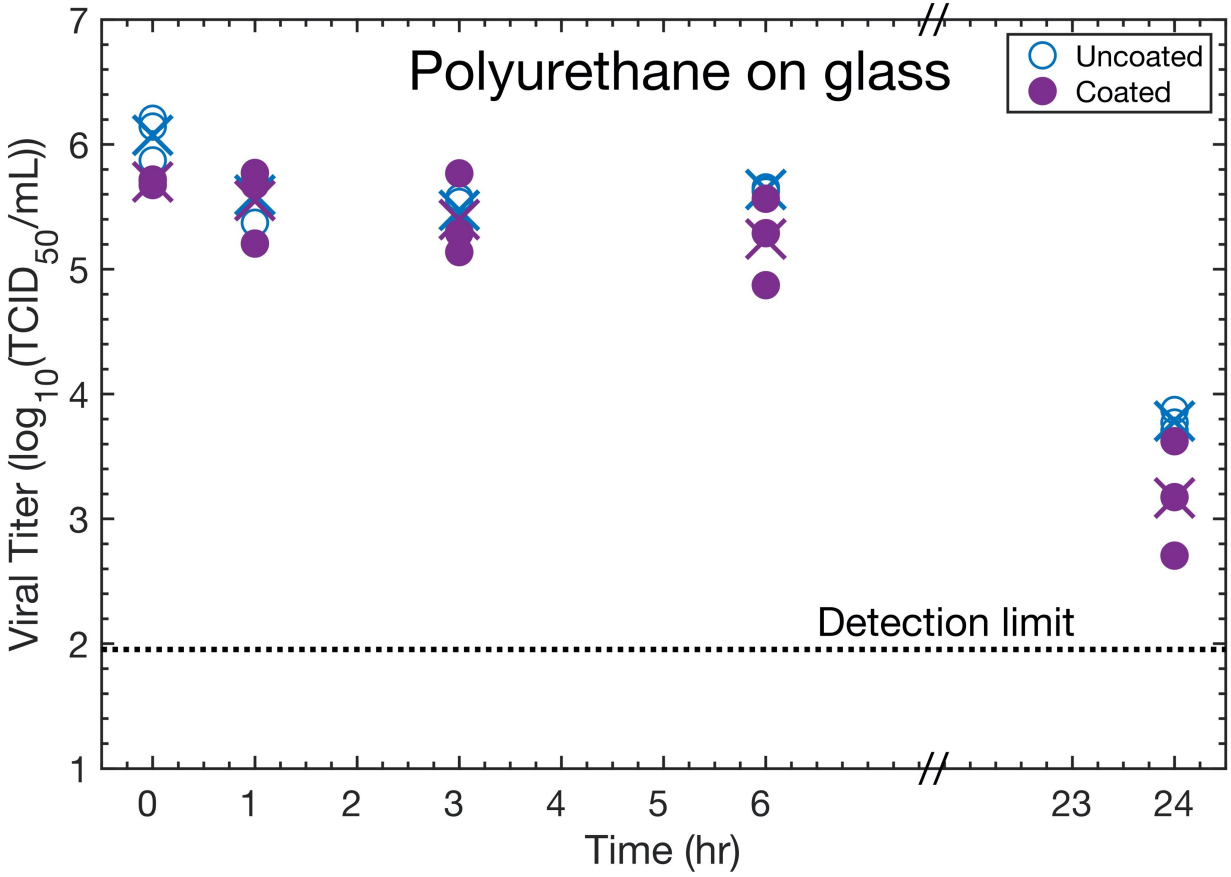
Results: stainless steel 301



- Viral reduction: 99.90% (=2.97 log, $p=8x10^{-3}$, $CI_{95\%}=[98.51,100]$) in 1 h
- Similarity of results on glass and stainless steel suggest that the coating is responsible for the inactivation of the virus ($p=0.59$)

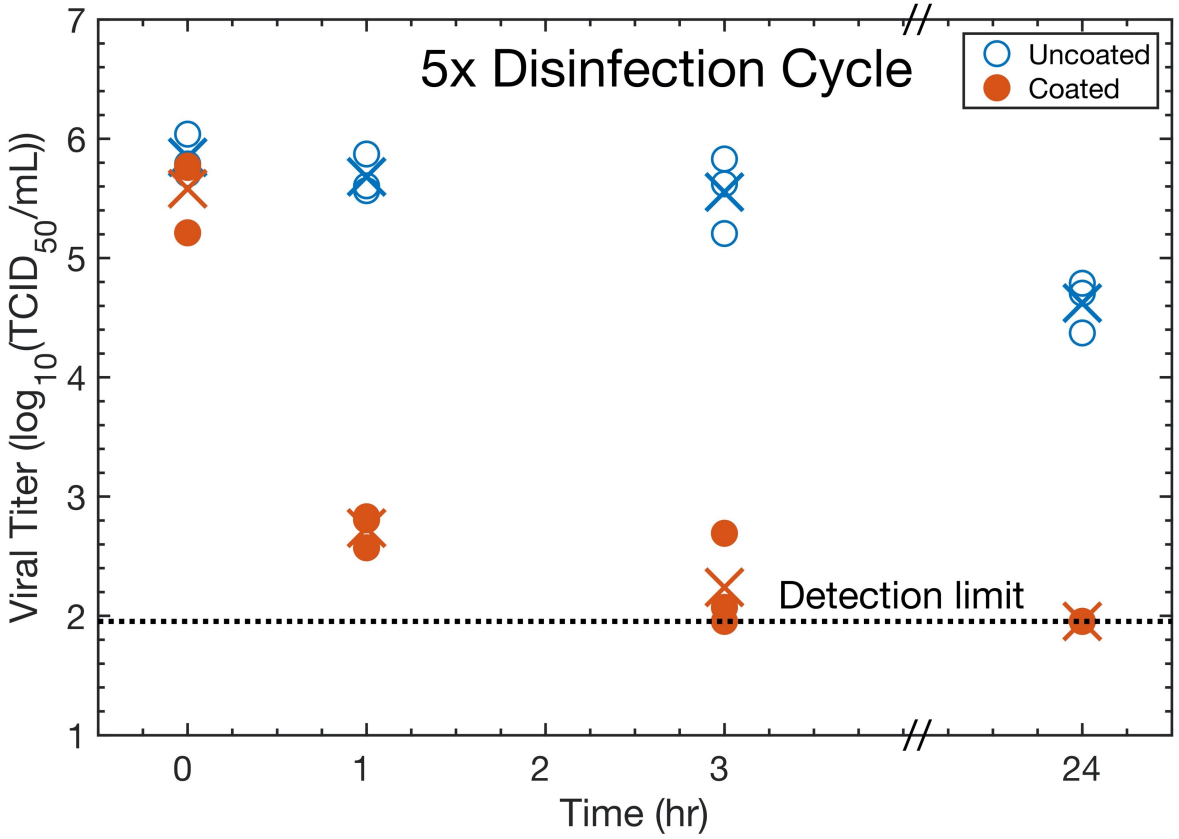
- Behzadinasab 2020 ACS Applied Materials and Interfaces
- Press coverage on BBC World, NPR, ABC, NBC, CBS, Fox

Results: Polyurethane Only



- Viral reduction: 10% (=0.04 log, p=0.22, $CI_{95\%}$=[-164,100]) in 1 h
- Cuprous oxide is necessary for the virucidal activity, likely the active ingredient

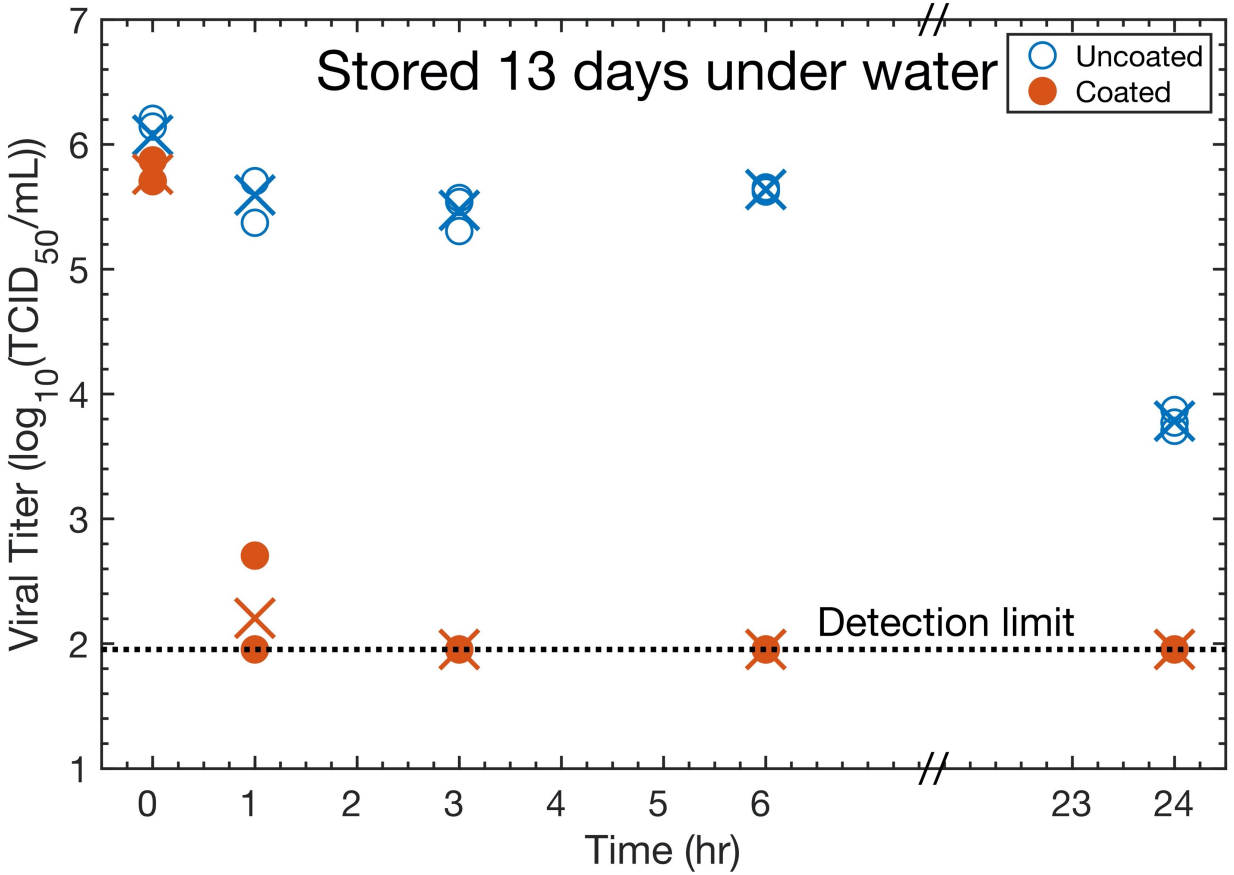
Results: Ongoing Kill



- Material: glass
- 1 cycle = exposed to SARS-CoV-2, disinfected with 70% ethanol in water.

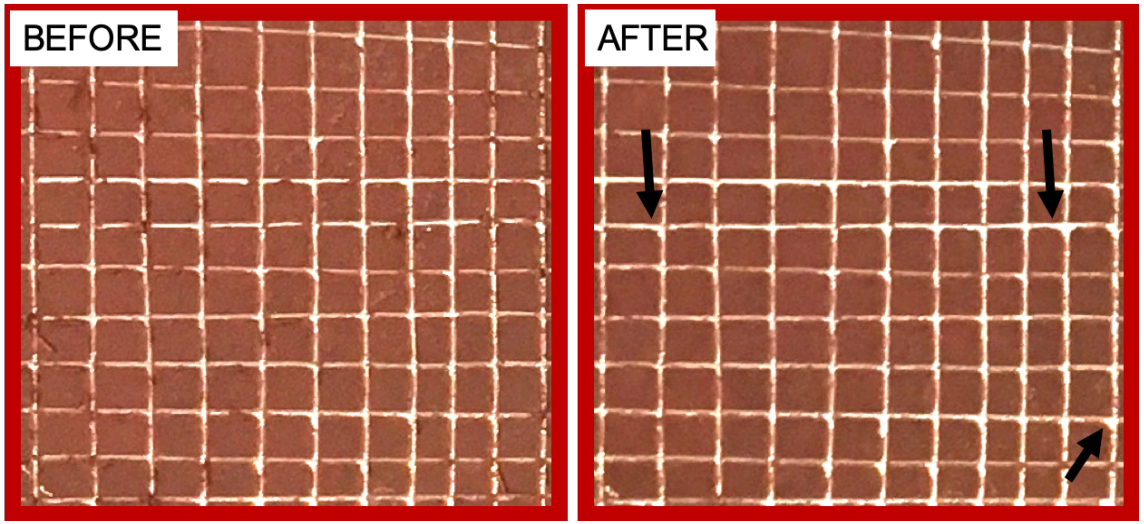
- Viral reduction: 99.89% (=2.95 log, $p=4x10^{-8}$, $CI_{95\%}=[99.79,100]$) in 1 h
- Coating does not lose its activity after repeated exposures to the viral particles

Results: Durability



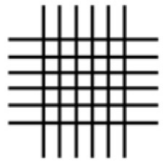
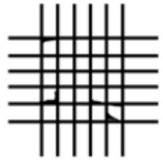
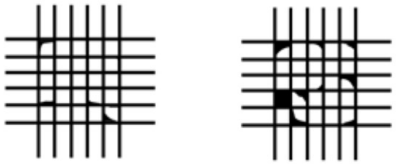
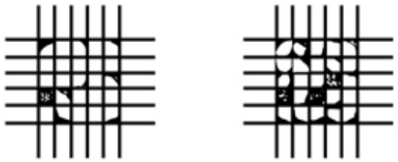
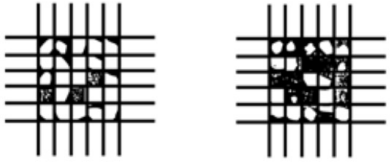
- Viral reduction: 99.96% (=3.39 log, $p=8x10^{-4}$, $CI_{95\%}=[99.56,100]$) in 1 h
- Film still active after storage under water

Durability



Cross-hatch test ASTM D3359-Method B

- Material: stainless steel
- 3 samples were tested
- Affected squares:
  - avg. = 2.4
  - std. dev. = 0.8

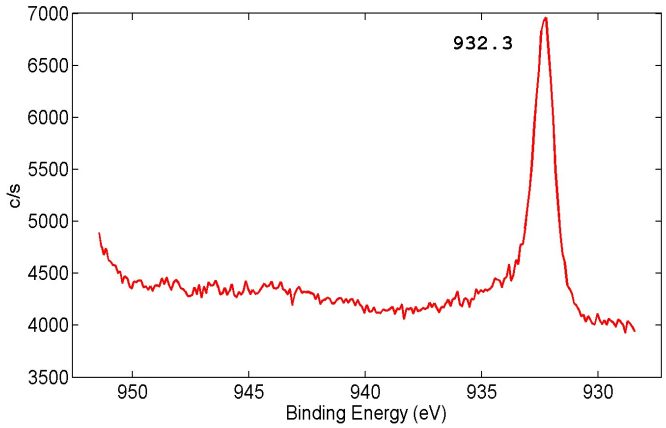
CLASSIFICATION OF ADHESION TEST RESULTS		
CLASSIFICATION	PERCENT AREA REMOVED	SURFACE OF CROSS-CUT AREA FROM WHICH FLAKING HAS OCCURRED FOR SIX PARALLEL CUTS AND ADHESION RANGE BY PERCENT
5B	0% None	
4B	Less than 5%	
3B	5 – 15%	
2B	15 – 35%	
1B	35 – 65%	
0B	Greater than 65%	

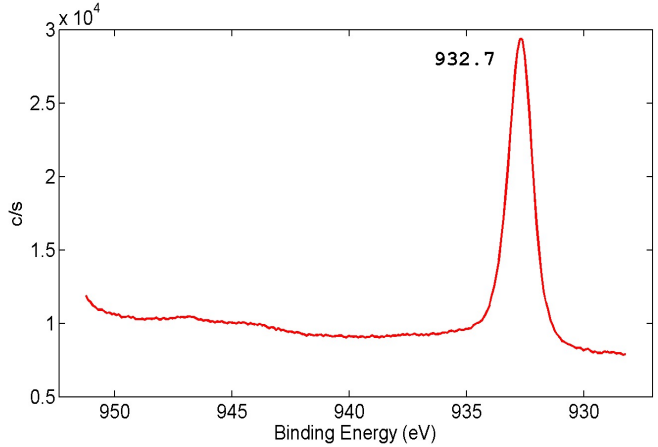
Characterization: XPS

Before plasma treatment

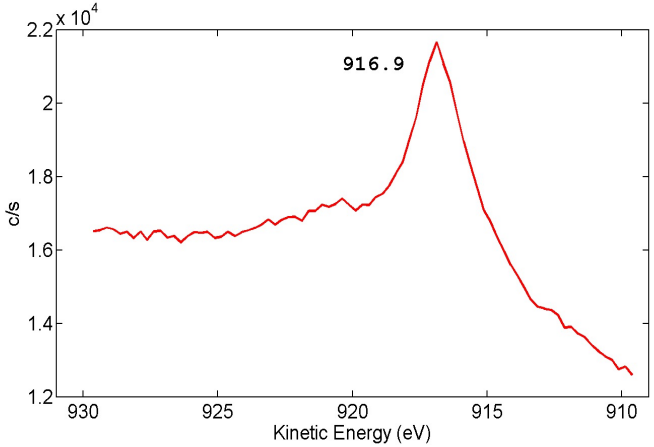
After plasma treatment

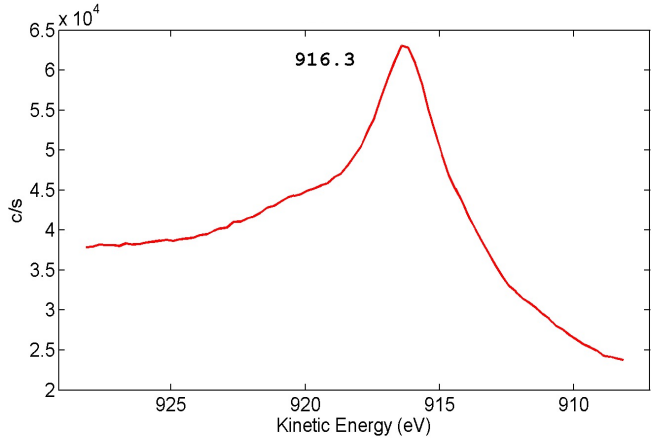
Cu $2P_{3/2}$





Cu $L_3M_{4,5}M_{4,5}$





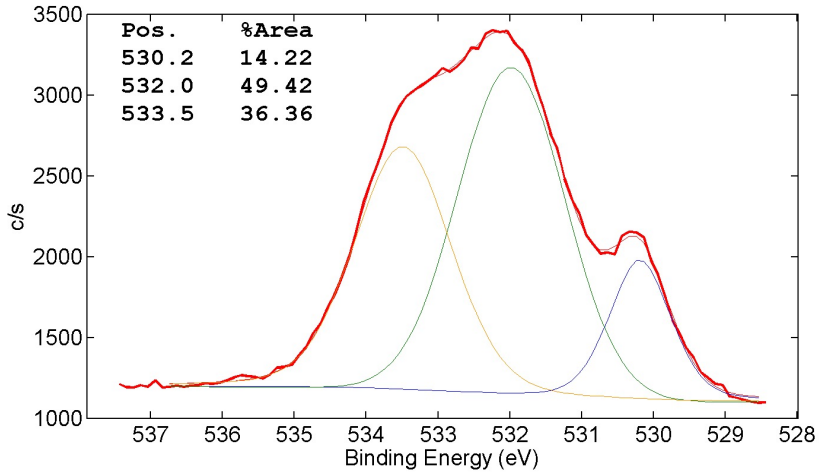
- Binding energy = 932.7 eV, can be assigned to either Cu metal or Cu_2O
- Kinetic energy = 916.2 eV
- E_b+E_k = 1848.9 eV is in excellent agreement with the value of Cu_2O

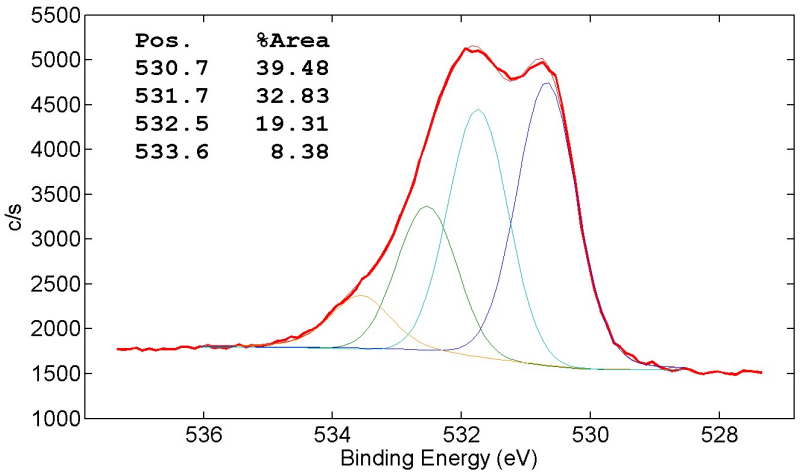
Characterization: XPS

Before plasma treatment

After plasma treatment

O 1S





Condition	Cu:O ratio of the surface
Before plasma treatment	1:1
After 3 min plasma treatment	1.8:1

The stoichiometry can also be measured by the ratio of Cu to O 1s band from metal oxide contribution (at 530.7 eV)

First Draft: Cu_2O in polyurethane

Also kills

(1) Bacteria:

Escherichia coli

Staphylococcus aureus

Methicillin-resistant *S. aureus* (MRSA)

Pseudomonas aeruginosa, Acinetobacter baumannii,

Stenotrophomonas maltophilia,:

Mycobacterium avium, Mycobacterium chimaera,

Mycobacterium abscessus,

(2) yeasts:

Candida albicans

Candida auris,

(3) fungus:

Aspergillus niger

Prof. Joe Falkinham
Myra Gordon
Virginia Tech

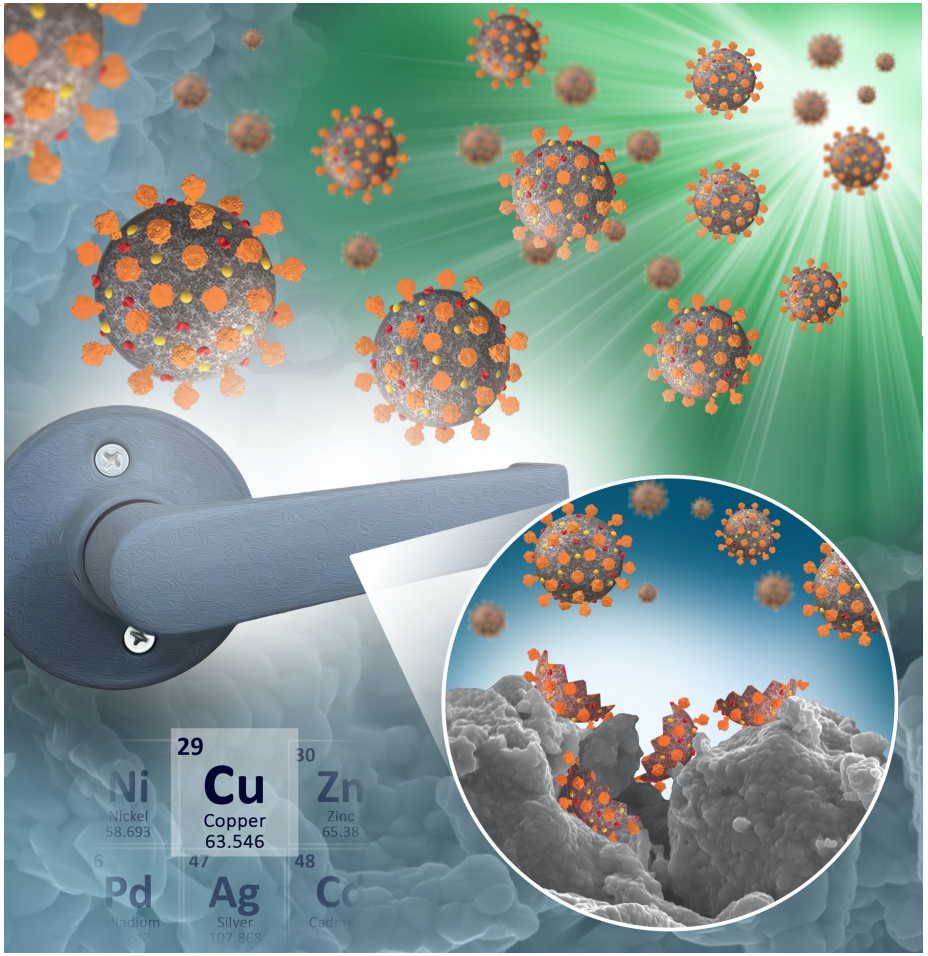
Conclusion

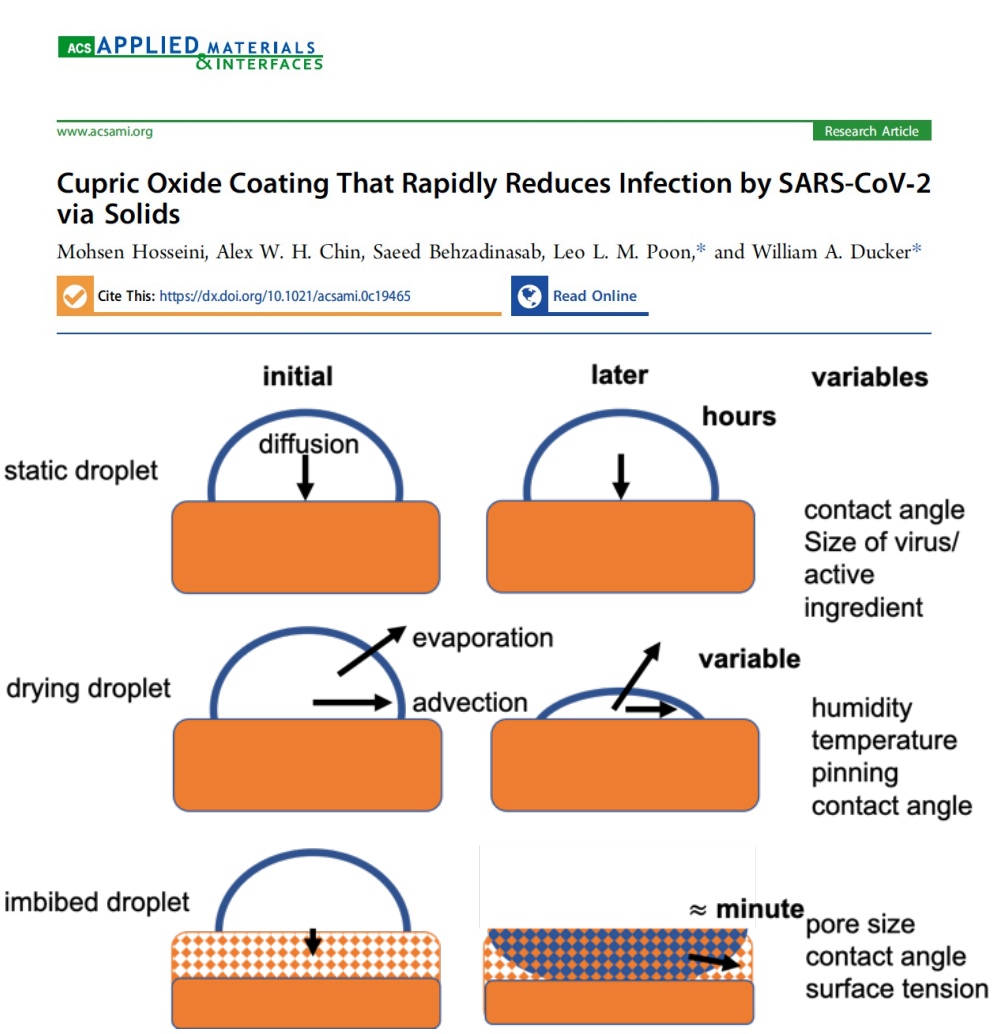
We have developed a surface coating that:

- Inactivates SARS-CoV-2 and other organisms quickly
- Is applicable to communal objects
- Has very high durability at various conditions
- Is mechanically robust

The Future I Porous Films

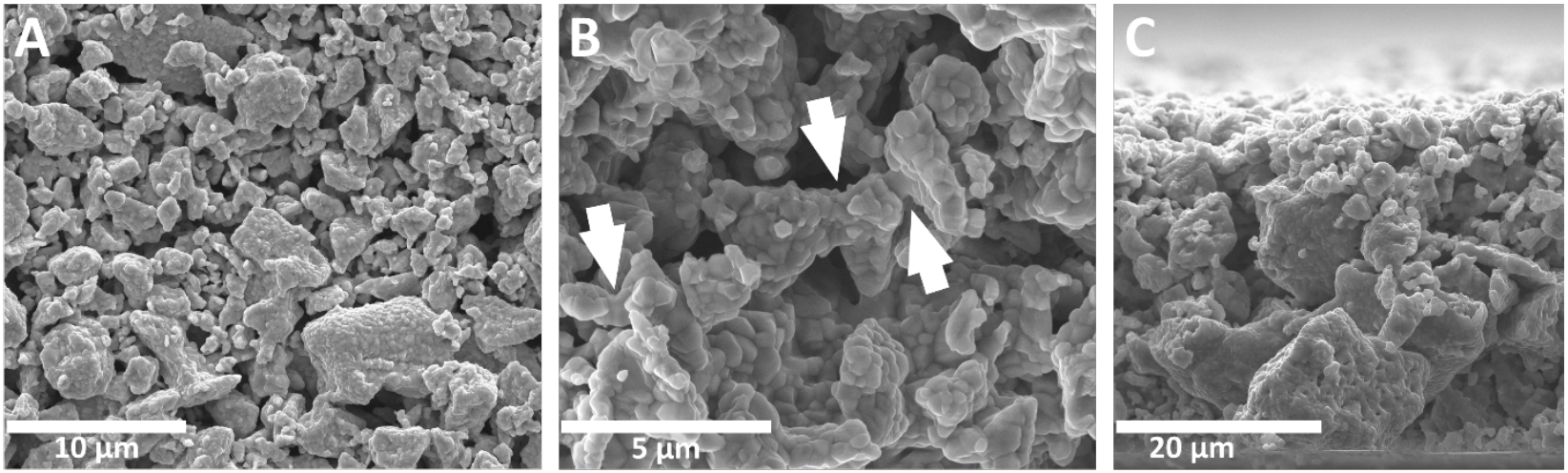
Inactivation in minutes: Imbibe the droplet into a surface film.

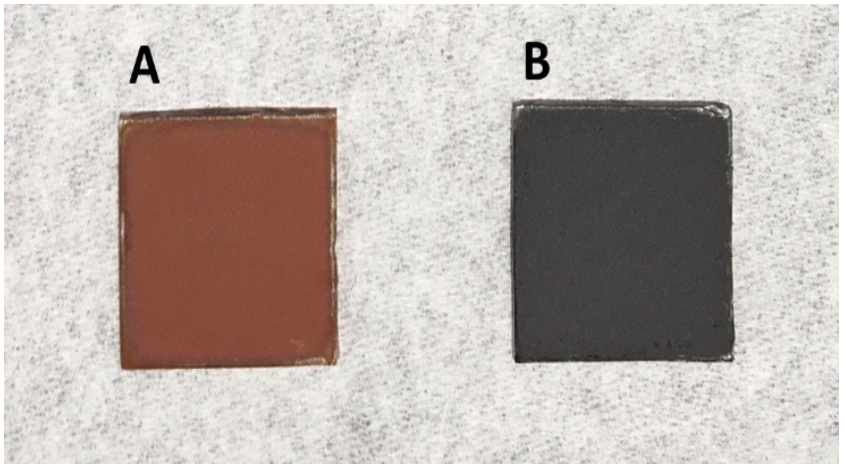




Hydrophilic Porous Coating

No polyurethane, sinter Cu_2O





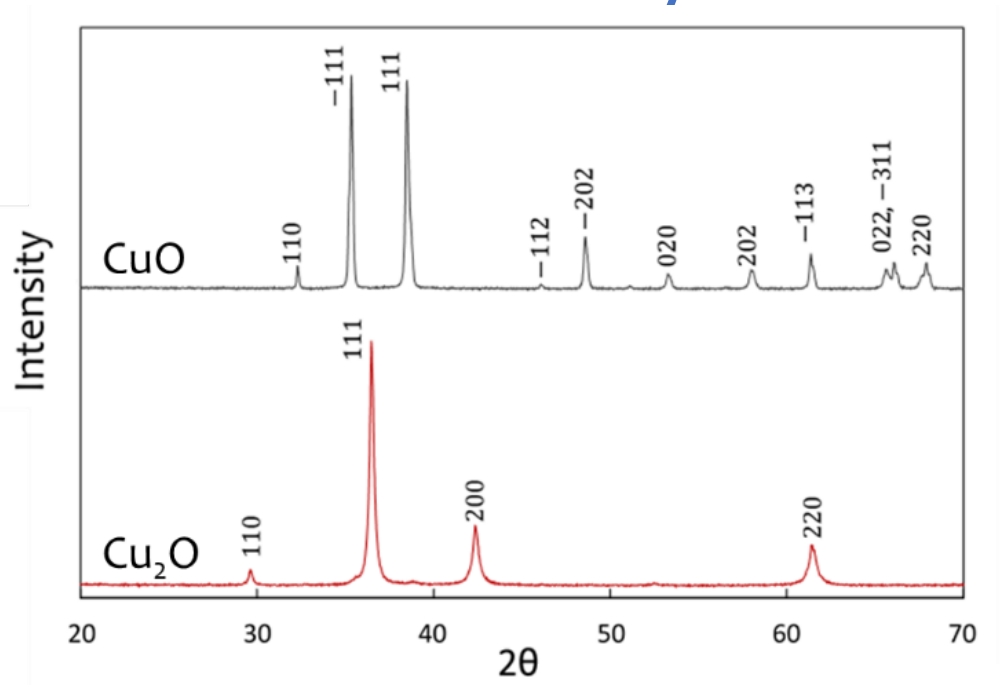
Cuprous oxide

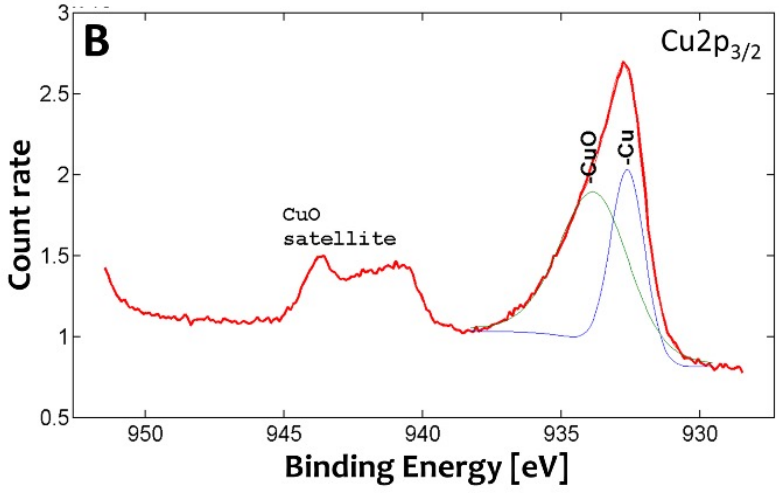
Cupric oxide

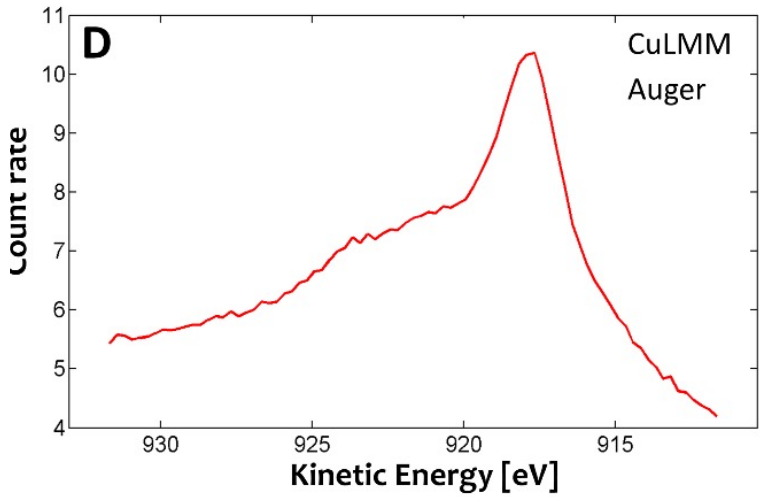
It is Actually CuO

X-ray diffraction

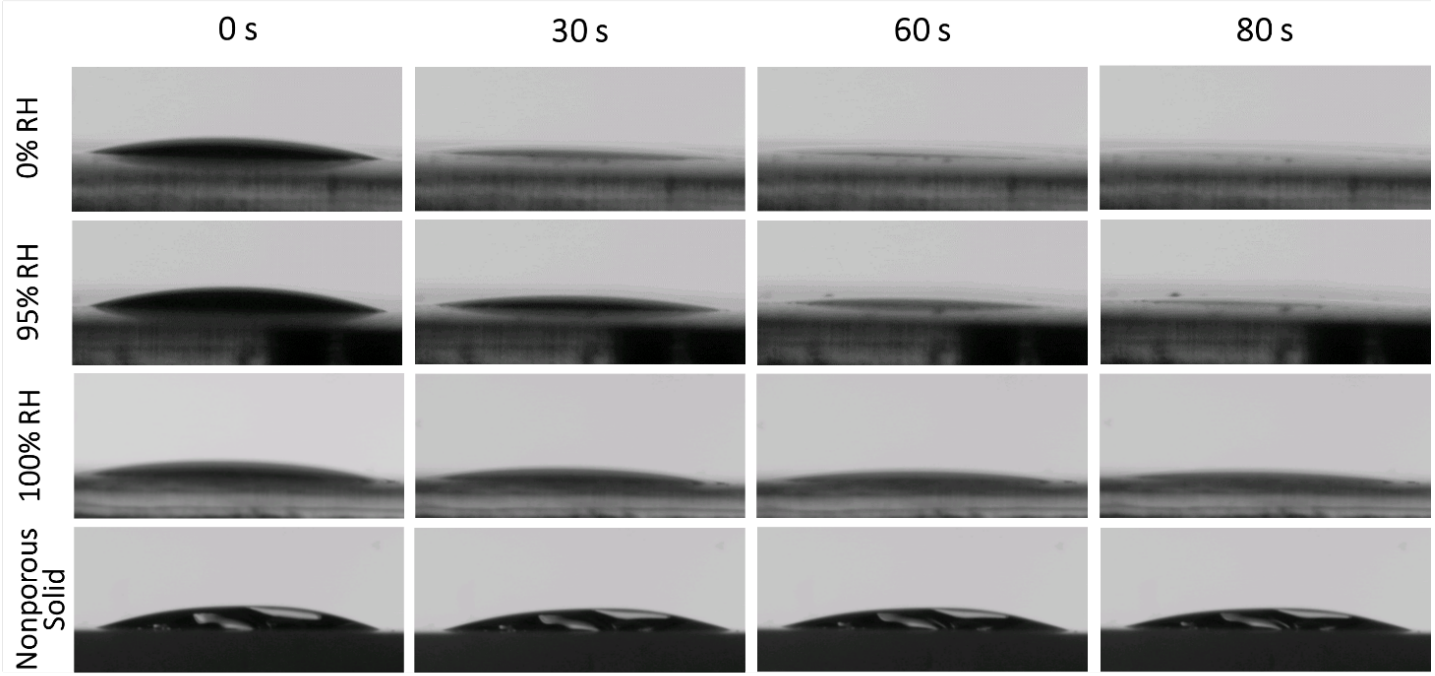
XPS







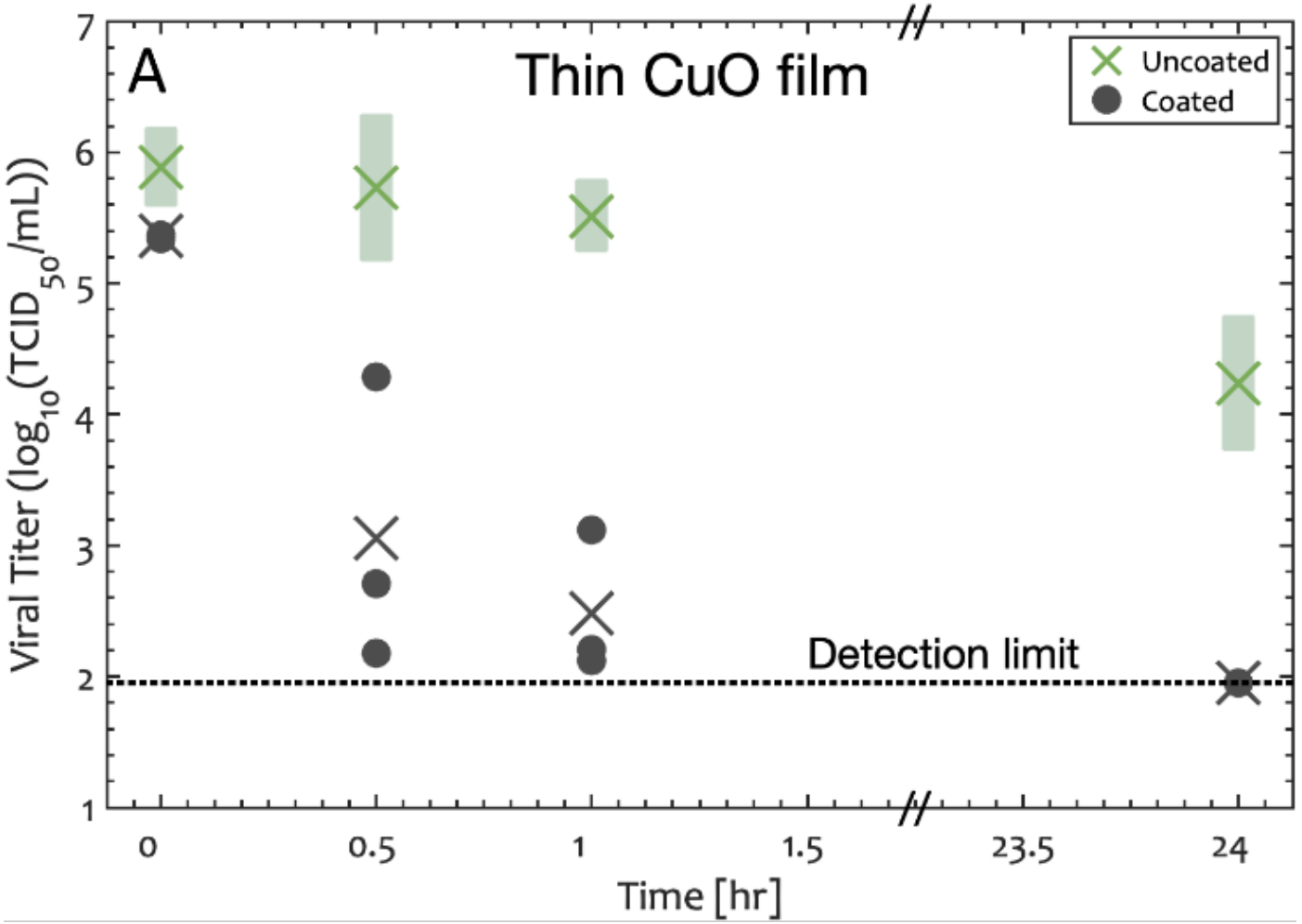
Imbibition of water into CuO



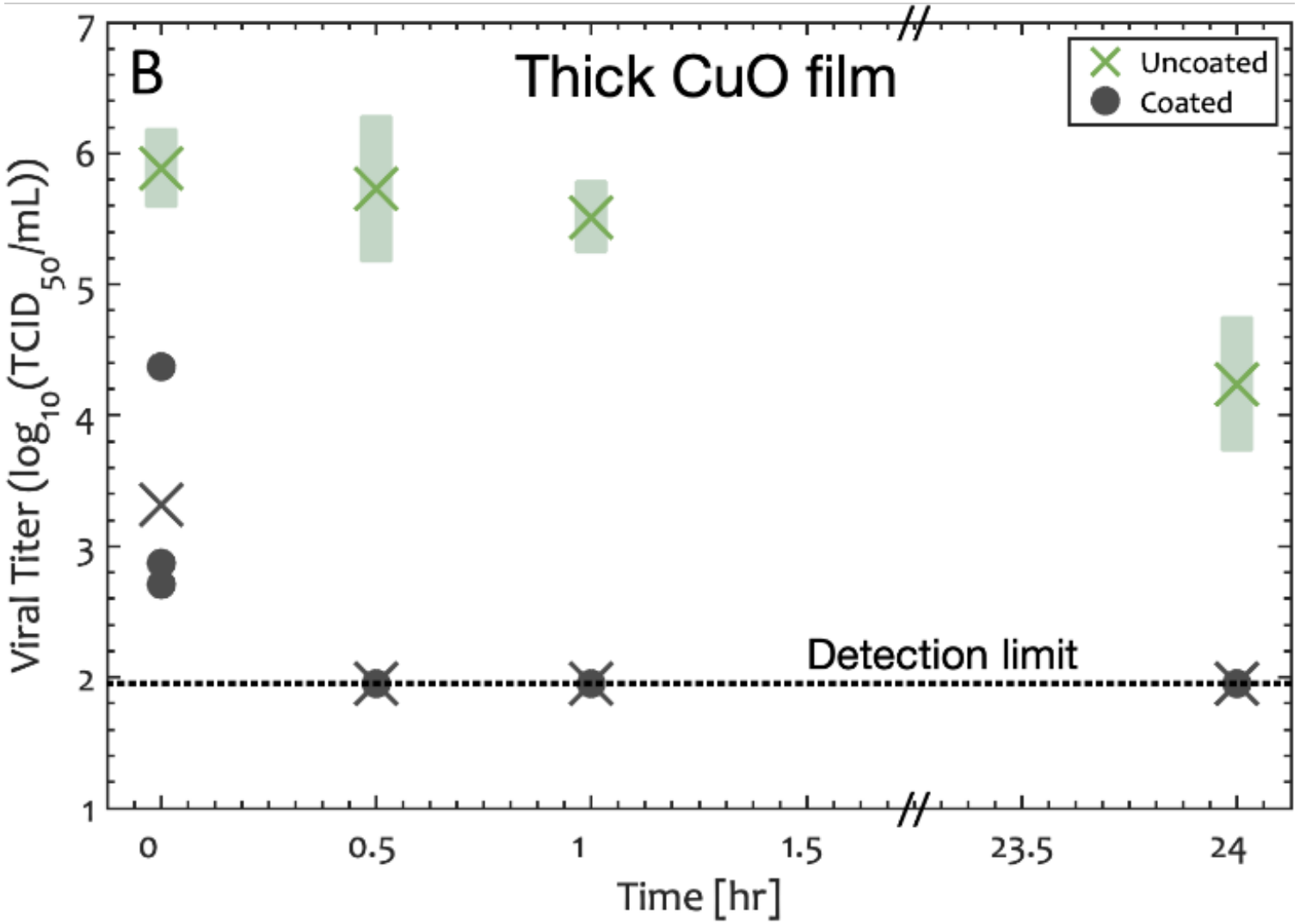
5 μL droplet

Hydrophilic for months

Rapid loss of Infection Ability

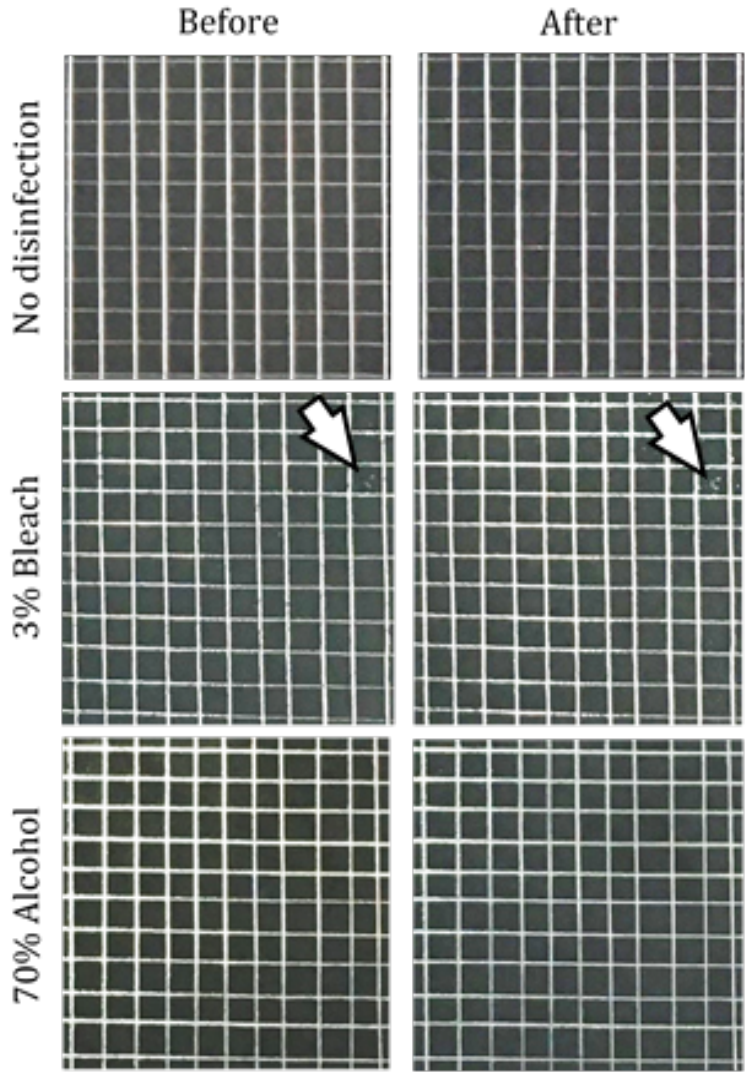


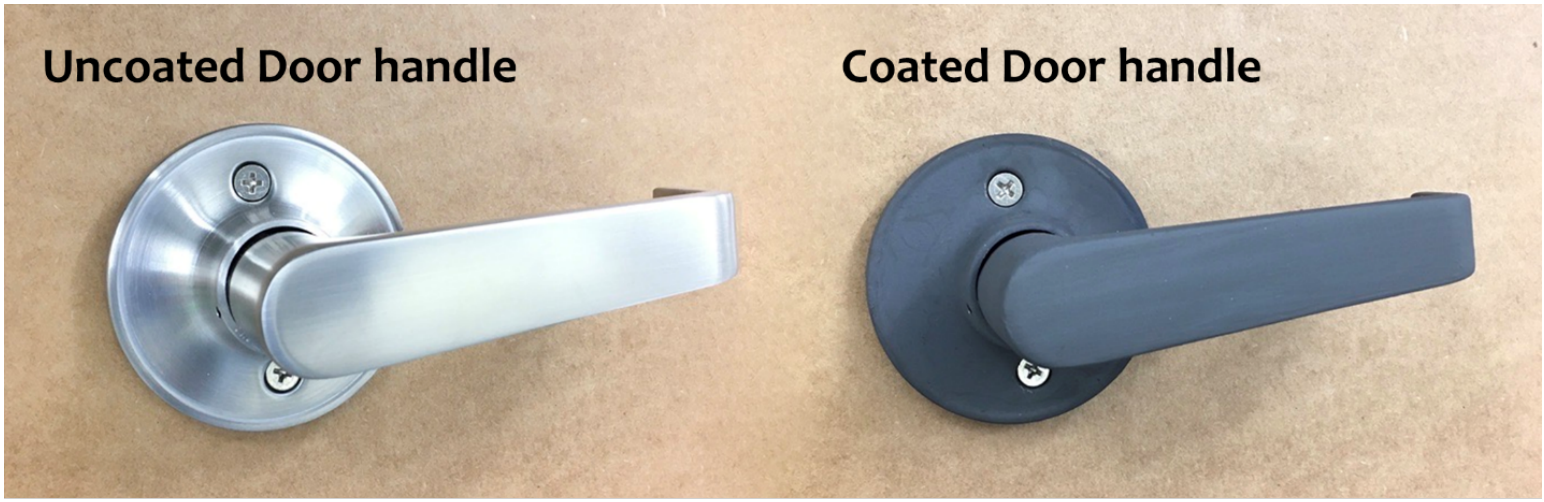
Loss of Infection Ability in < 1 min

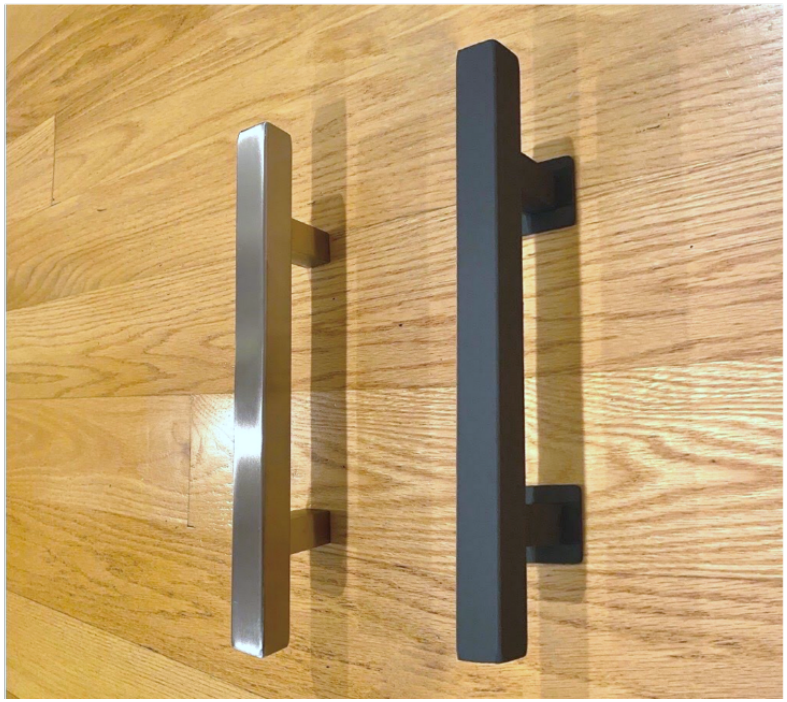


99.7% reduction compared to glass within 1 minute (p = 0.0189)

Peel test on CuO Coating

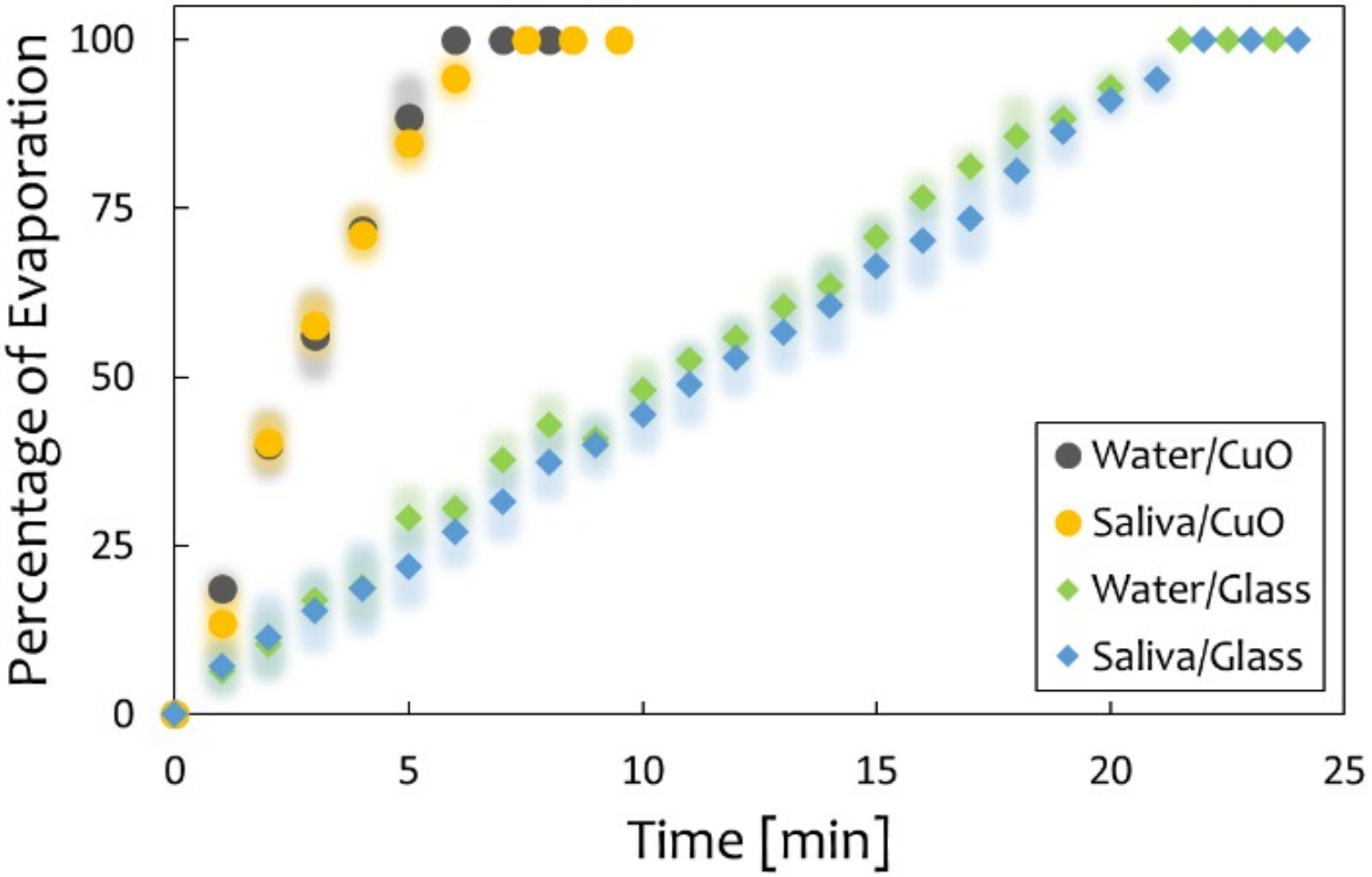



Uncoated Door handle
Coated Door handle



Reload Time

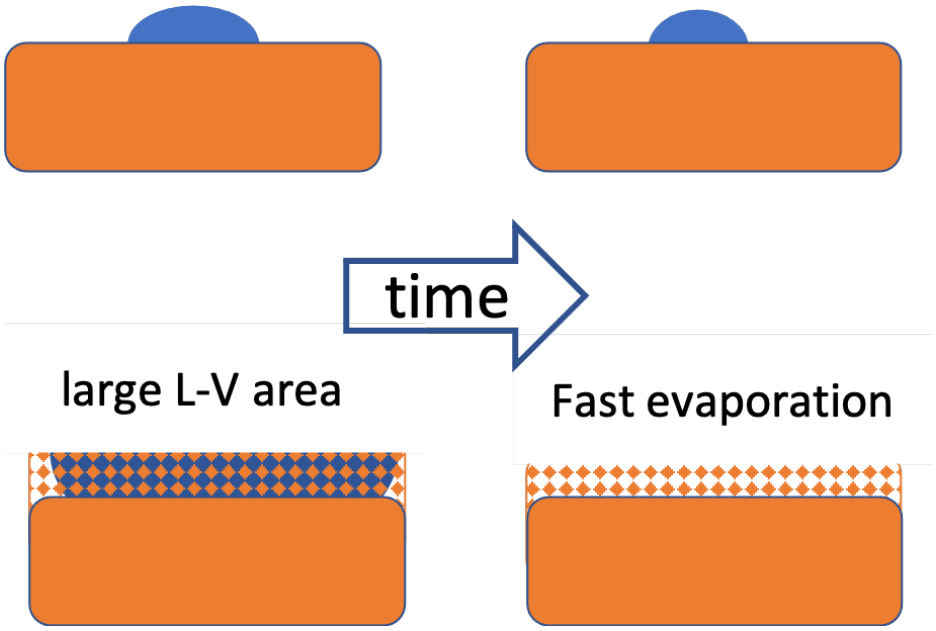
Fast-Drying



35% RH

Droplet is spread out by imbibition
Fast drying pull virus close to solid

Fast-Drying



Porous film:

1. Fast drying
2. Smaller diffusion distance
3. More active ingredient

Current Work

- We now have about 7 coatings that inactivate SARS-CoV-2

Can you become infected by SARS-CoV-2 by touching a contaminated surface?

CDC: https://www.cdc.gov/coronavirus/2019-ncov/more/science-and-research/surface-transmission.html#ref8
Science Brief: SARS-CoV-2 and Surface (Fomite) Transmission for Indoor Community Environments

"The principal mode by which people are infected with SARS-CoV-2 (the virus that causes COVID-19) is through exposure to respiratory droplets carrying infectious virus. It is possible for people to be infected through contact with contaminated surfaces or objects (fomites), but the risk is generally considered to be low."
"Because of the many factors affecting the efficiency of environmental transmission, the relative risk of fomite transmission of SARS-CoV-2 is considered low compared with direct contact, droplet transmission, or airborne transmission [1, 2]"
(Ref 1 is a model based on assumptions, Ref 2 is a review)

However, it is not clear what proportion of SARS-CoV-2 infections are acquired through surface transmission." "Hand hygiene is a barrier to fomite transmission and has been associated with lower risk of infection [6]." …"the risk of SARS-CoV-2 infection via the fomite transmission route is low, and generally less than 1 in 10,000, which means that each contact with a contaminated surface has less than a 1 in 10,000 chance of causing an infection [7, 8, 9].

Causality

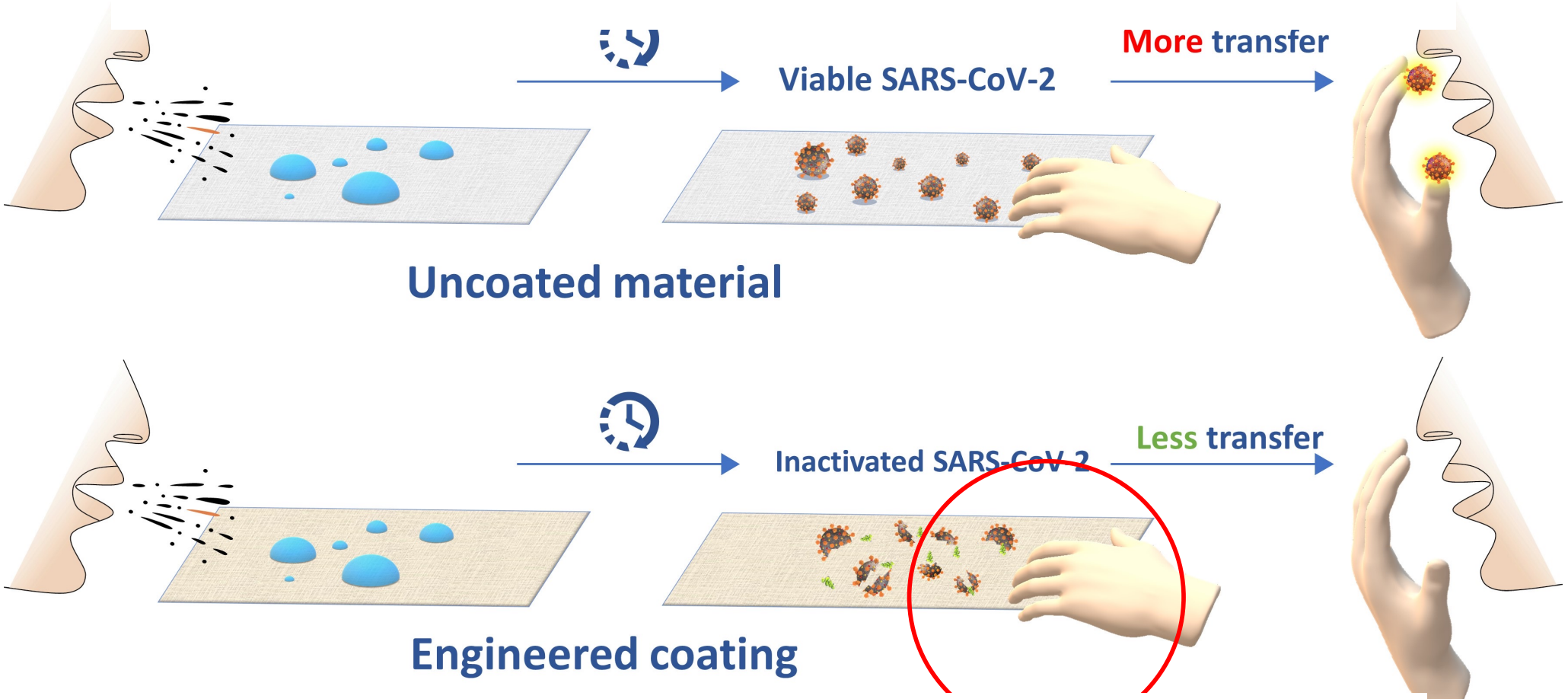
A study on Golden Hamsters showed that the virus can be indirectly transmitted through fomites.
Sia et al: Pathogenesis and transmission of SARS-CoV-2 in golden hamsters. *Nature* 2020, 583:834-838

Epidemiology

Modelling of outbreaks suggest that transmission via fomites may contribute up to 25% of deaths during periods of lockdown.

Meiksin A: Dynamics of COVID-19 transmission including indirect transmission mechanisms: a mathematical analysis. *Epidemiol Infect* 2020, 148:E257.

The other step

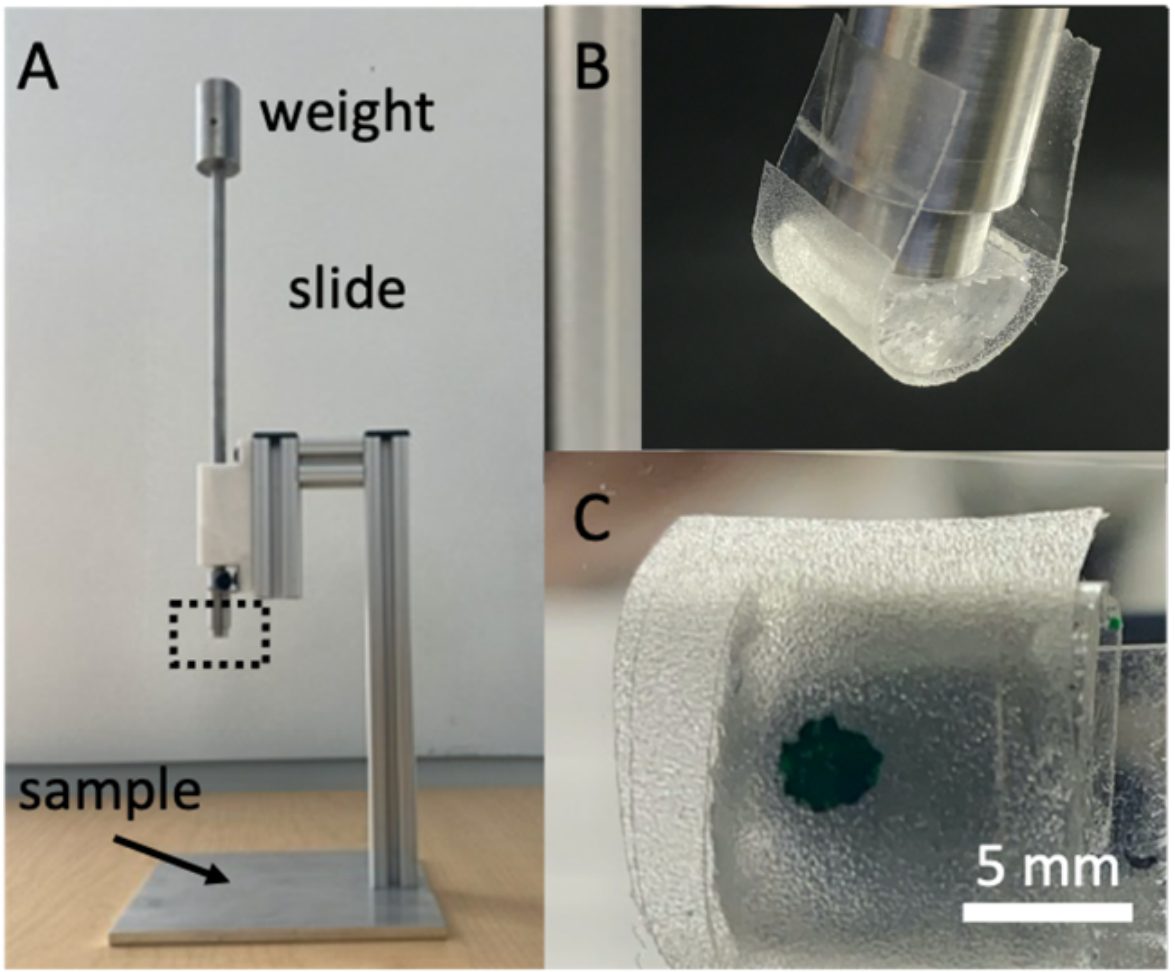


Does SARS-CoV-2 transfer from hand to solid?

The Fake Finger

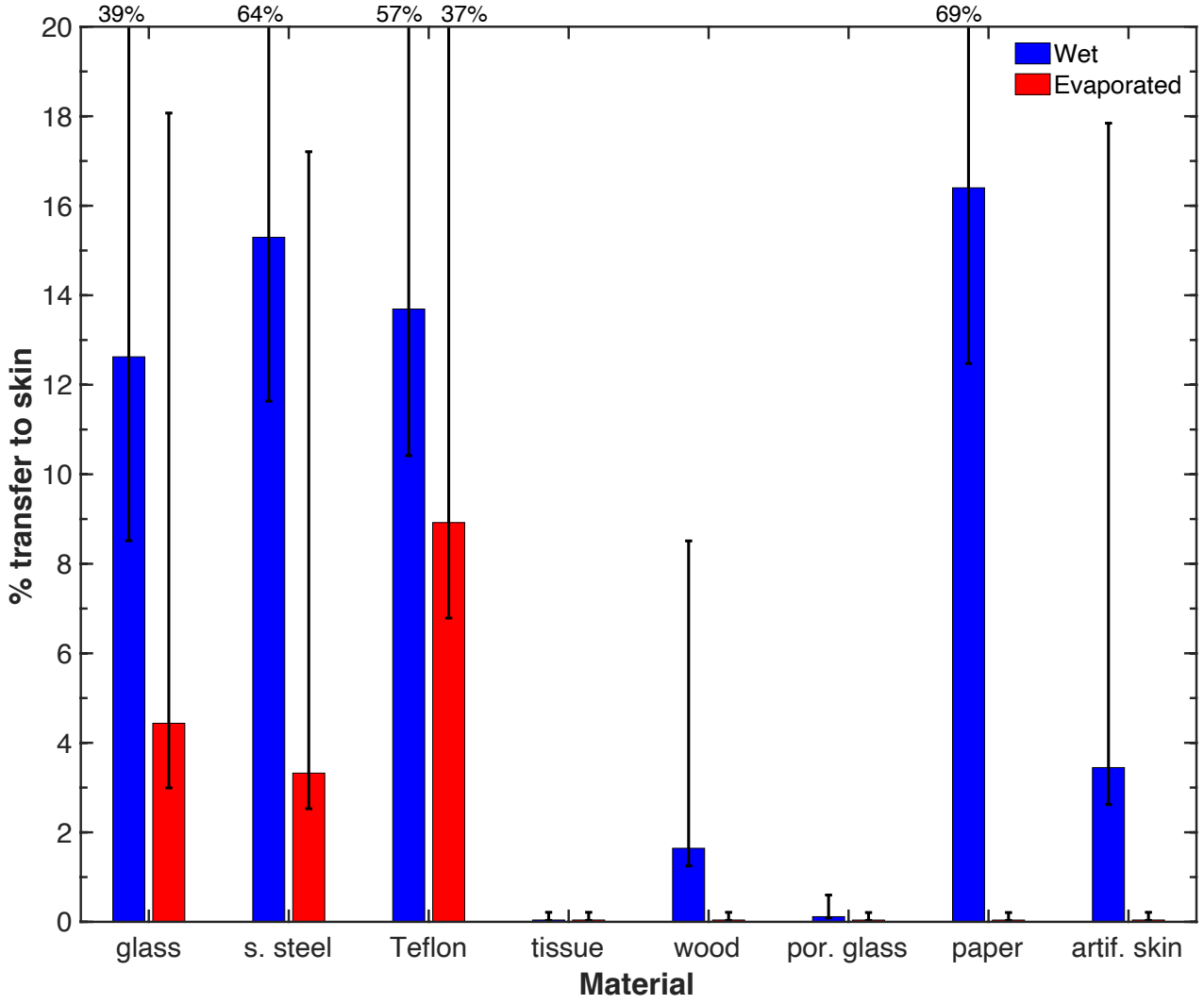
Vitroskin®

PDMS backing



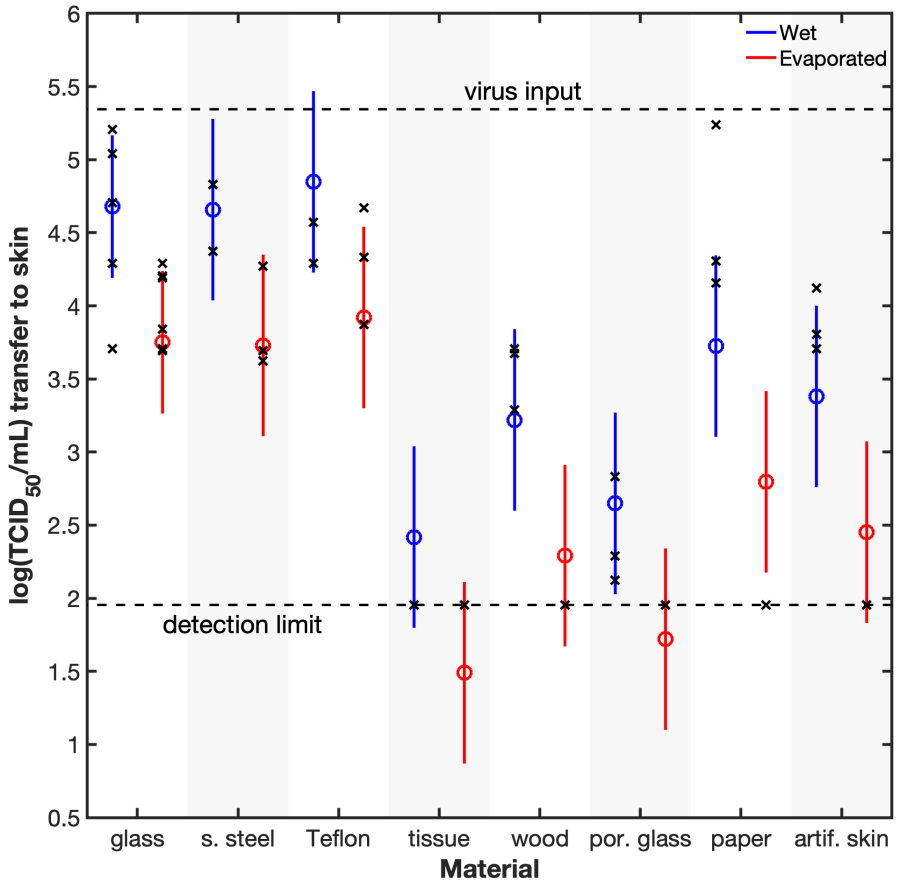
3 N, 5 s, no rubbing

Transfer Results



- Hard surfaces transfer about 12-16% of virus
- Porous surfaces very little

Transfer Results



- More transfer when the solid is still wet (20 min)
- Surface wettability not that important for non-porous

Conclusions II

- Transfer of SARS-CoV-2 to fingers is important.

Acknowledgments

The Ducker lab
- Saeed Behzadinasad
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