Uncovering Hidden Glasses

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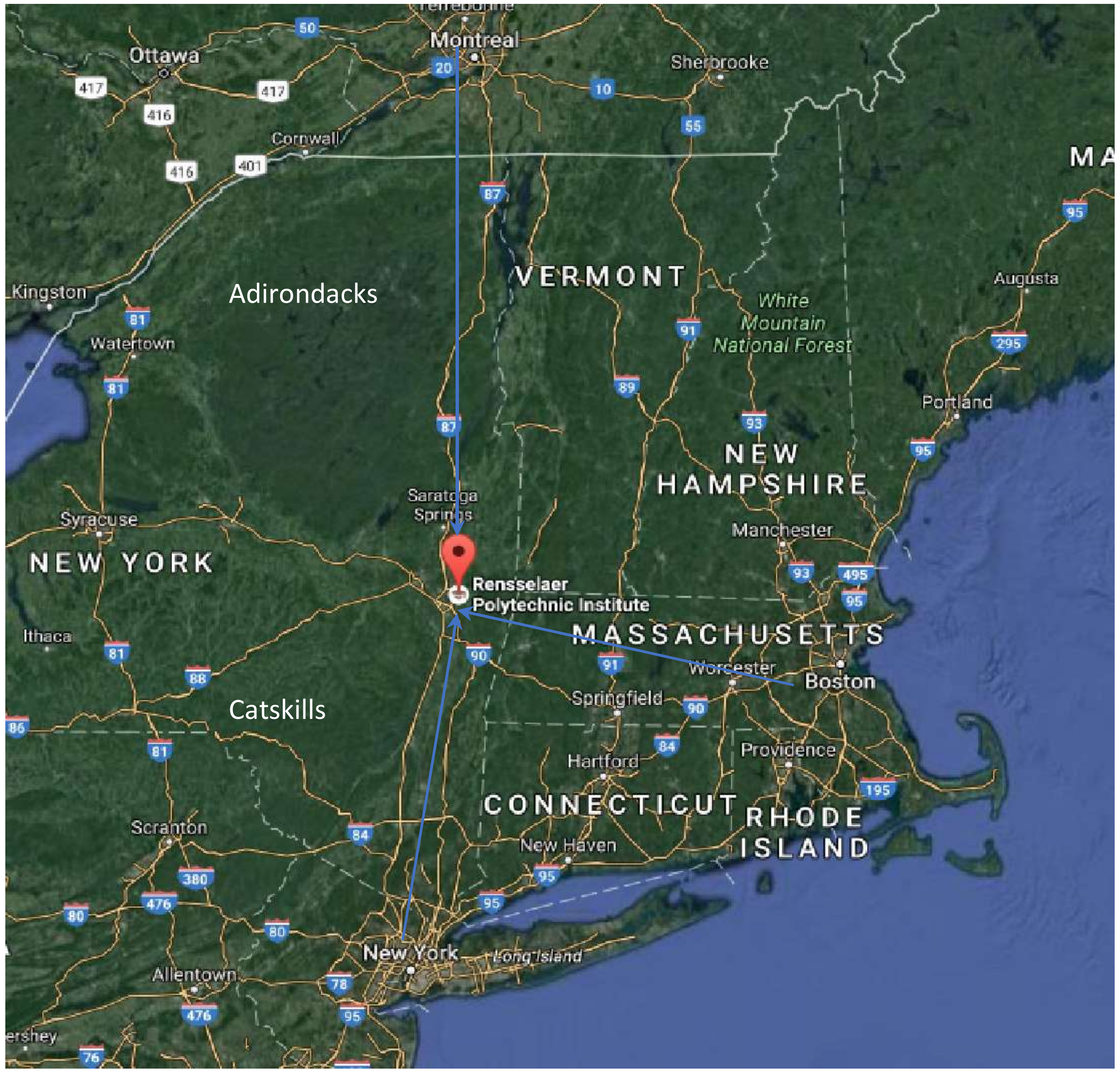
April 13th, 2026, Lyon, France

Rensselaer

DMR-1508410
DMR-1936368

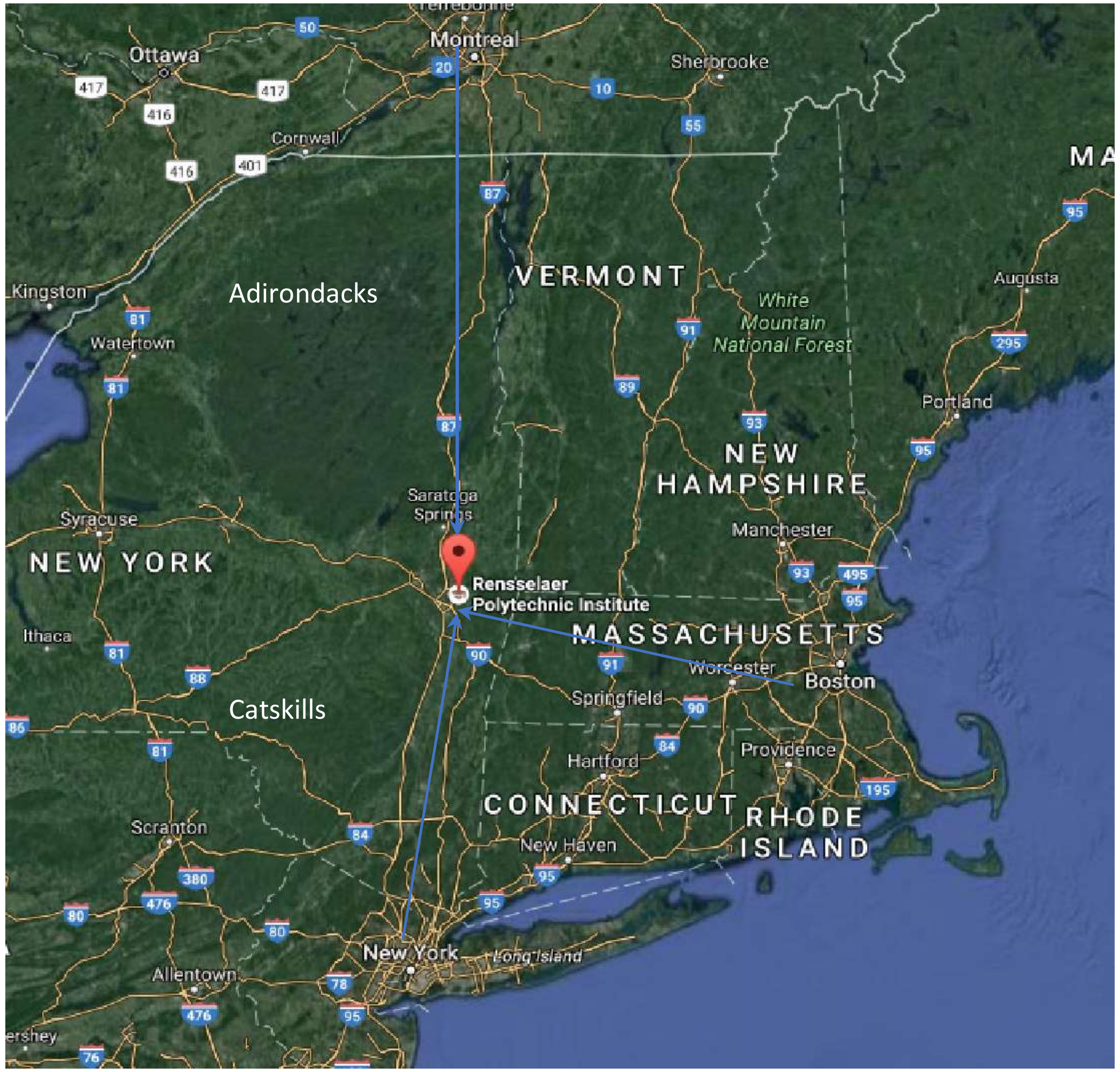
Where is RPI?

Founded in 1824 by Stephen Van Rensselaer, the nation's oldest technological research university.

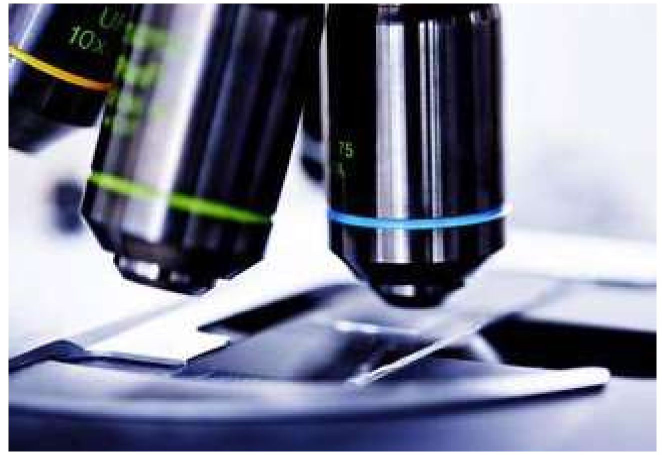


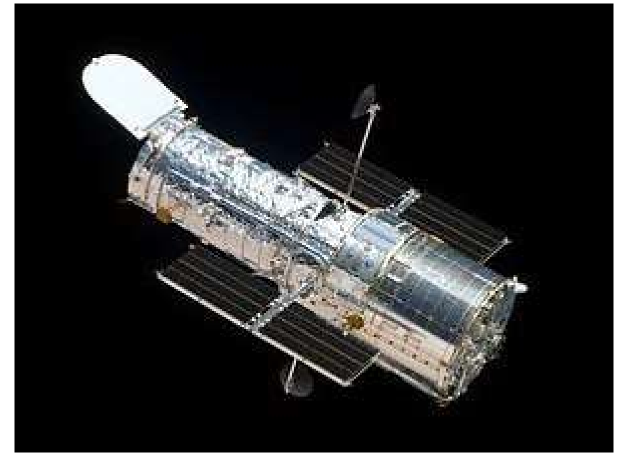
Where is RPI?

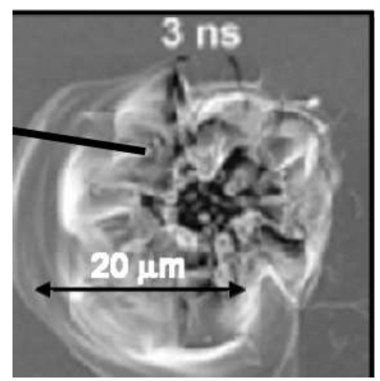
Surrounded by the Adirondack, Catskill and Berkshire ranges

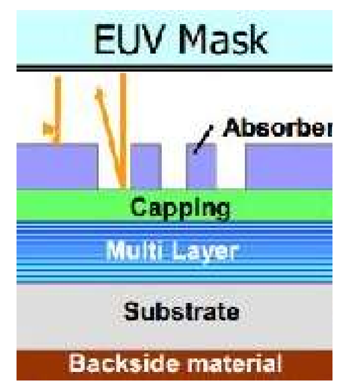


Glass as an Enabling Material



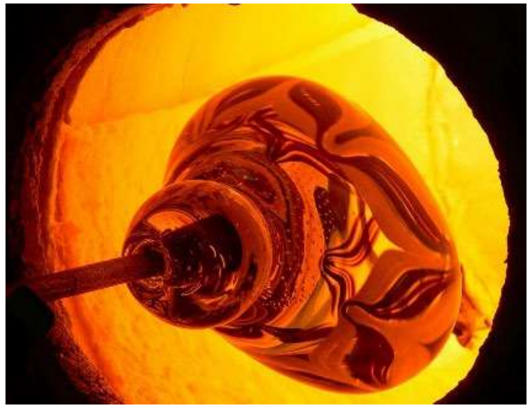


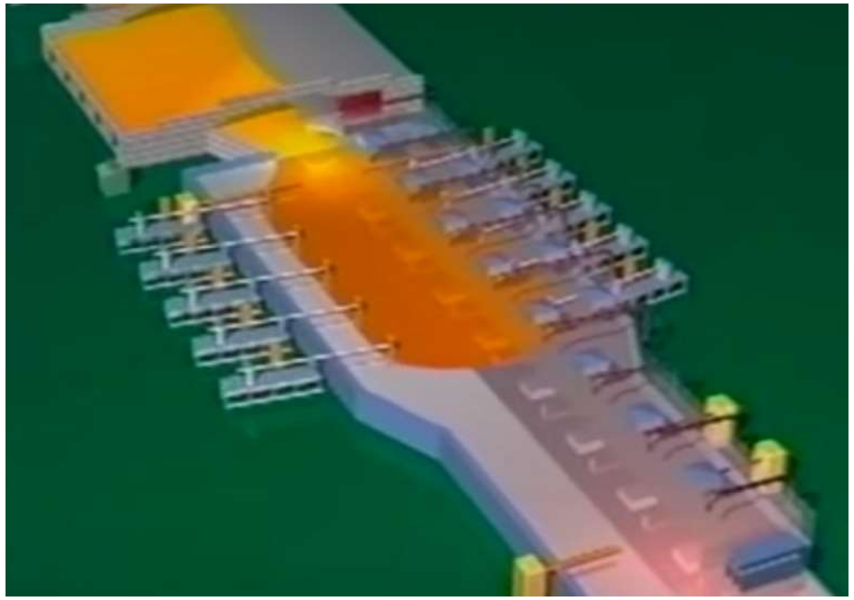




Conventional Approaches to Glass Formation





Pilkington Float Process

https://www.youtube.com/watch?v=OVokYKqWRZE

Corning Fusion Draw Process

http://www.wired.com/2012/09/ff-corning-gorilla-glass/

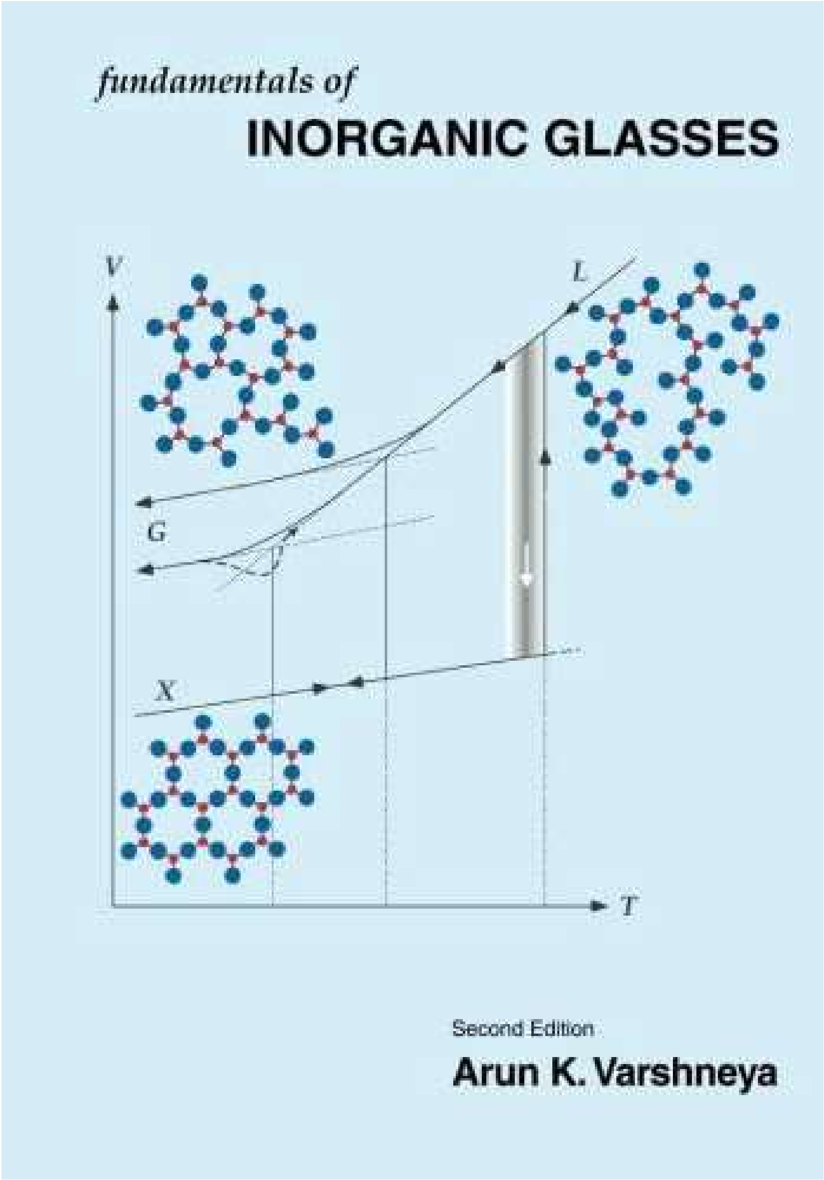
Melting in a container

Varying composition

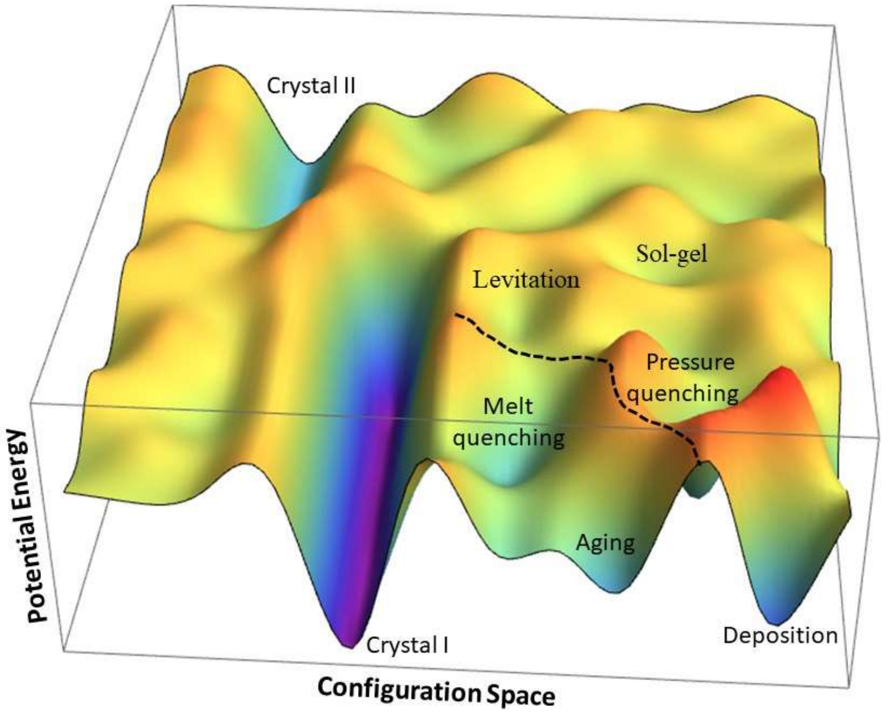
Controlling thermal history (temperature and time)

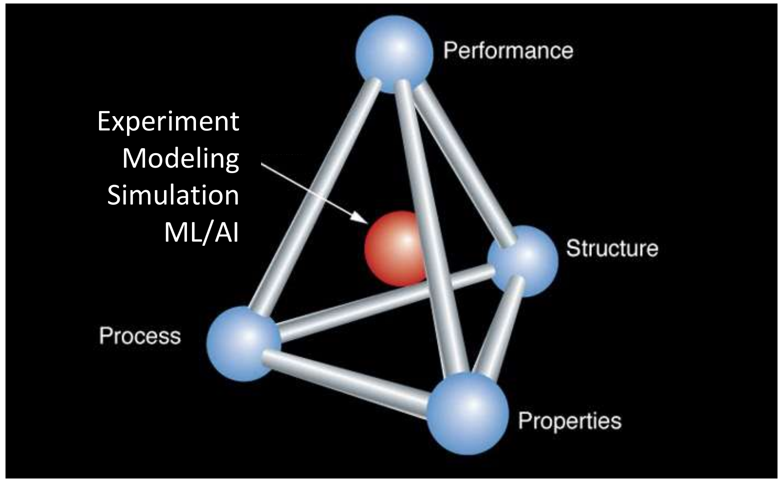
Limited glass forming range

Uncovering Hidden Glasses



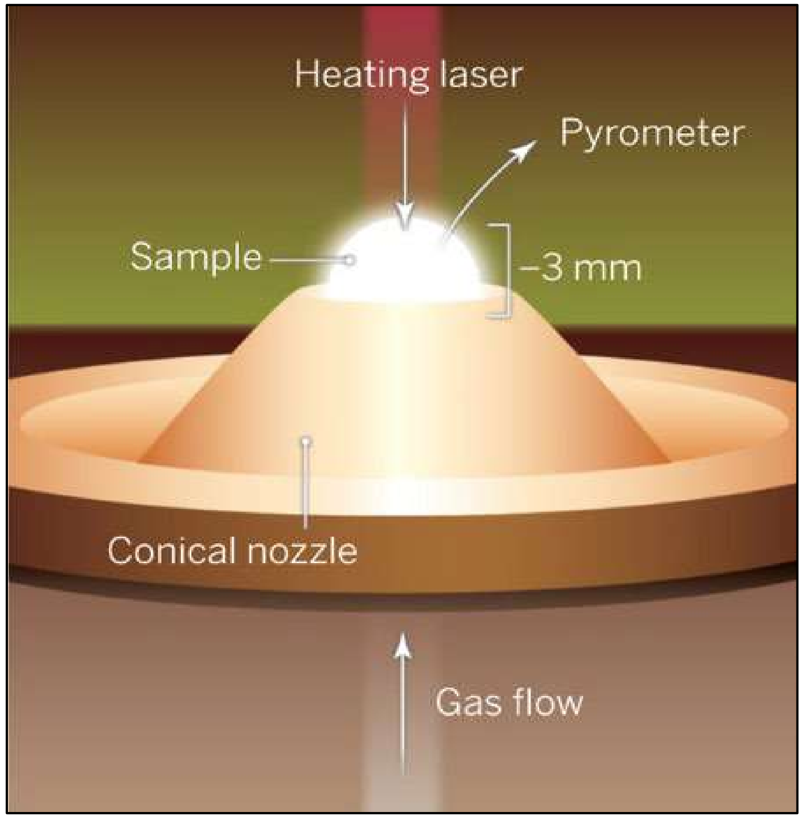
Fundamentals of Inorganic Glasses, 2nd Edition



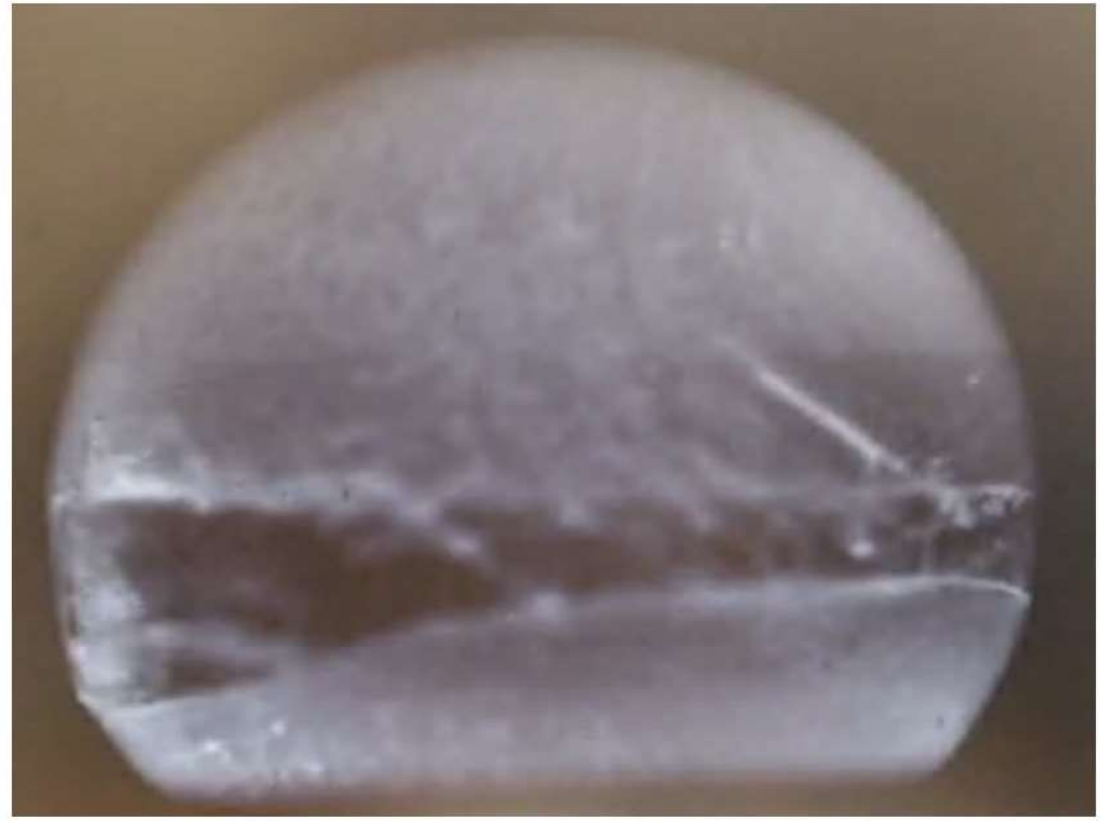


Adventures in a Glass Wonderland

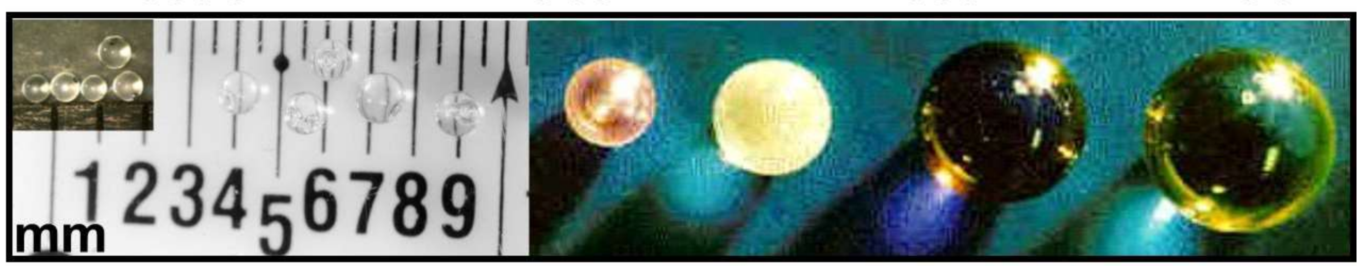
Melting with Levitation



A. Navrotsky, *Science*, 346, 916 (2014)



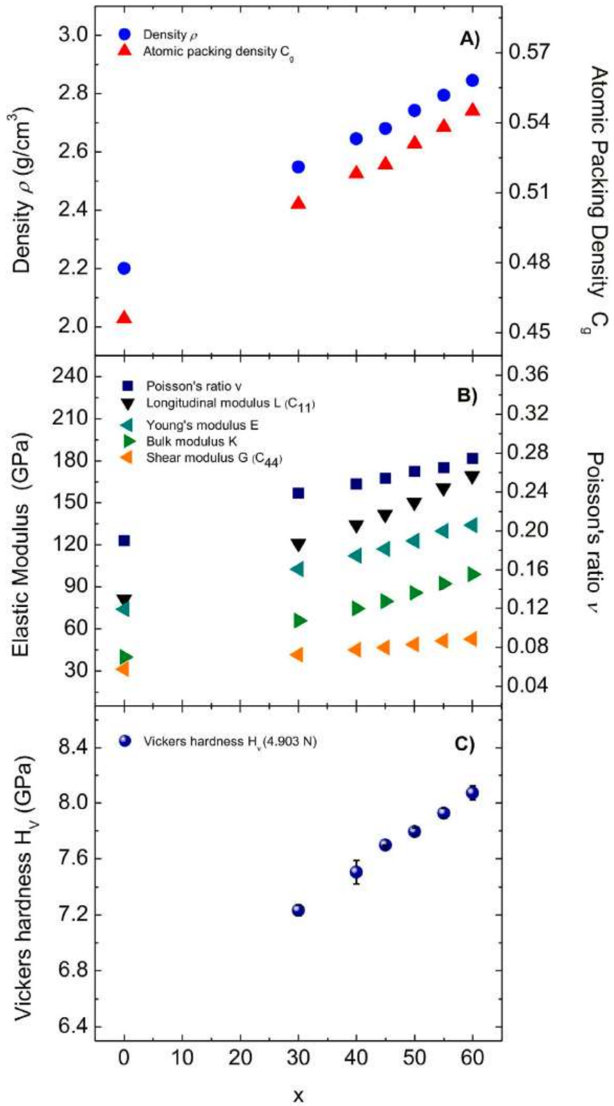
Courtesy of Dr. Yuanzheng Yue, Denmark

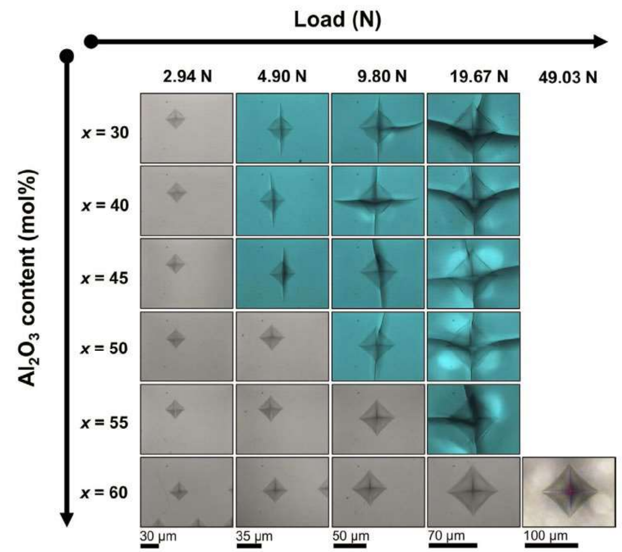


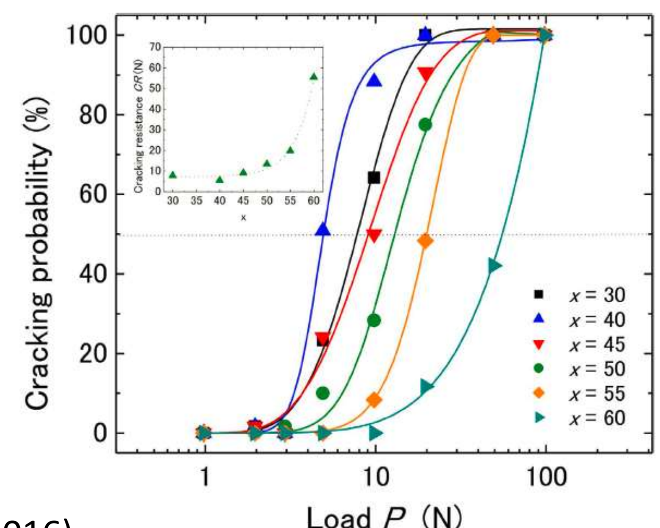
Materials Development, Inc.

Crack Resistant Al_2O_3–SiO_2 Glasses

>30% Al_2O_3, low glass-forming ability, high melting temperatures



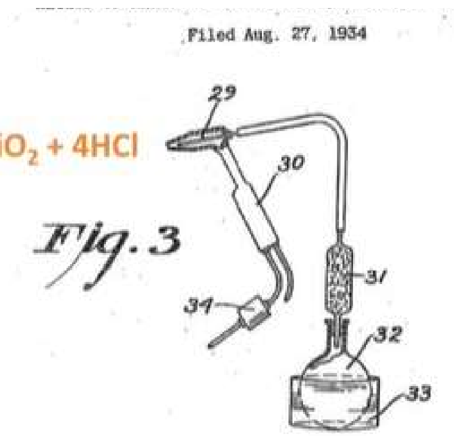




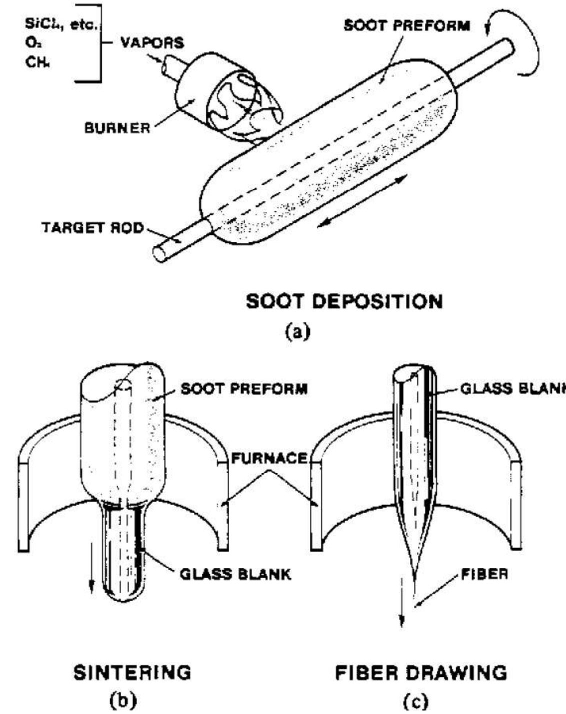
G. A., Rosales-Sosa et al., *Scientific Reports,* **6**, 23620 (2016)

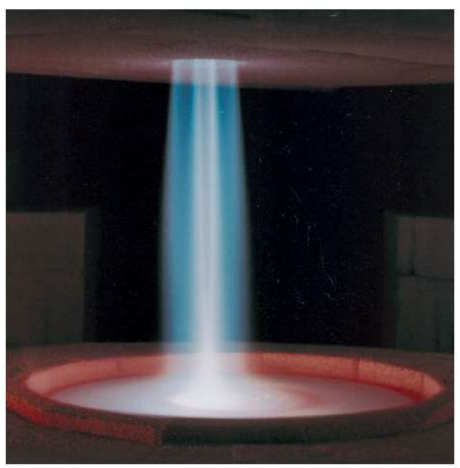
Flame Hydrolysis Deposition

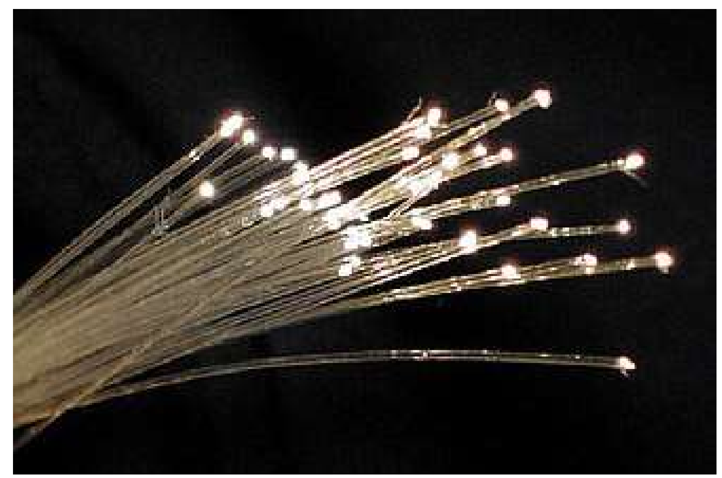
$SiCl_4 + H_2O \rightarrow SiO_2 + 4HCl$



Frame hydrolysis process to make fused silica glass invented by Dr. James Franklin Hyde, Corning, 1934

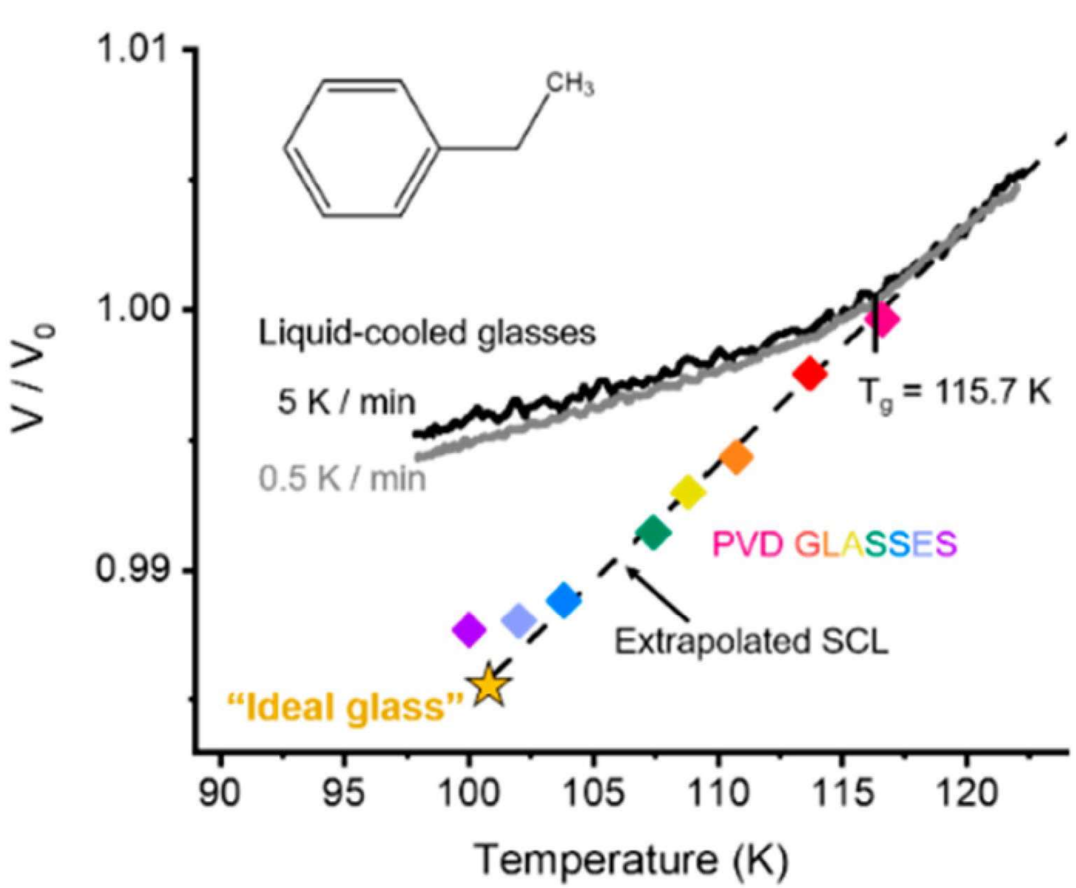




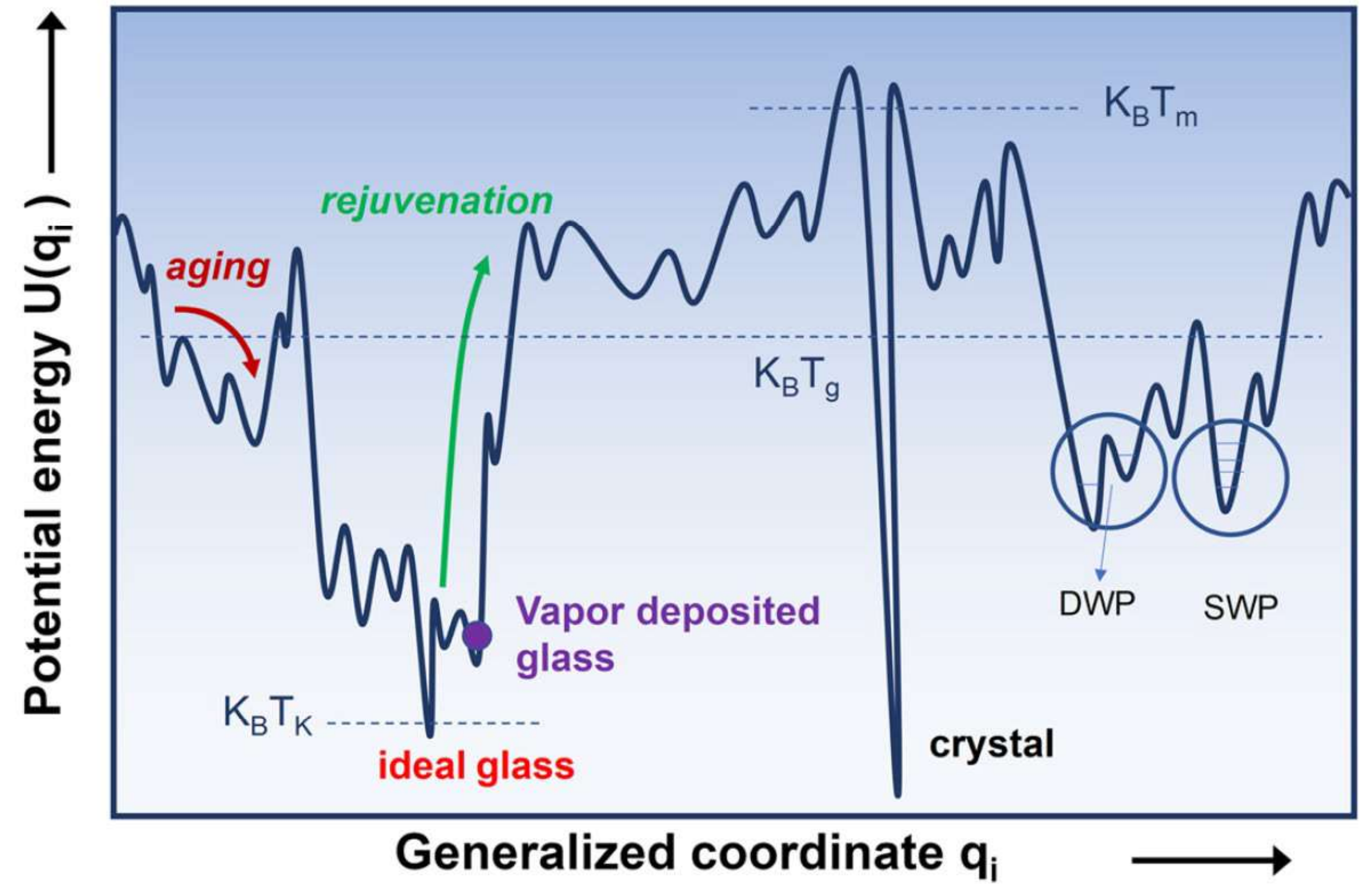


Corning flame hydrolysis fused silica boule in 1960’s.

Physical Vapor Deposition

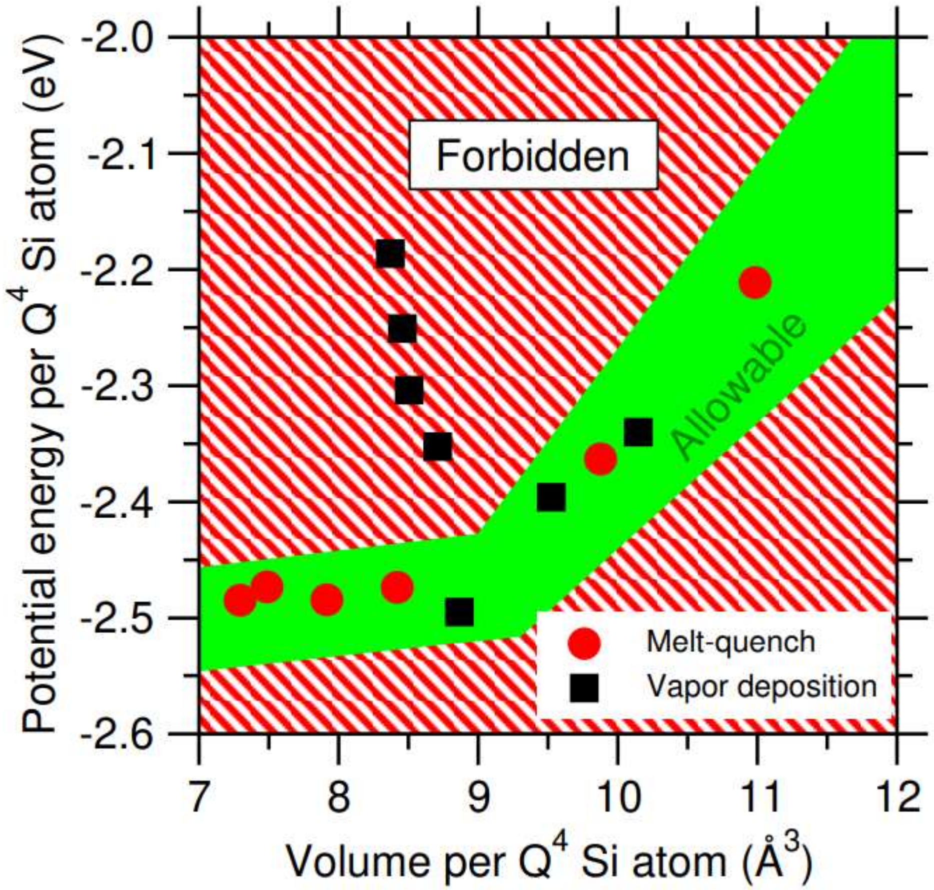


M. S. Beasley et al., *J. Phys. Chem. Lett.,* **10**, 4069 (2019)

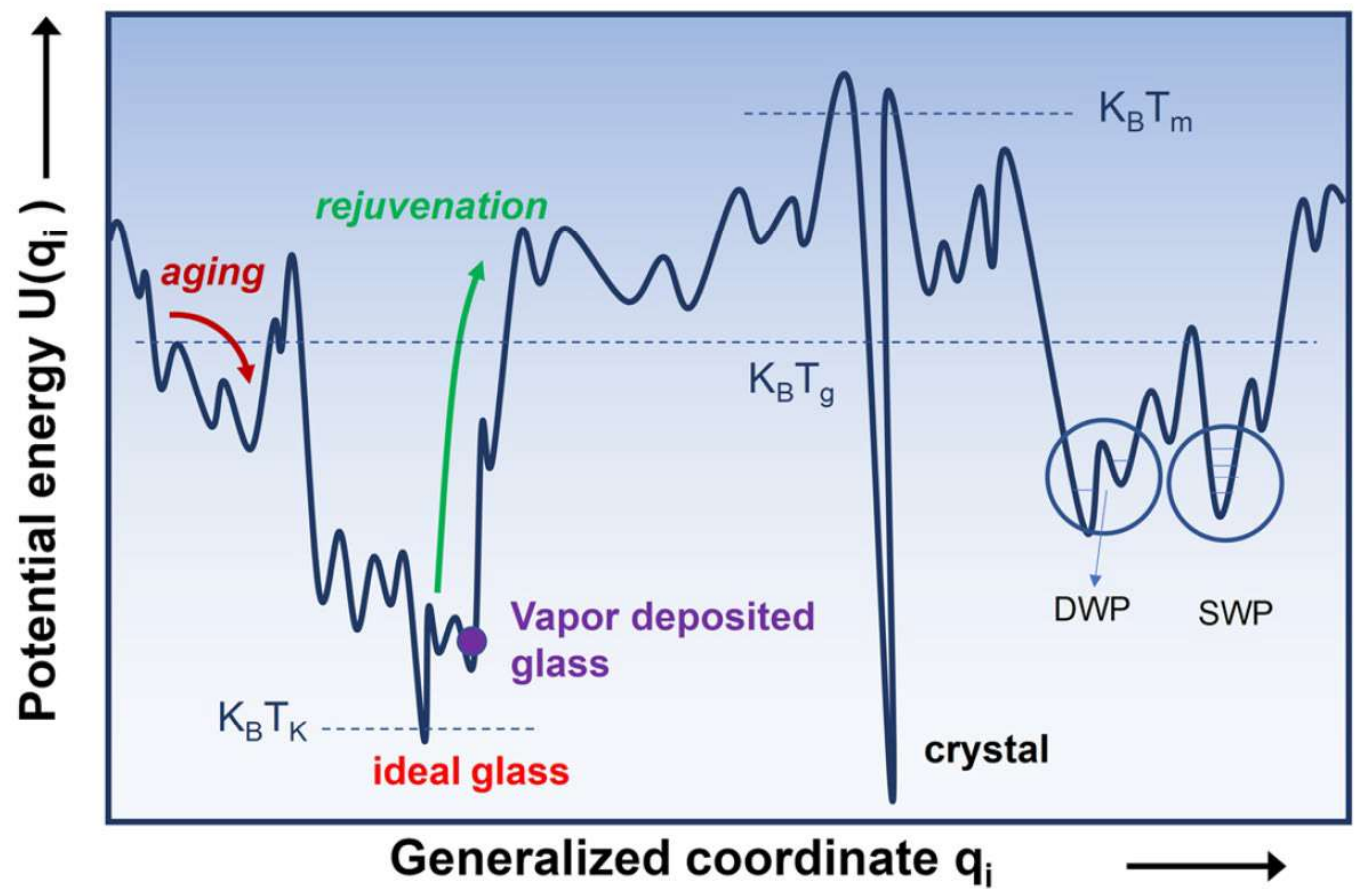


C. Rodriguez-Tinoco et al., *La Rivista del Nuovo Cimento*, **45**, 325 (2022).

Physical Vapor Deposition

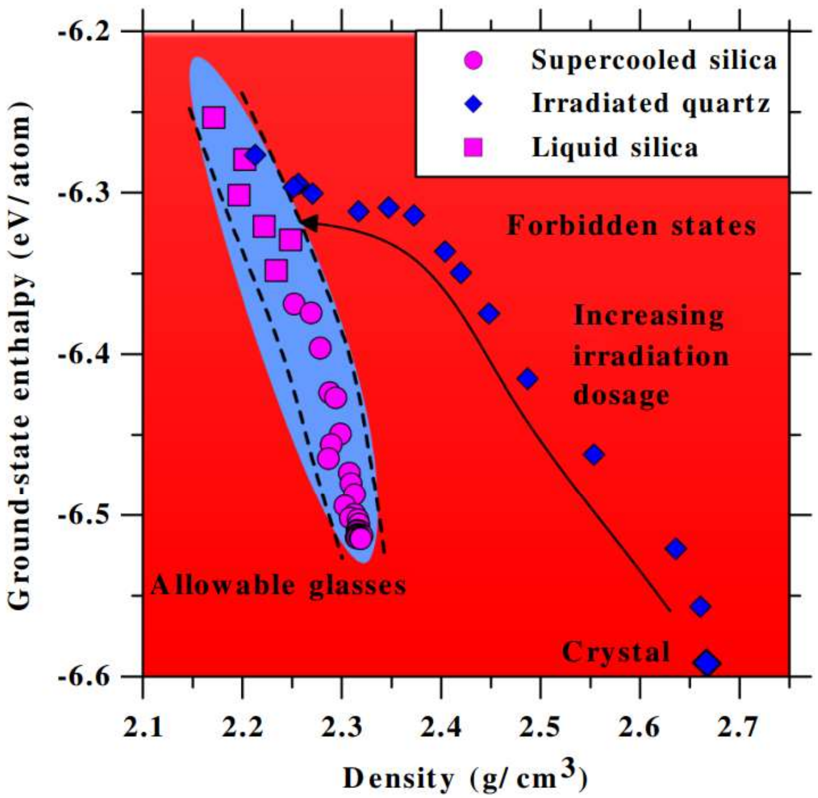


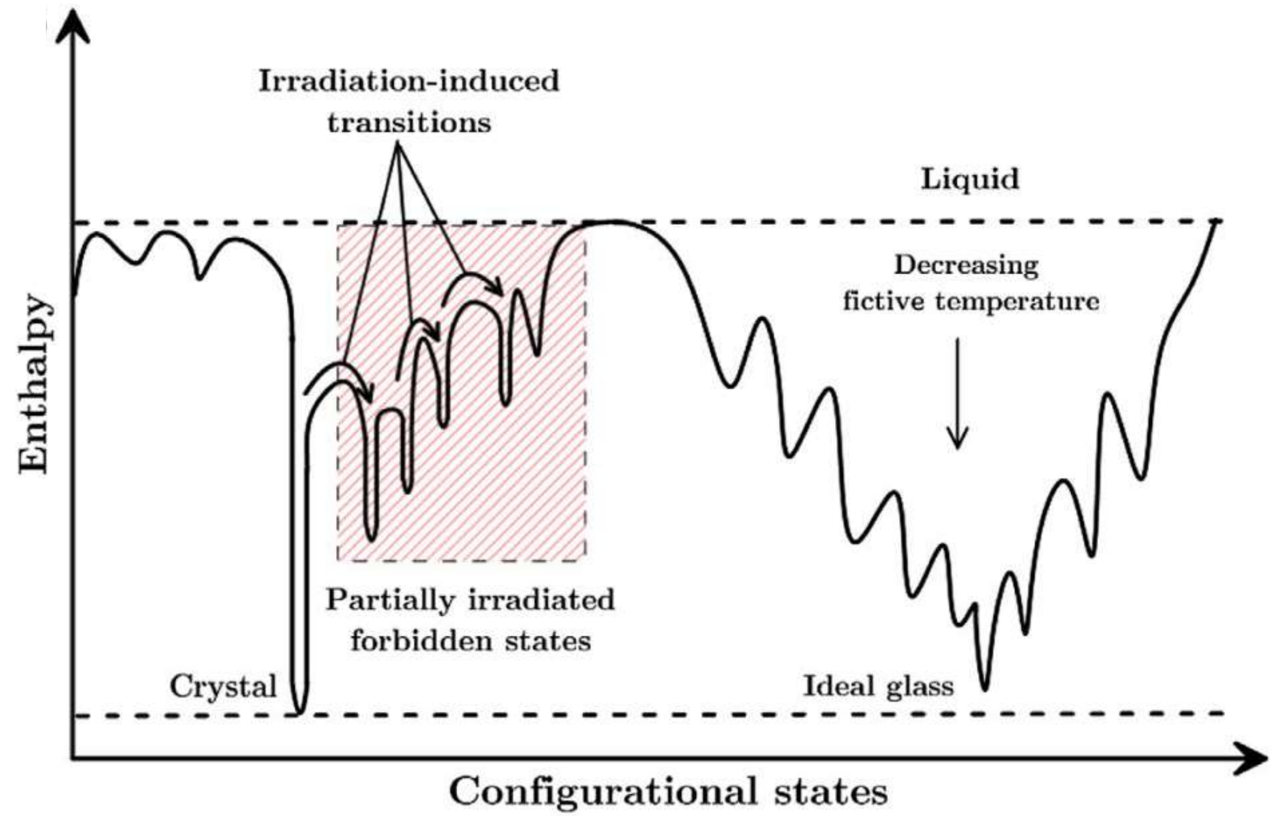
Z. Wang et al., *J. Chem. Phys.*, **152**, 164504 (2020)

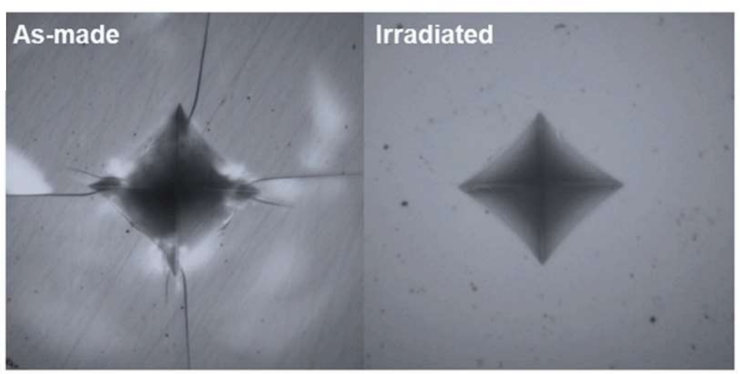


C. Rodriguez-Tinoco et al., La Rivista del Nuovo Cimento, **45**, 325 (2022)SS

Effects of Ion Irradiation







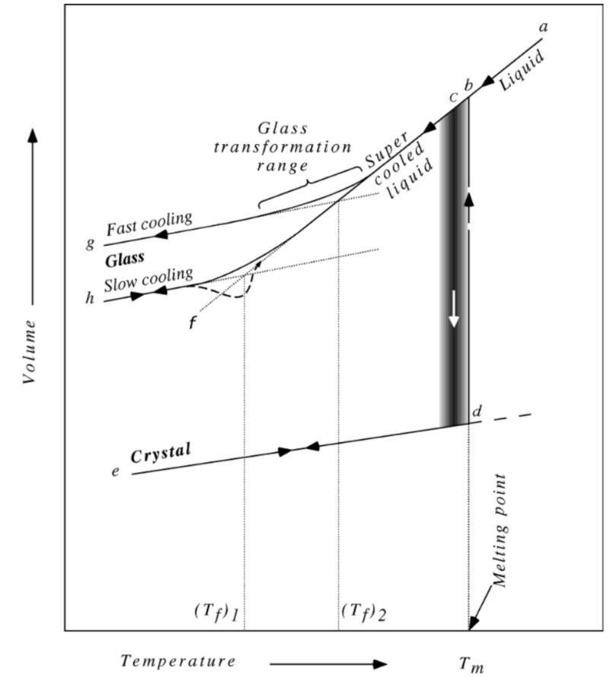
N. M. A., Krishnan et al., *Phys. Rev. X*, **7**, 031019 (2017)

X. T. Ren et al., *Materials Today Communications*, **31**, 103649 (2022)

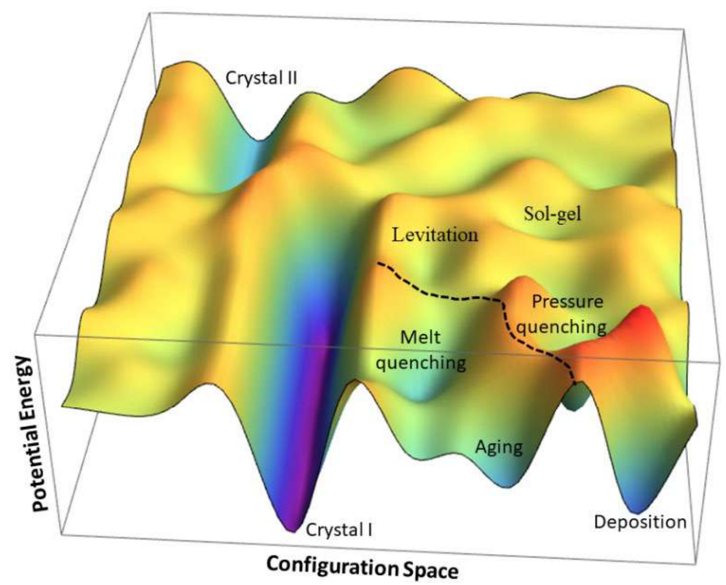
Pressure as a "New" Knob

nbcnews.com

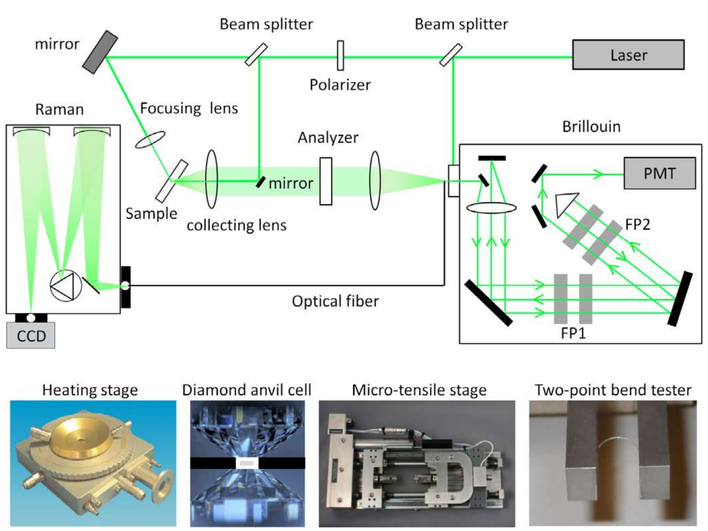
P. W. Bridgman, *Am. J. Sci.*, **7**, 81 (1924)
P. W. Bridgman, *Am. J. Sci.*, **10**, 359 (1925)

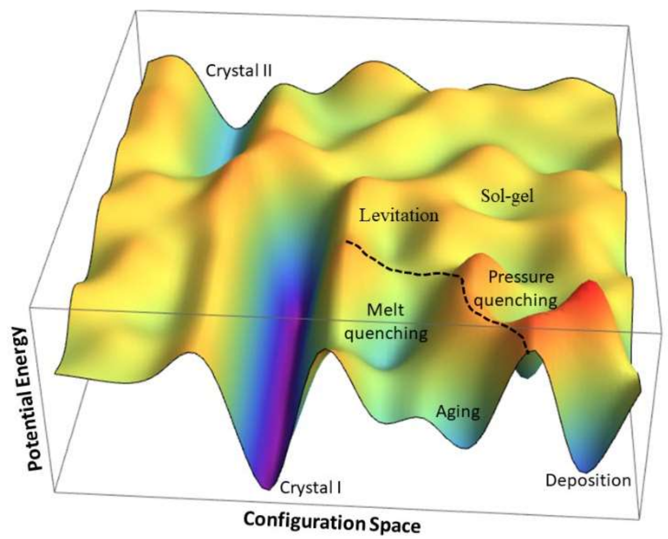


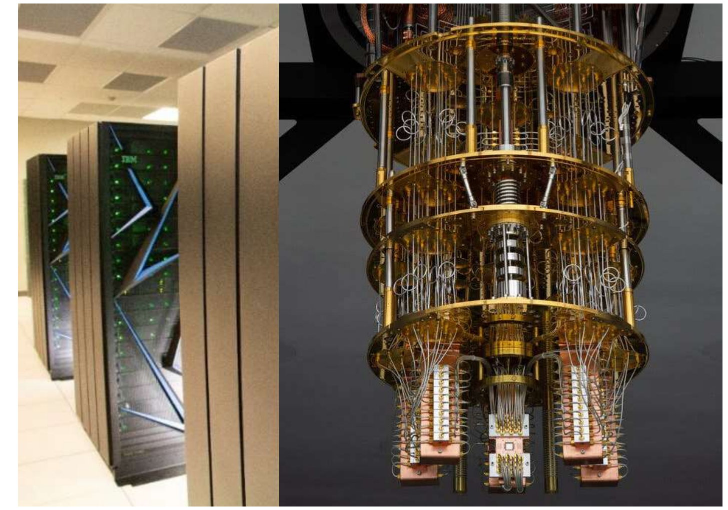
Fundamentals of Inorganic Glasses, 2nd Edition



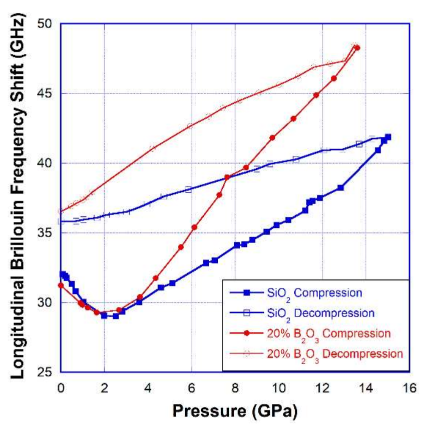
Research Theme of My Group



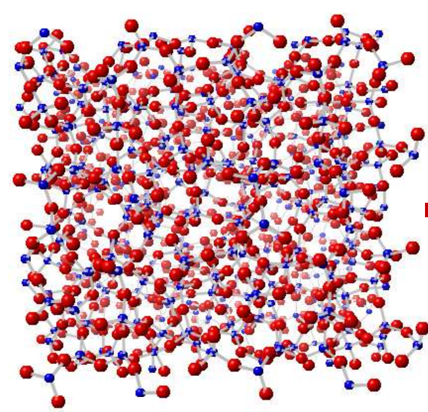




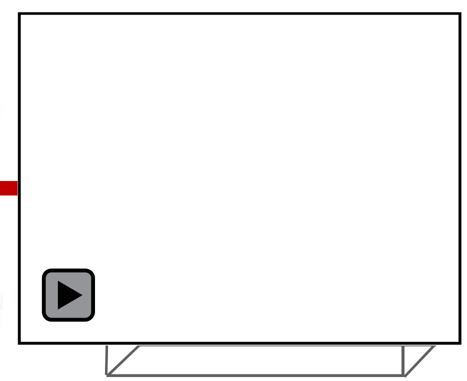
In-situ measurement



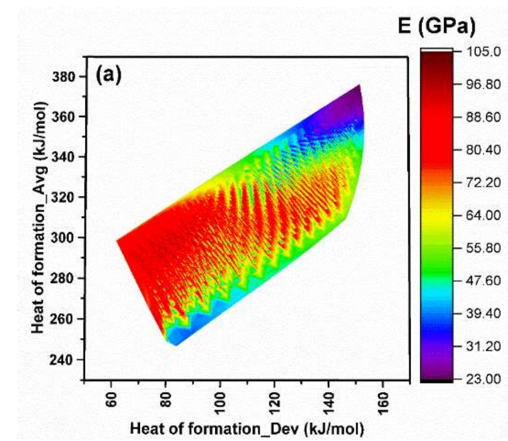
Atomic model



Simulation of virtual test



Machine learning prediction



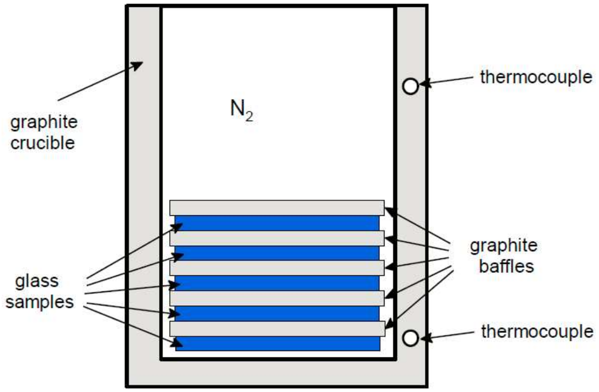
Na, Li, K, Ca, Mg, B, Al, Si, O, Ge

Sundararaman et al., J. Chem. Phys., 2018, 2019, 2020; Shih et al., JNCS, 2021.

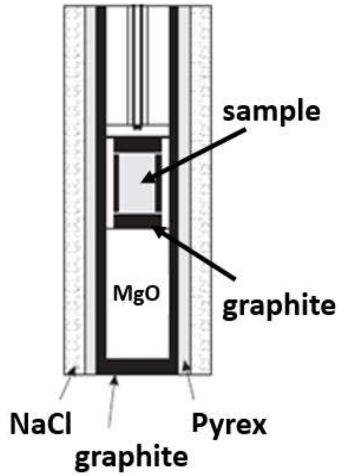
Pressure Processing Glass

Diamond anvil cell

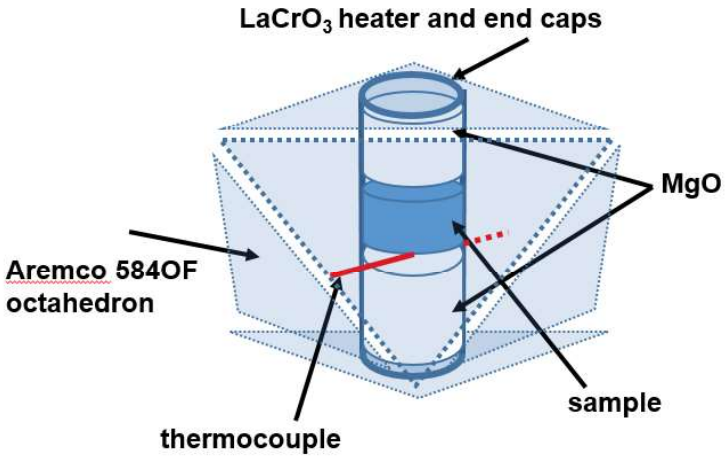
Gas medium press



Piston-cylinder apparatus



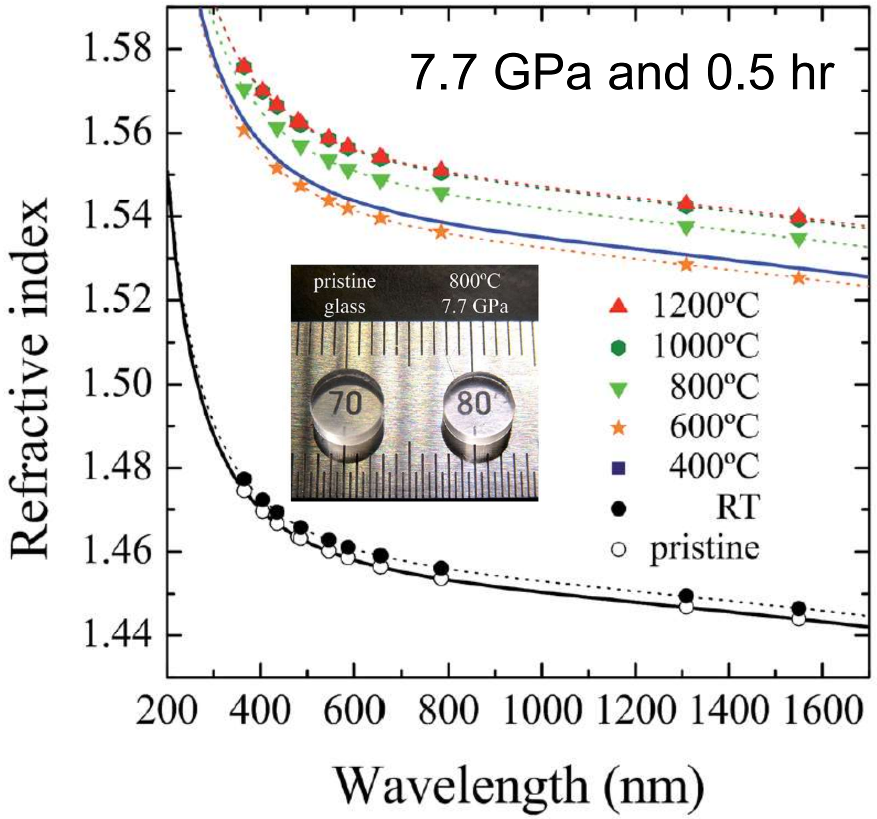
Multianvil cell



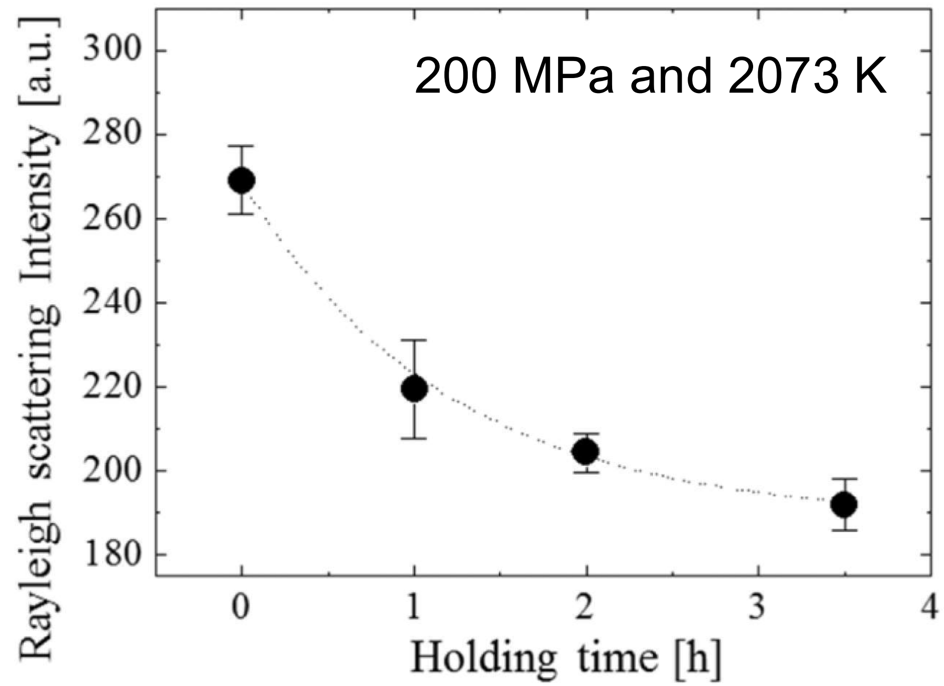
Smedskjaer et al., *J. Chem. Phys.*, **140**, 054511 (2014)

Guerette et al., *Scientific Reports*, **5**, 15343 (2015)

Pressure Effect on Optical Properties

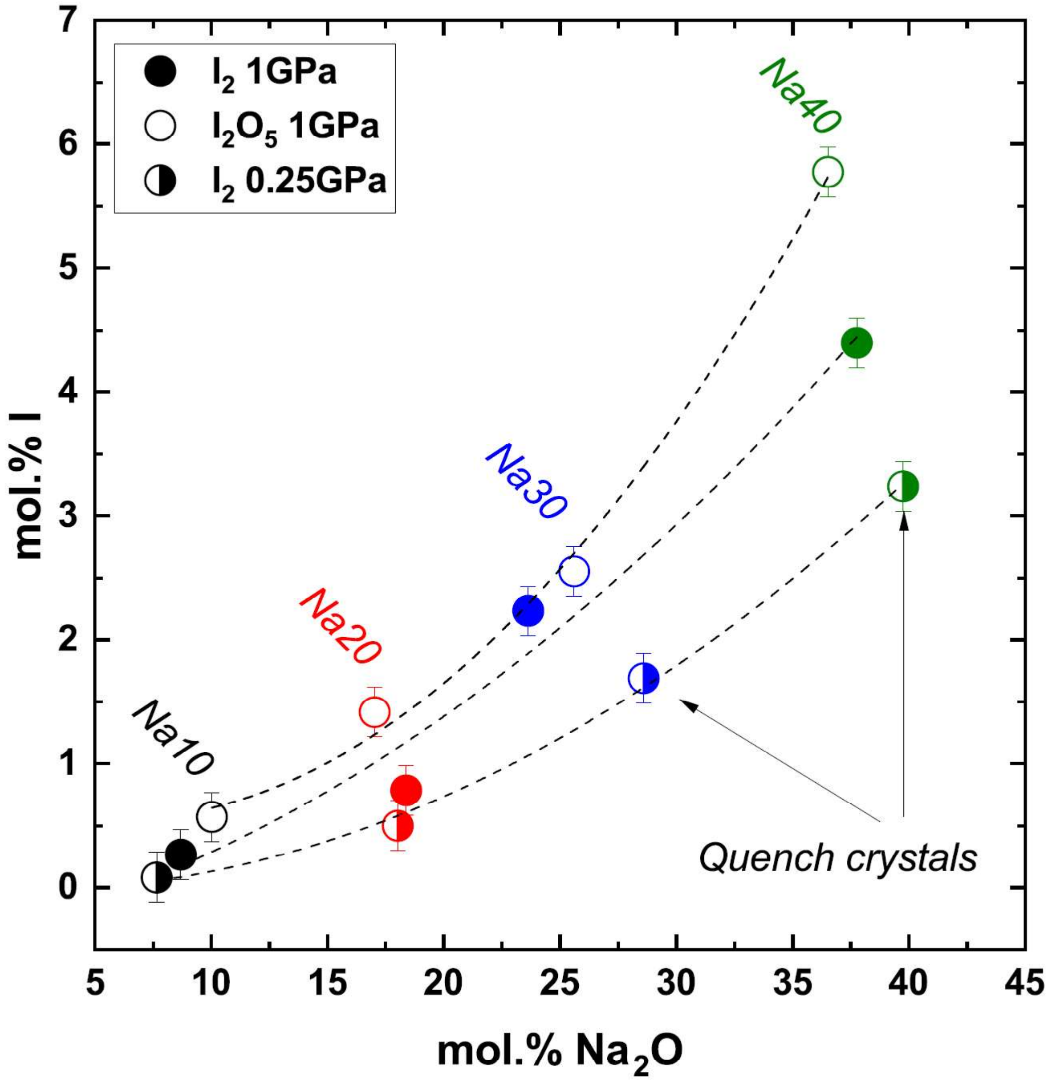


A. Masuno et al., *RSC Adv*., **6**, 19144 (2016)



M. Ono et al., *OPTICS EXPRESS*, **26**, 7943 (2018)

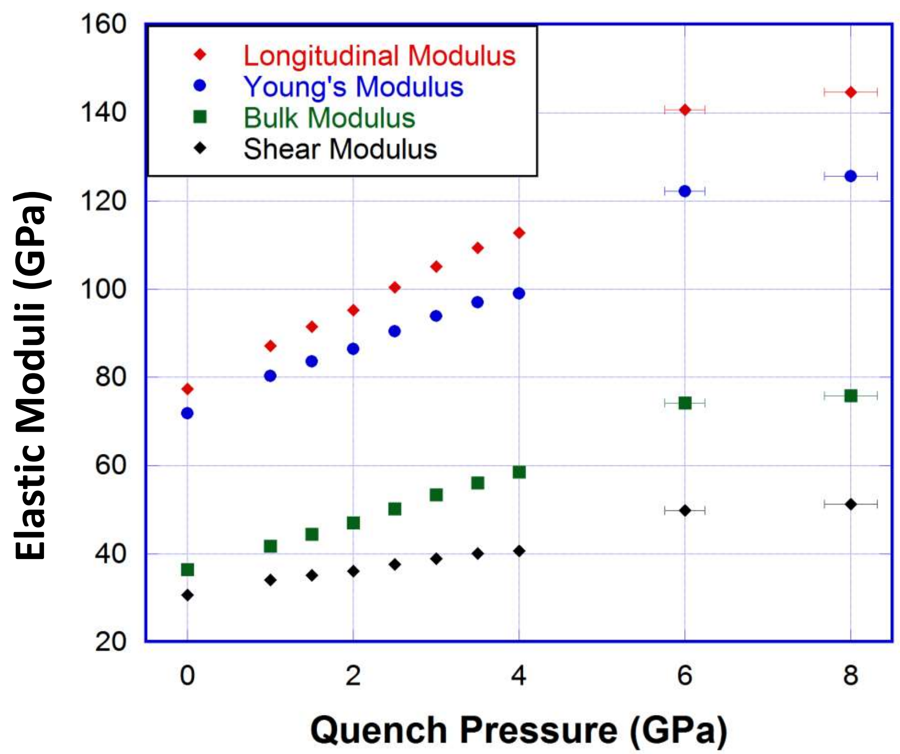
Pressure Effect on Iodine Dissolution

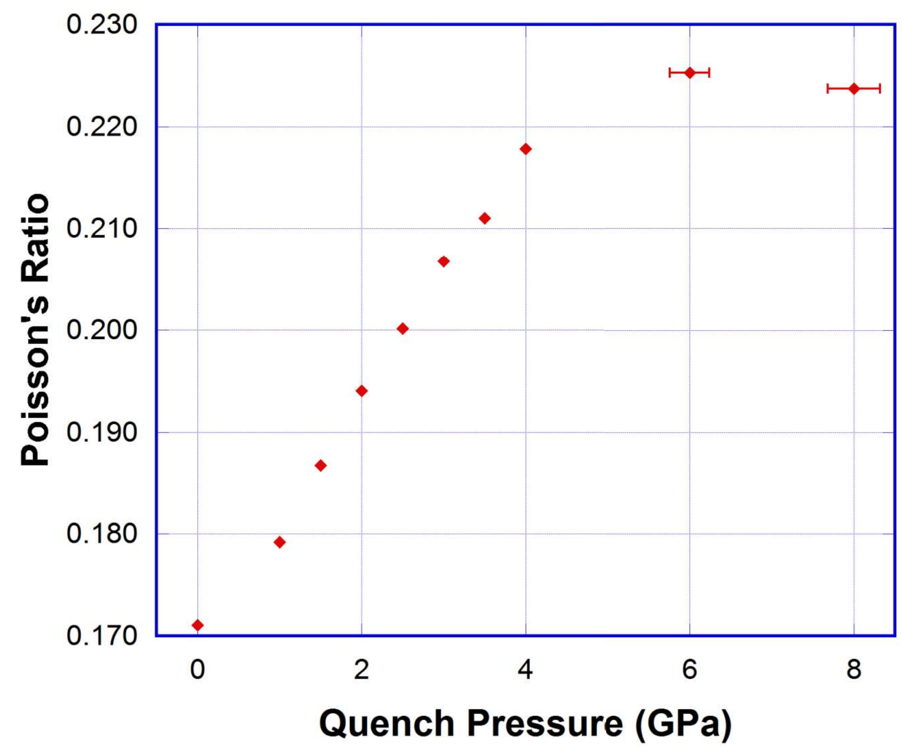


Y. Morizet et al., *Journal of Materials Chemistry A*, **11**, 22891 (2023)

Pressure Effect on Elastic Properties

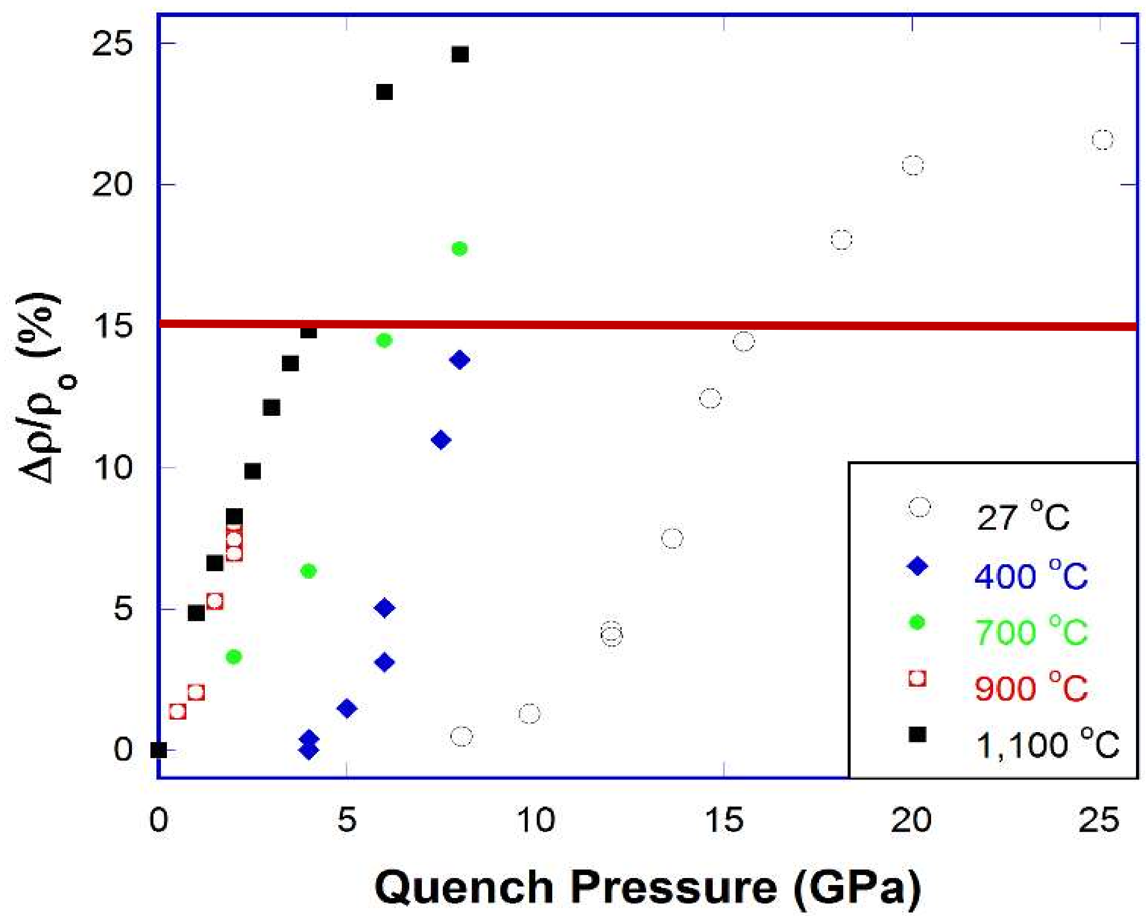
SiO_2 glass: 1100 °C , 0, 1, 1.5, 2, 2.5, 3, 3.5, 4, 6 and 8 GPa for 0.5 hr





Guerette et al., *Scientific Reports*, **5**, 15343 (2015)

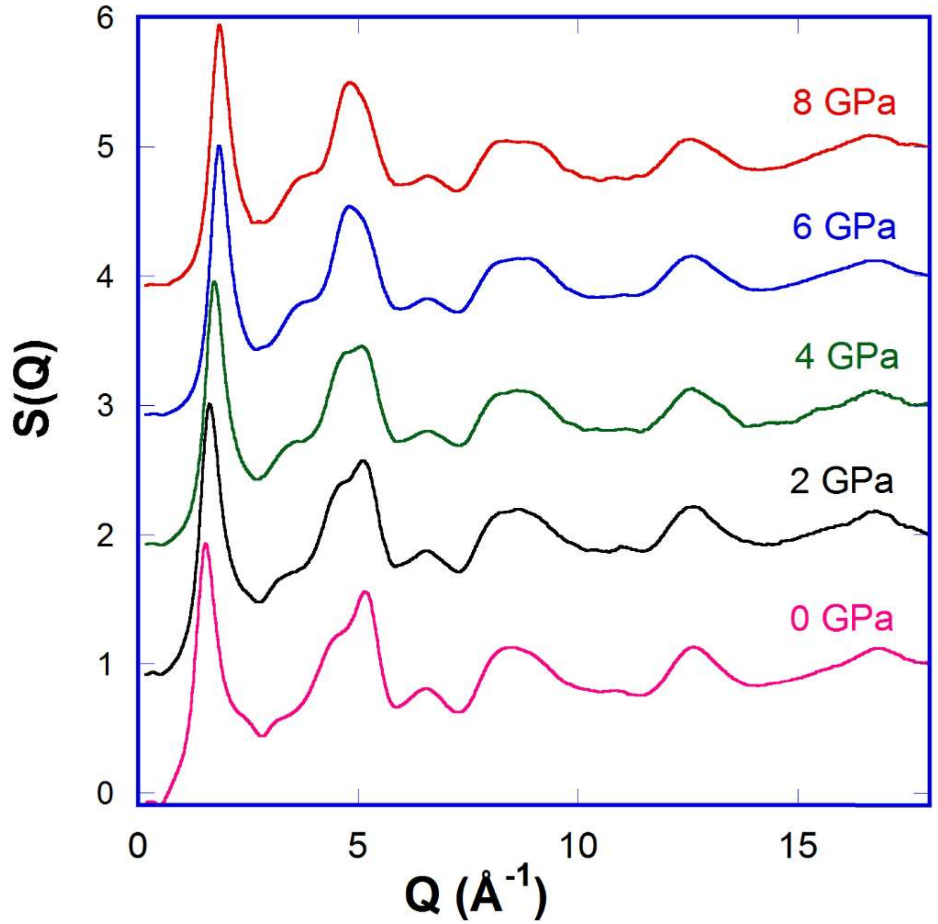
Permanent Densification of Silica Glass



Cold compression	27°C	from Rouxel et al., 2008 and Deschamps et al., 2014
	400°C	from Mackenzie, 1963 and Arndt and Stöffler, 1969
	700°C	from Poe et al., 2004
	900°C	from Hofler and Seifert 1984
Hot compression	1100 °C: our study	

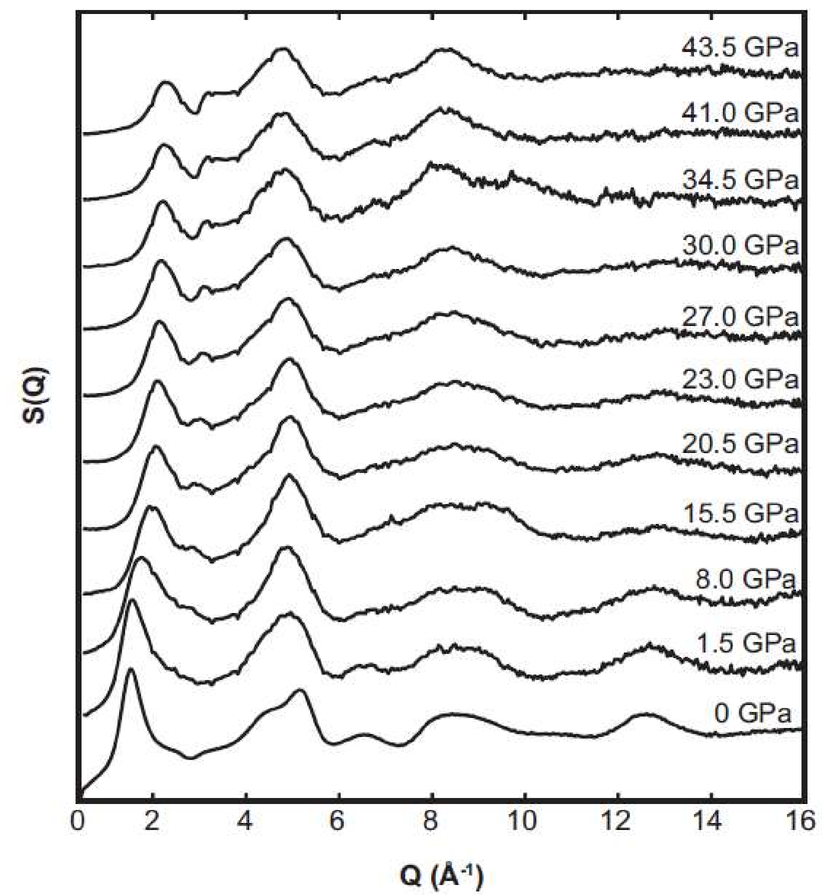
Ambient XRD

Hot compression



Guerette et al., *Scientific Reports*, **5**, 15343 (2015)

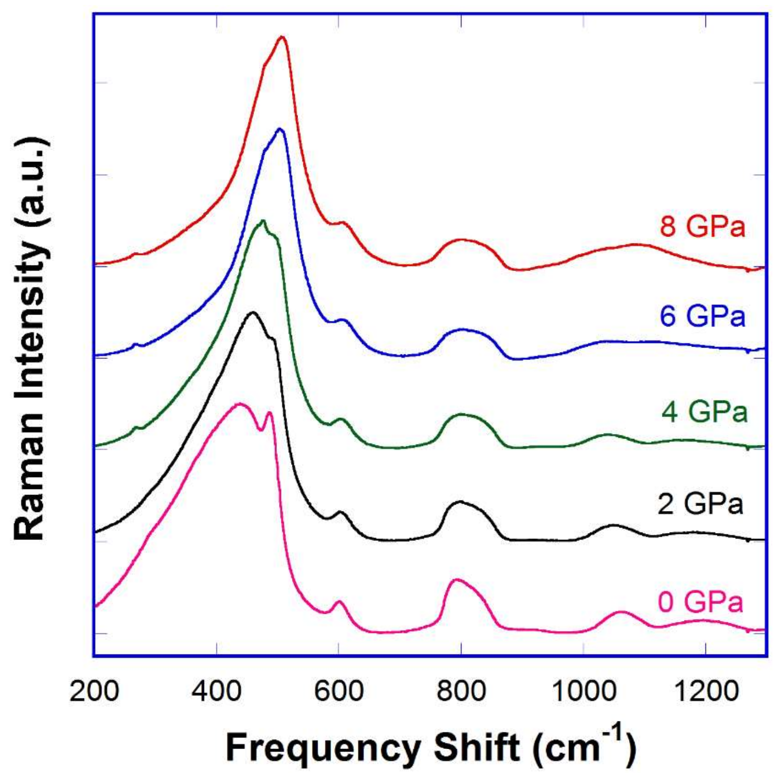
Cold compression



Benmore et al. , *Phys. Rev. B: Condens. Matter,* **81**, 054105 (2010)

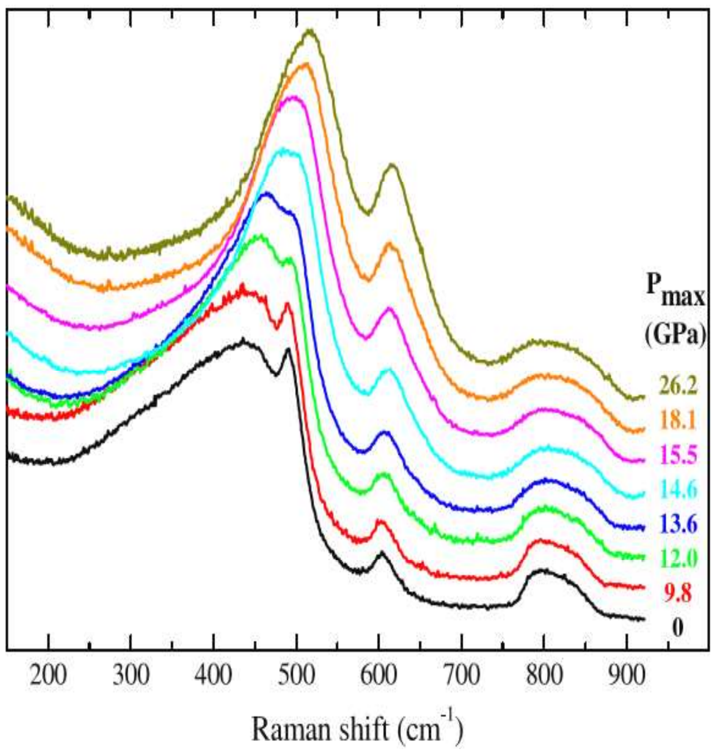
Ambient Raman Spectra

Hot compression



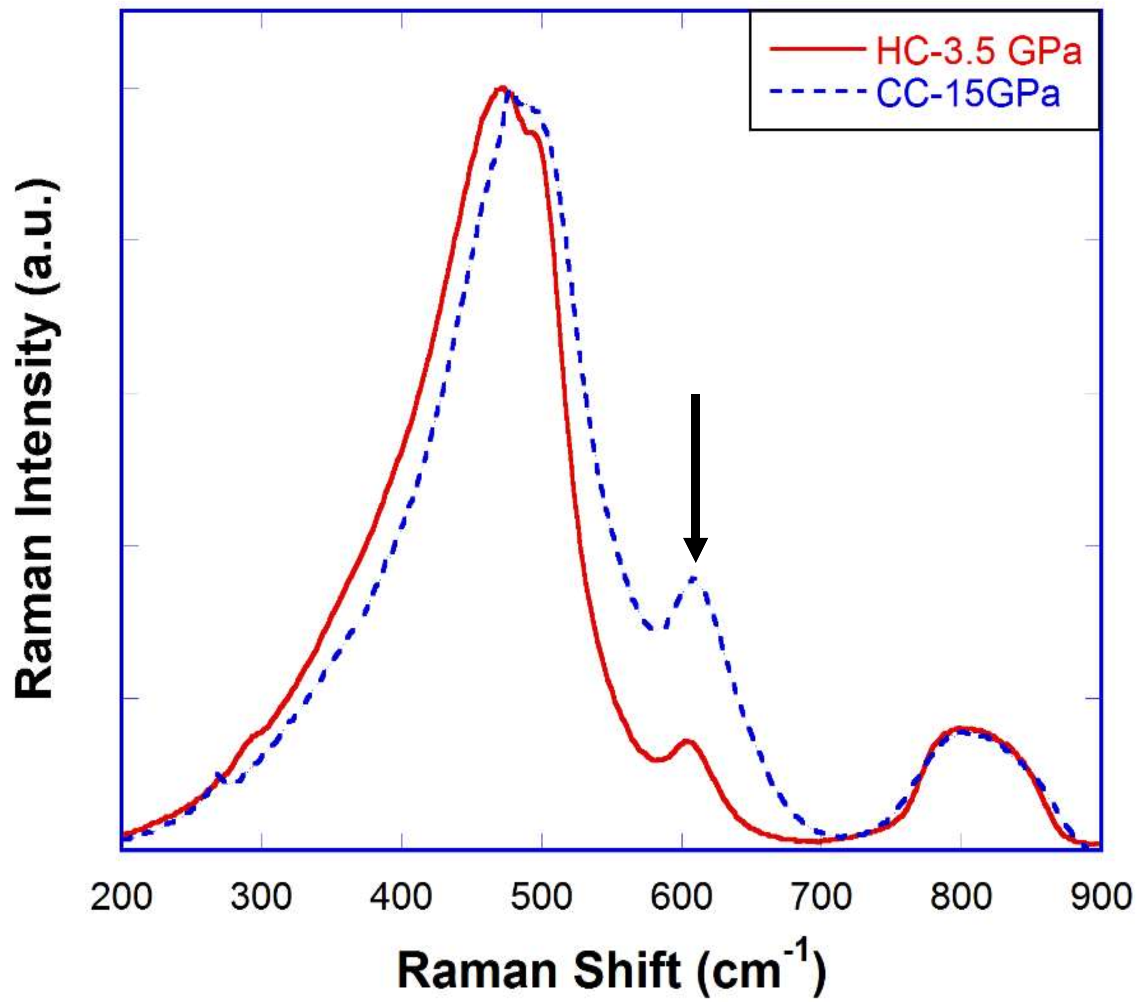
Guerette et al., *Scientific Reports*, **5**, 15343 (2015)

Cold compression



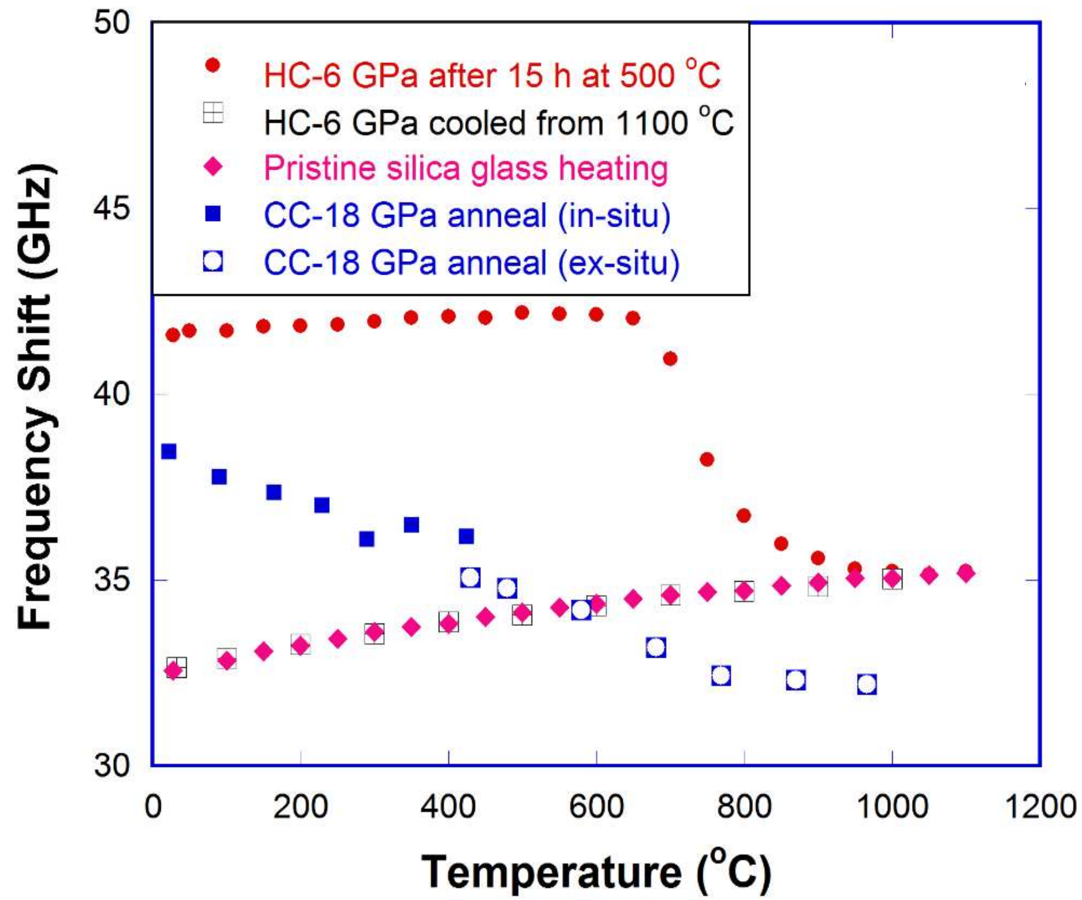
Deschamps et al., *J. Phys.: Condens. Matter* **25**, 025402 (2013)

Ambient Raman Spectra



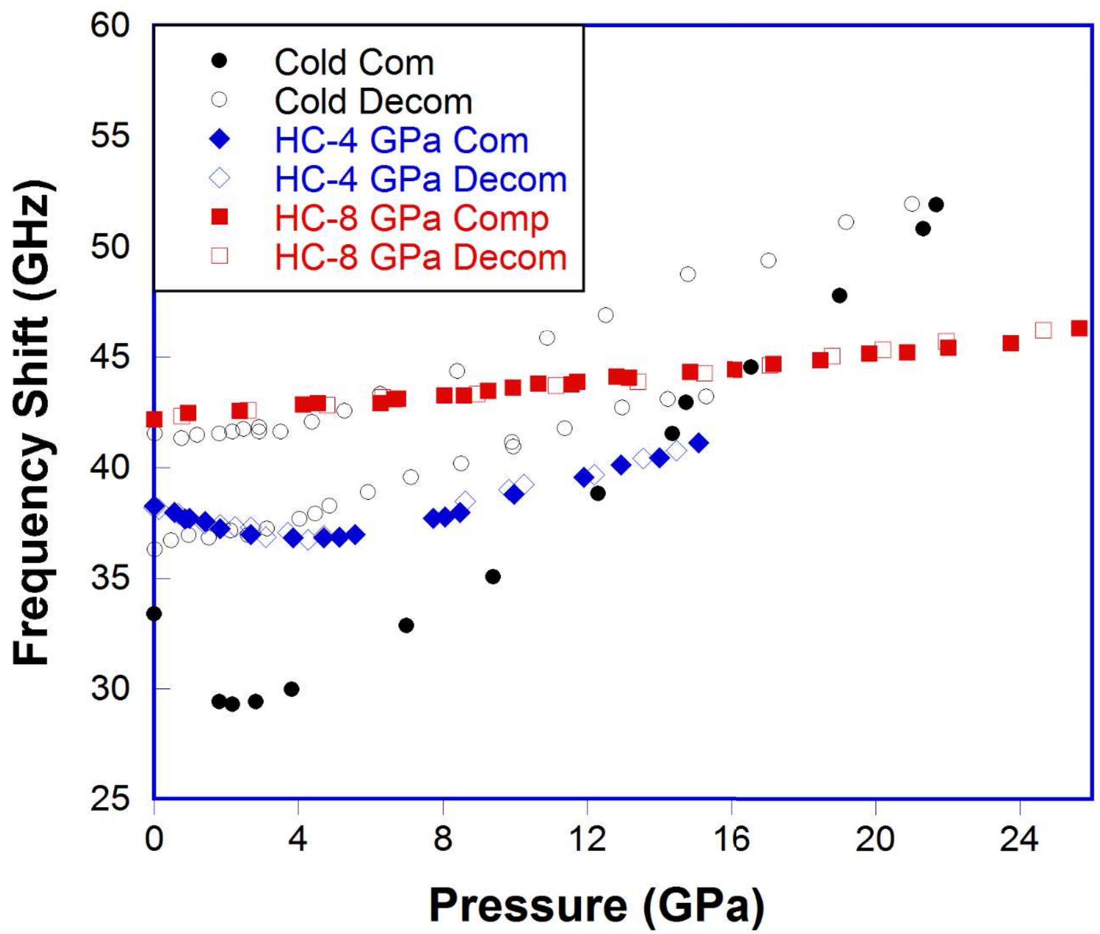
Guerette et al., *Scientific Reports*, **5**, 15343 (2015)

Response of Pressure-quenched Silica Glass to Temperature

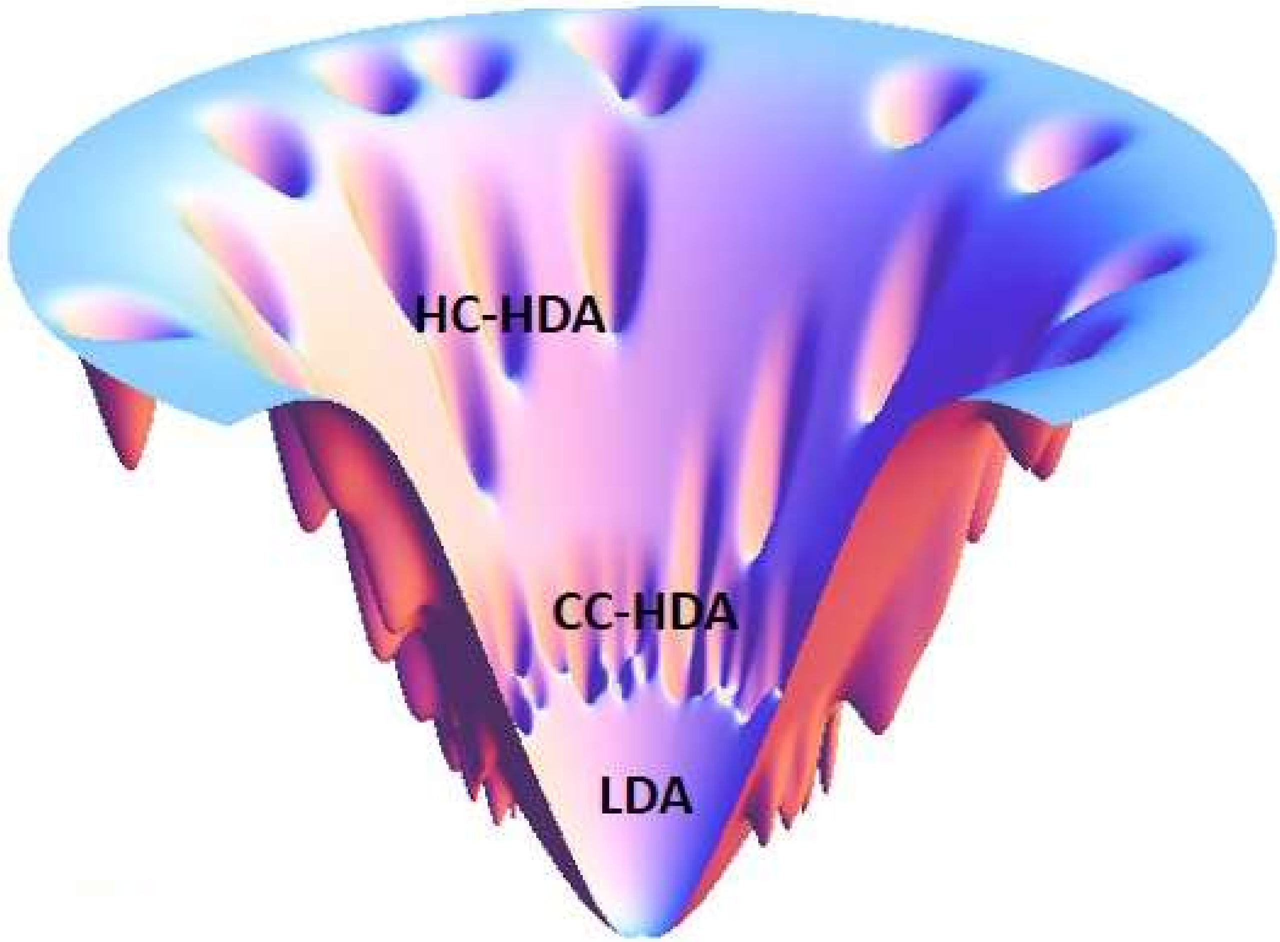


Grimsditch, *Phys. Rev. B: Condens. Matter,* **34**, 4372 (1986) Guerette et al., *J. Chem. Phys*., **21**, 194501 (2018)

Response of Pressure-quenched Silica Glass to Pressure

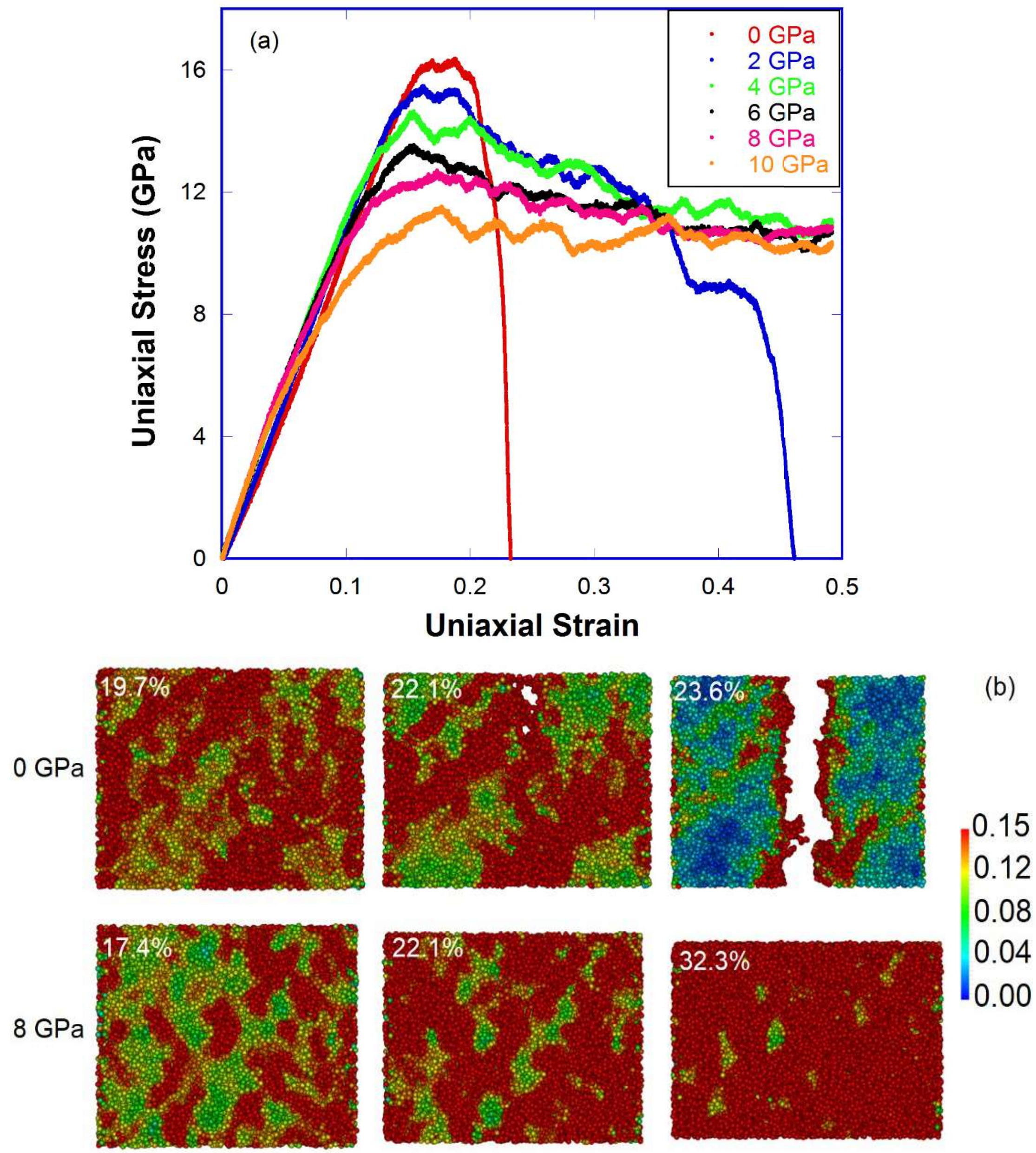


Guerette et al., *Scientific Reports*, **5**, 15343 (2015) C Sonneville, et al., *J. Chem. Phys.*, **137**, 124505 (2012)



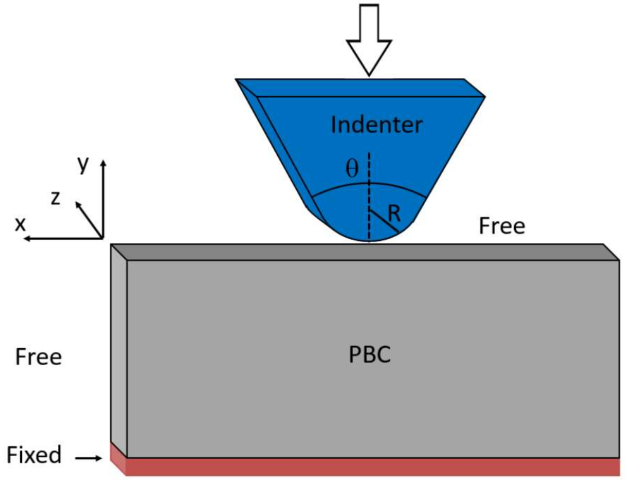
Guerette et al., *J. Chem. Phys.*, **21**, 194501 (2018)

Enhanced Ductility in Densified Silica Glass

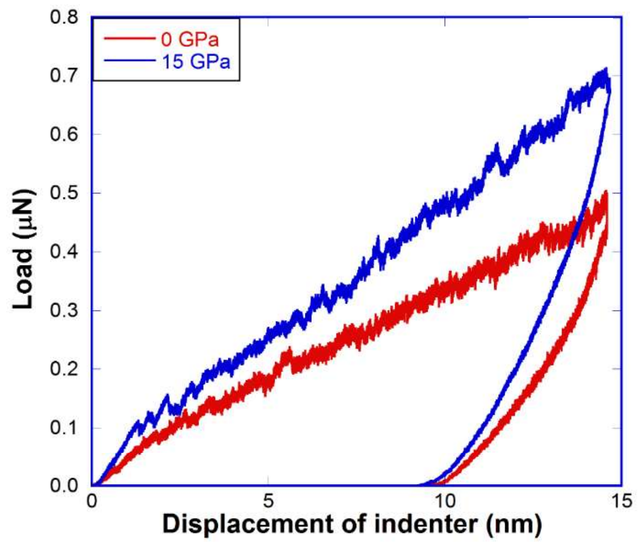


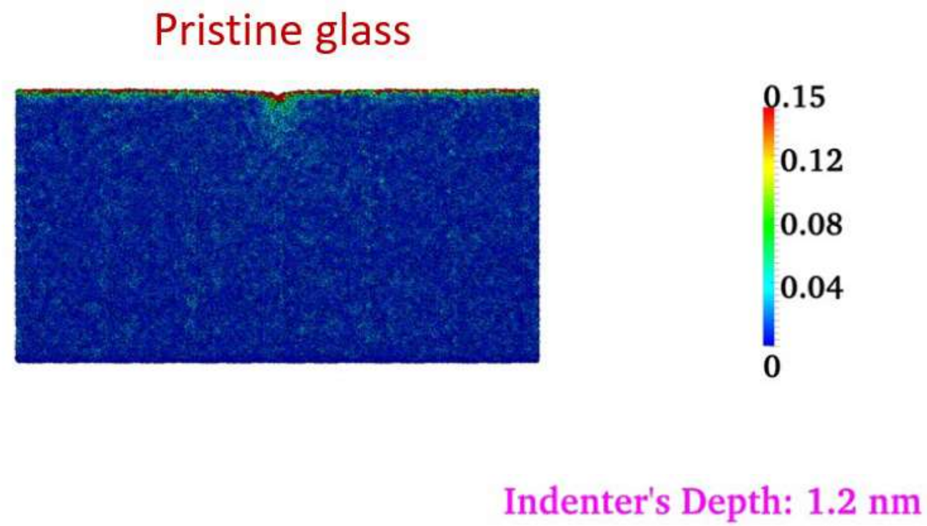
Yuan and Huang, *Scientific Reports*, **4**, 5035 (2014)

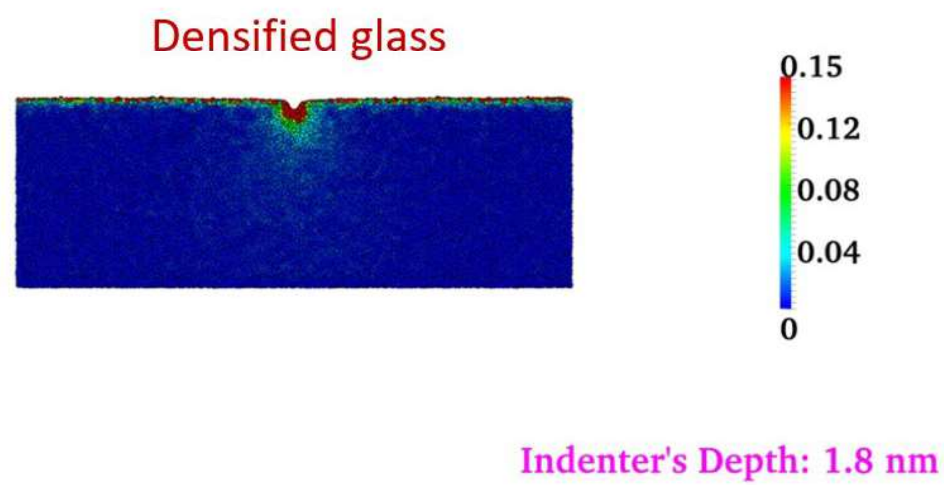
Simulated Nano-indentation in Silica Glass



56.48 × 56.48 × 2.82 nm
~half million atoms
Tip angle: 60°, tip radius: 1 nm
Loading speed: ~12.5 m/s

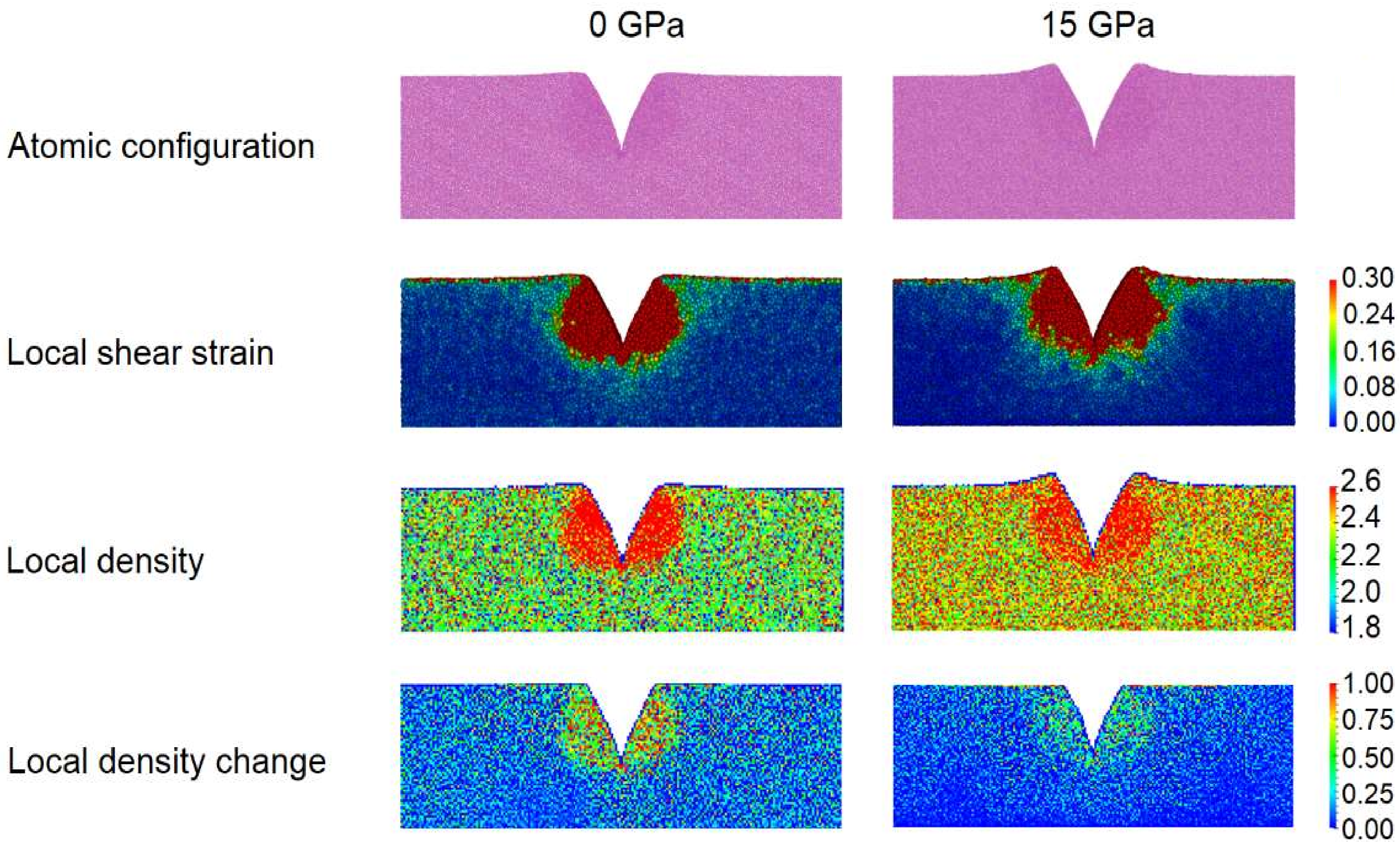






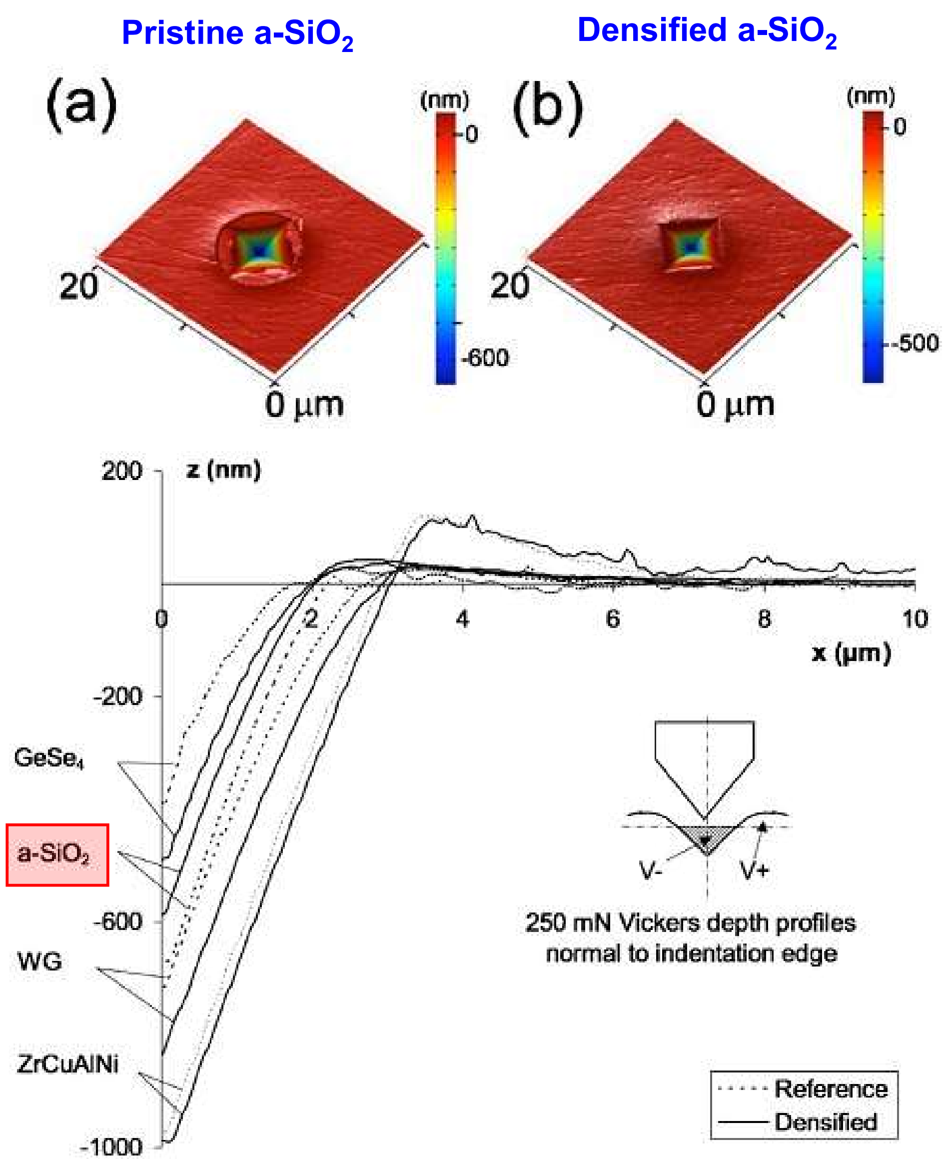
Yuan and Huang, *Scientific Reports*, **4**, 5035 (2014)

Deformation Modes under Indentation

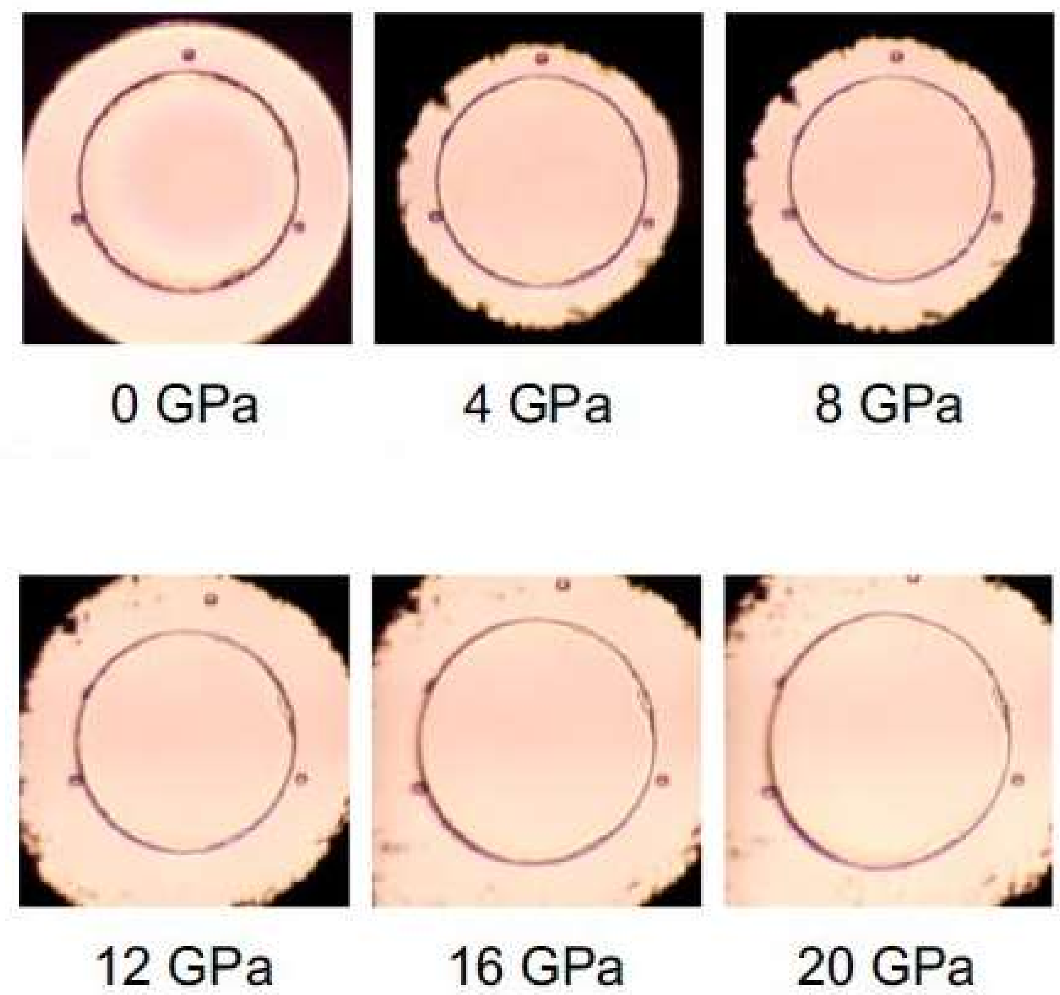


Yuan and Huang, *Scientific Reports*, **4**, 5035 (2014)

Enhanced Shear Flow in Densified Silica Glass

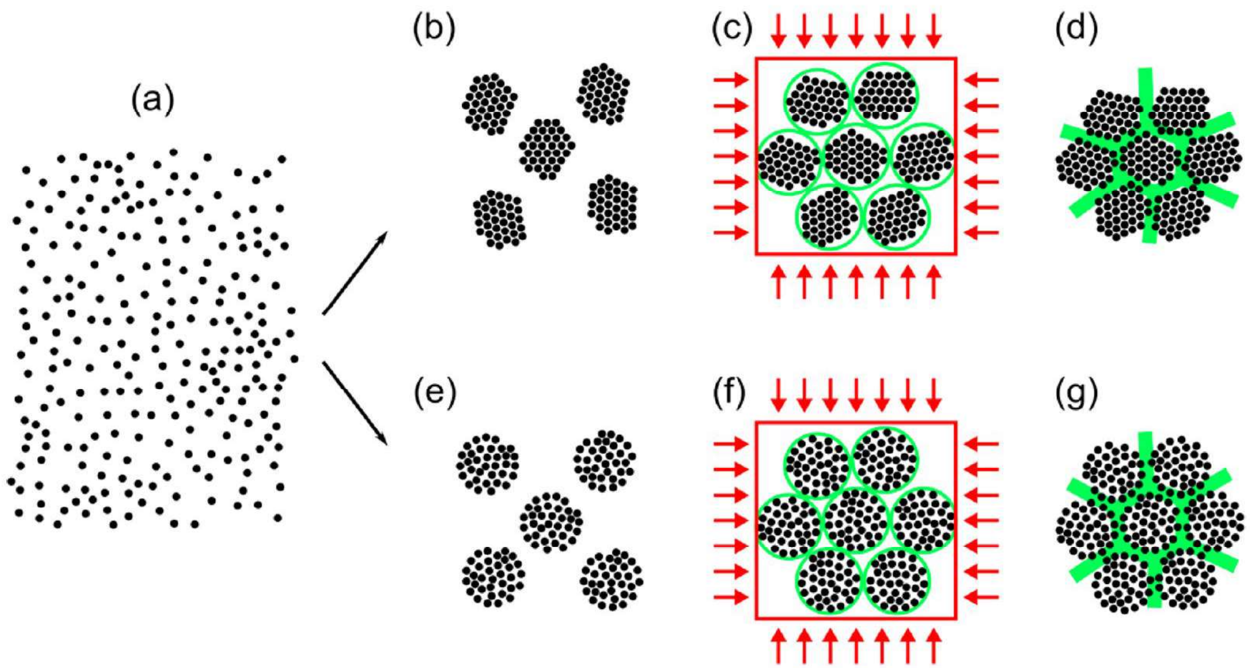


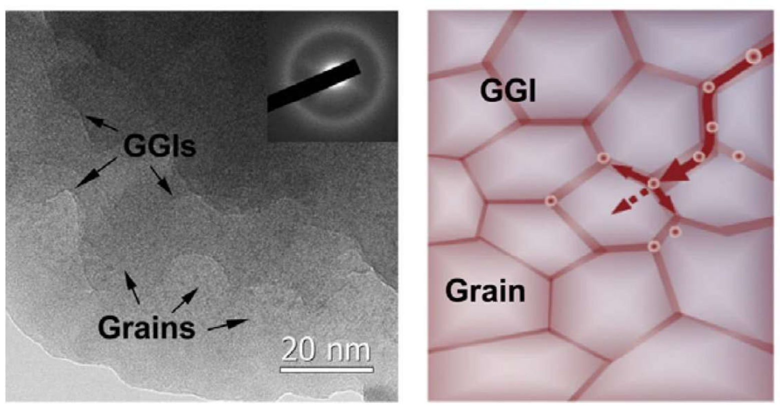
T. Rouxel et al., *J. Appl. Phys.*, **107**, 094903 (2010)

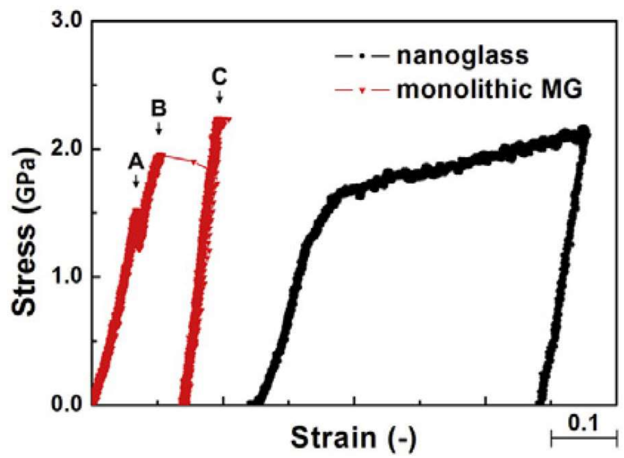


D. Wakabayashi et al., *Phys. Rev. B*, **91**, 014106 (2015)

Nanoglass from Consolidation

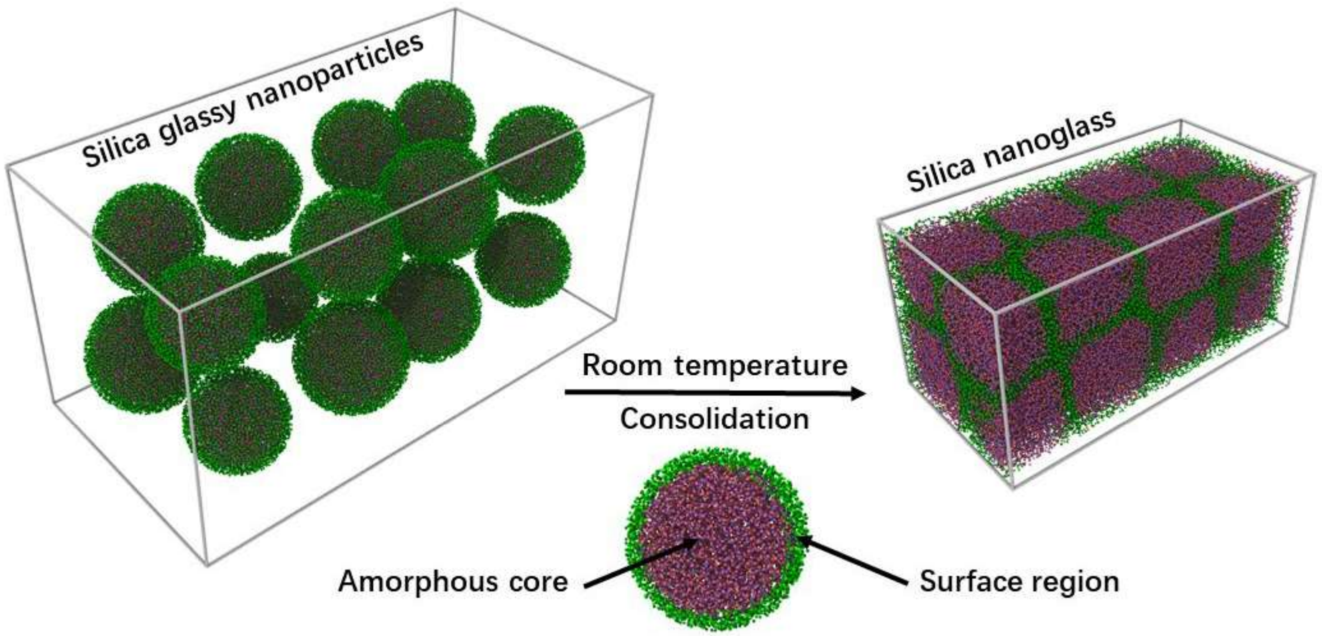


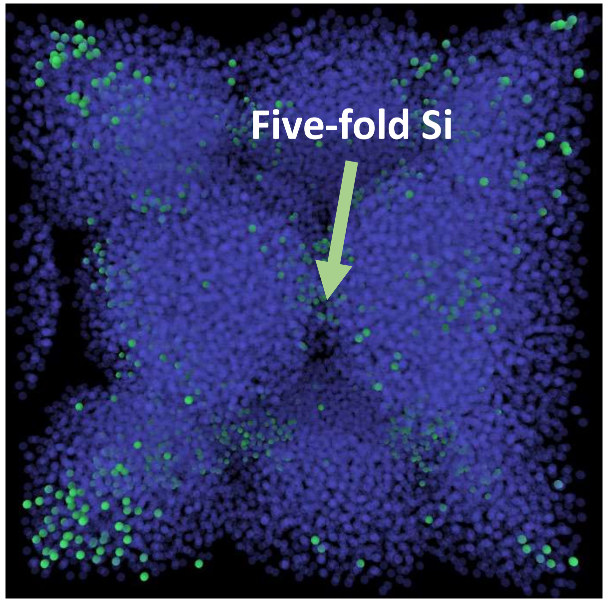




D. Danilov et al., *ACS Nano,* **10**, 3241 (2016) X. L. Wang et al., *Scripta Materialia*, **98**, 40 (2015)

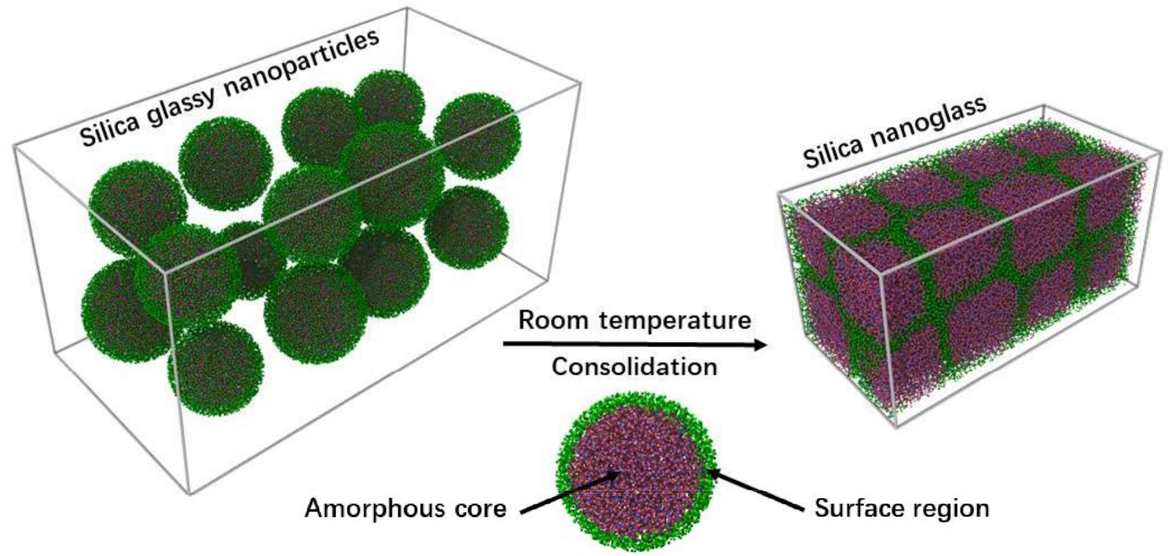
Glass from Consolidation of Silica Nanoparticles

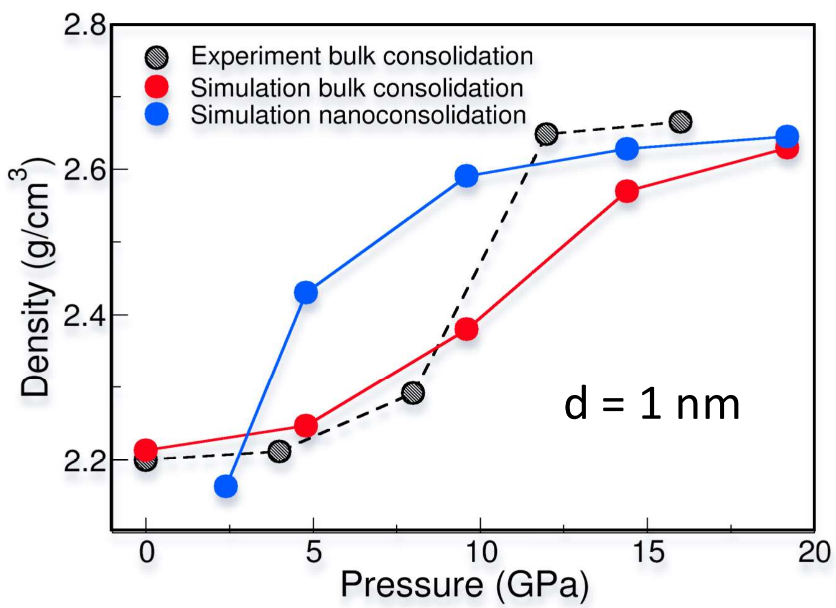


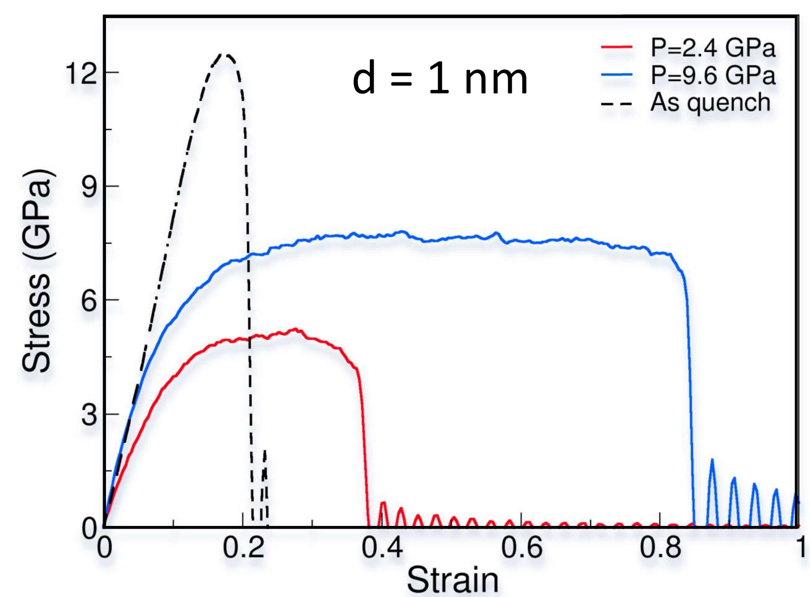


Y. Zhang et al., *Nano Letter*, **19**, 5222 (2019)

Consolidation of Silica Nanoparticles







Rouxel T. et al., *Phys Rev Lett*, **100**, 225501 (2008)

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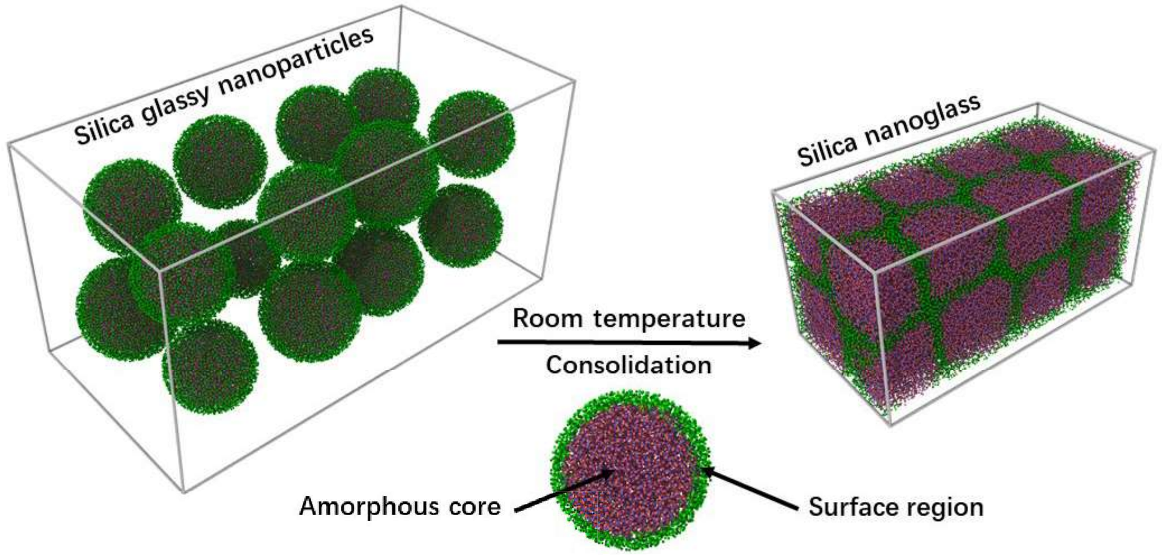
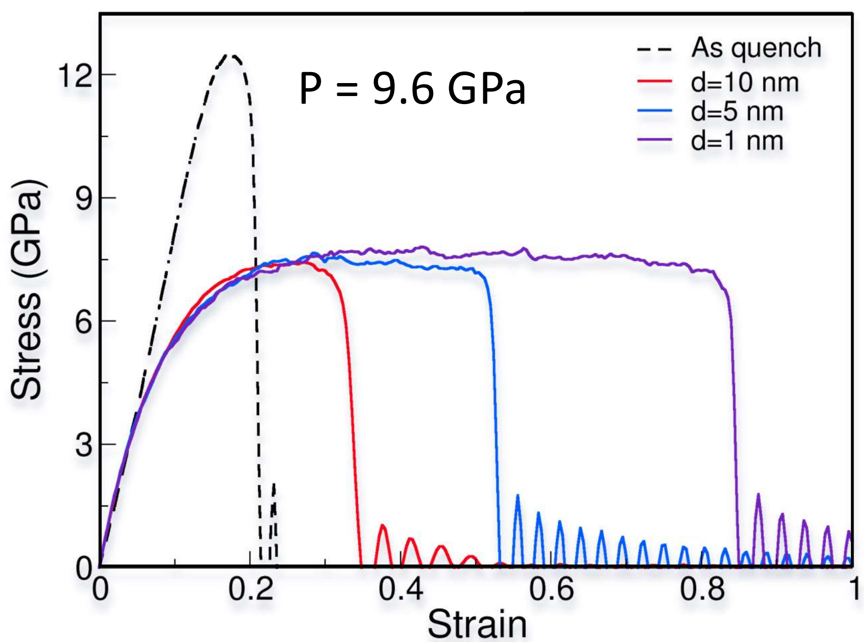
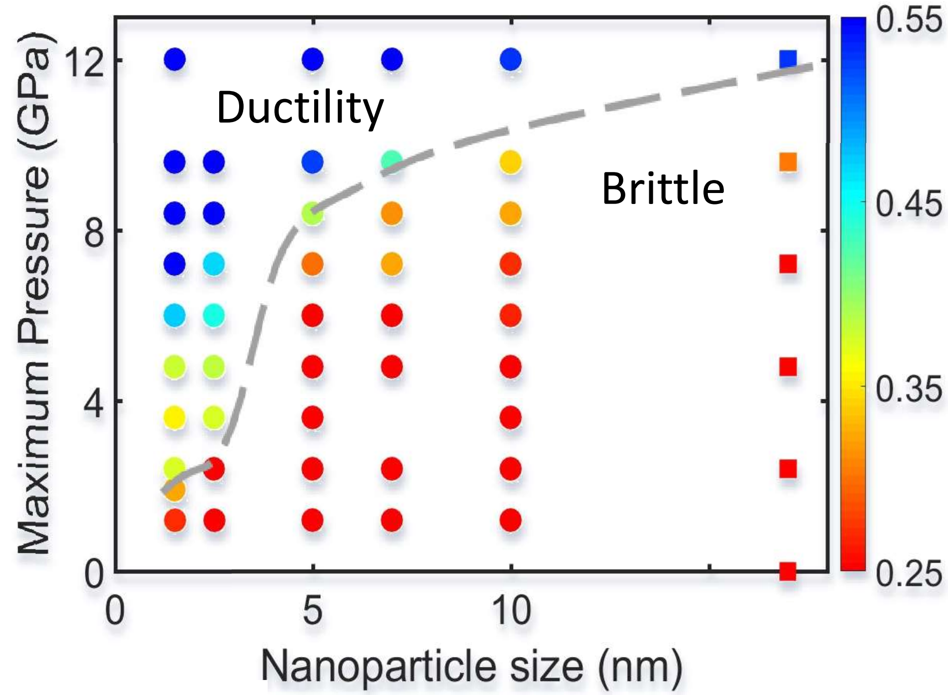
Effect of Nanoparticle Size

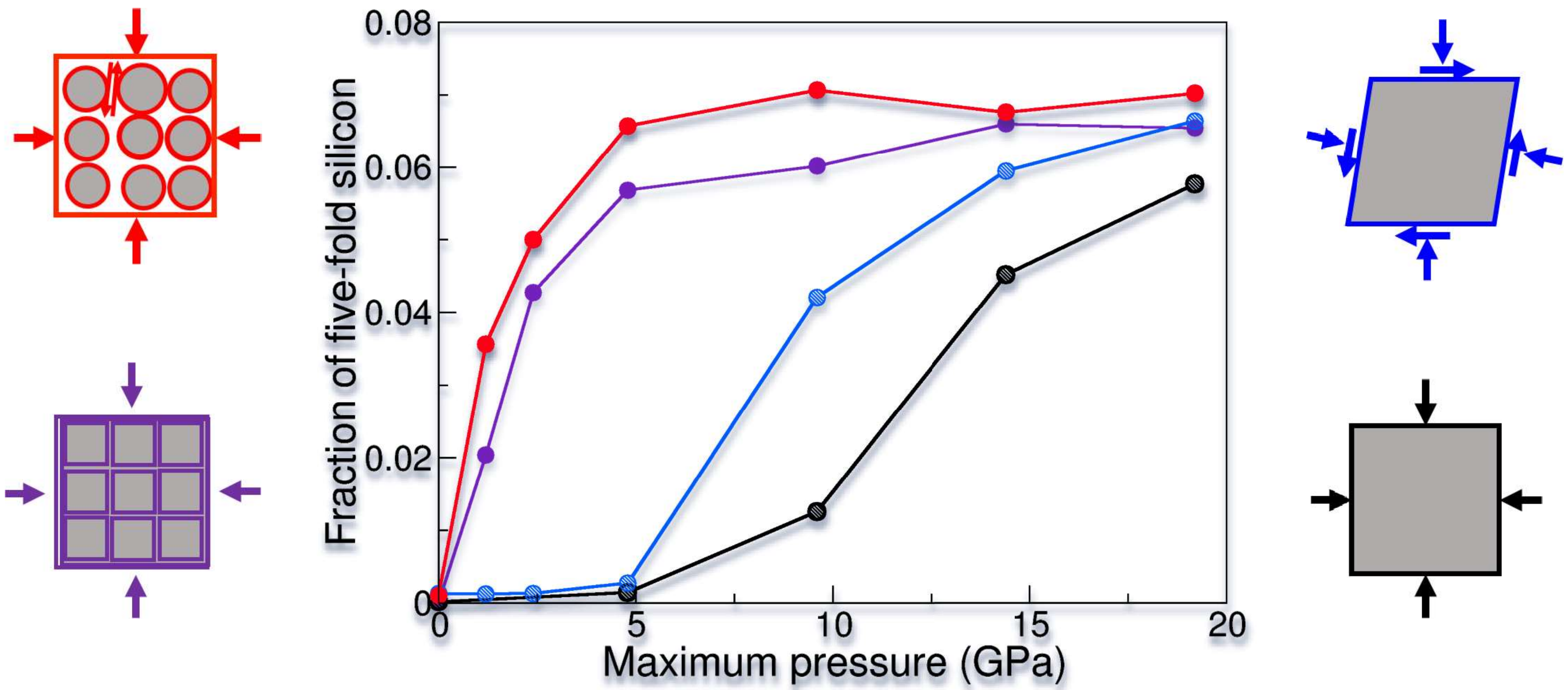






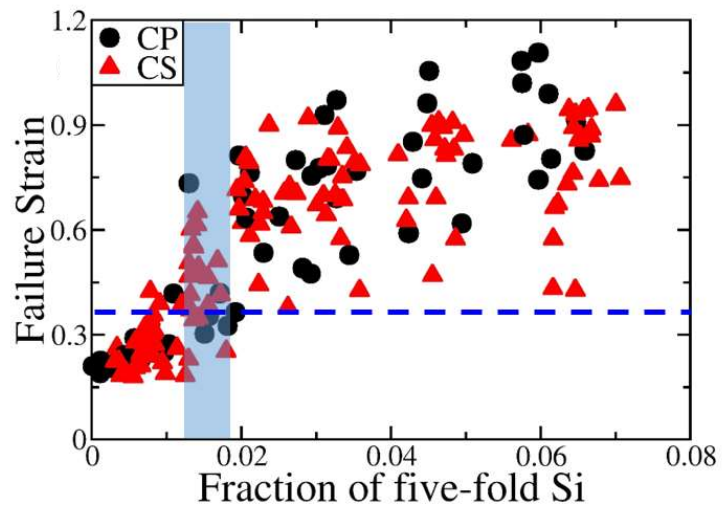
Y. Zhang et al., *Nano Letter*, **19**, 5222 (2019)

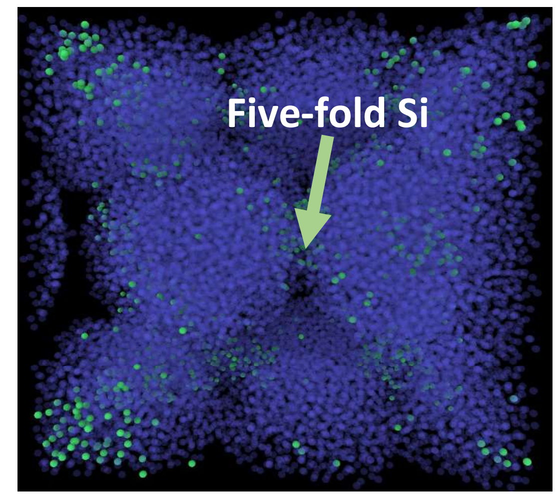
Formation of 5-fold Coordinated Si

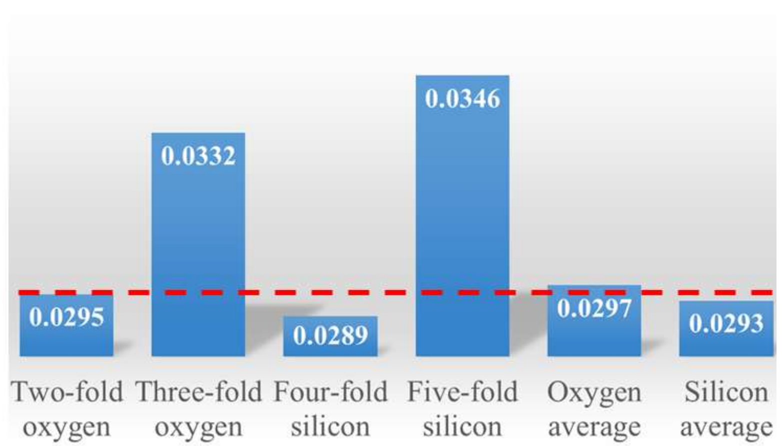


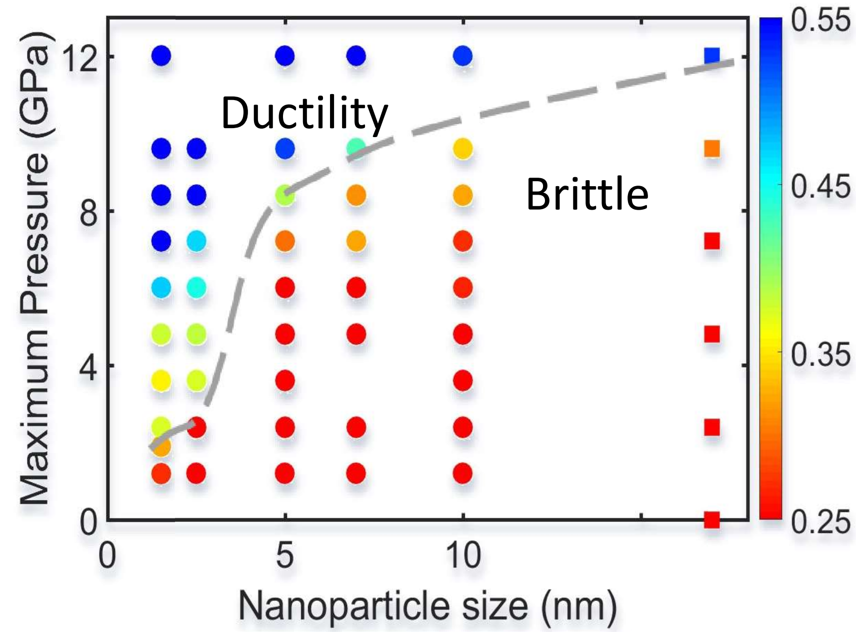
Y. Zhang et al., *Nano Letter*, **19**, 5222 (2019)

5-fold Coordinated Si as Plasticity Carriers



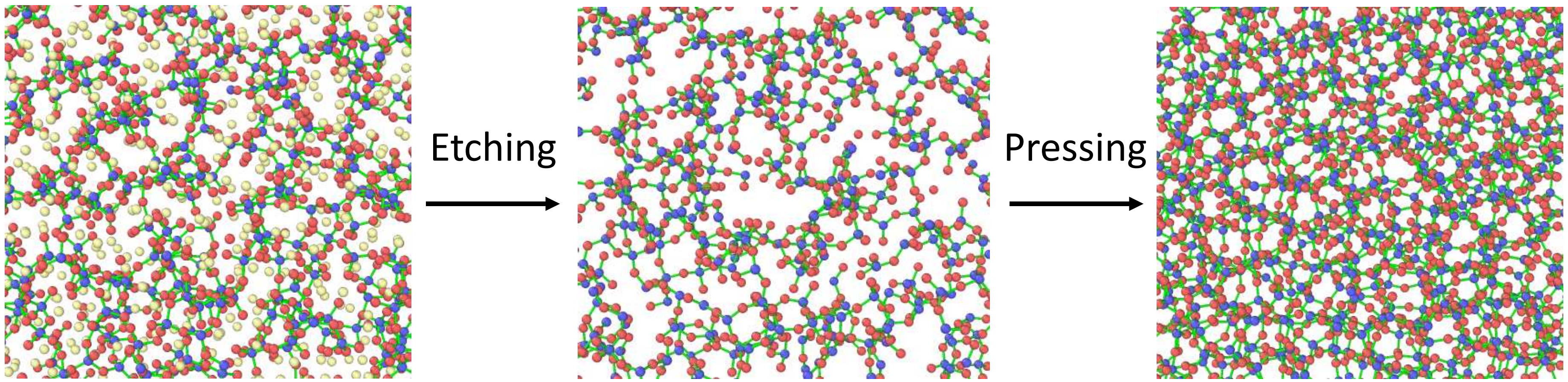


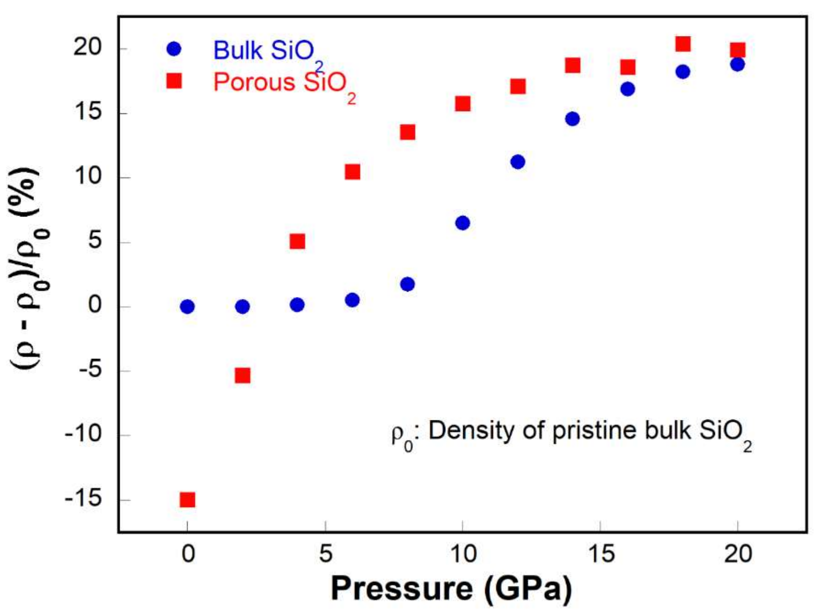


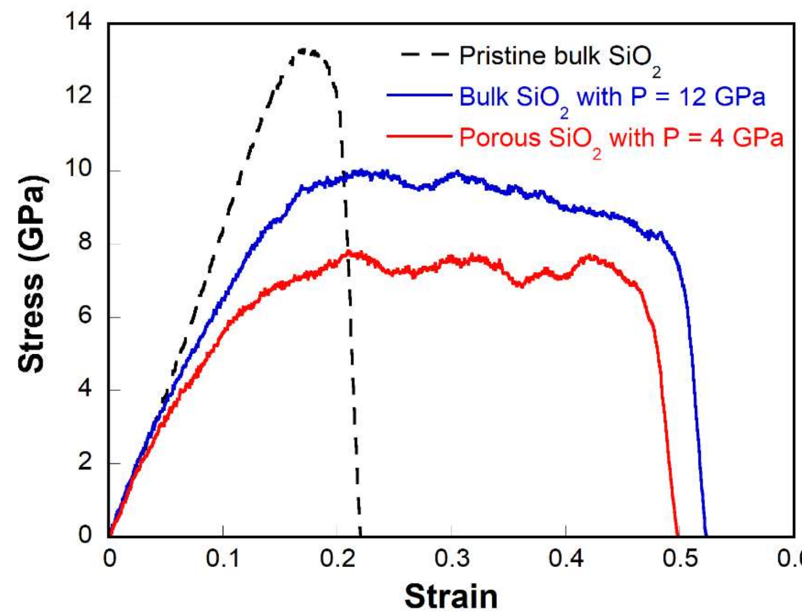


Y. Zhang et al., *Nano Letter*, **19**, 5222 (2019)

Consolidation of Porous Silica

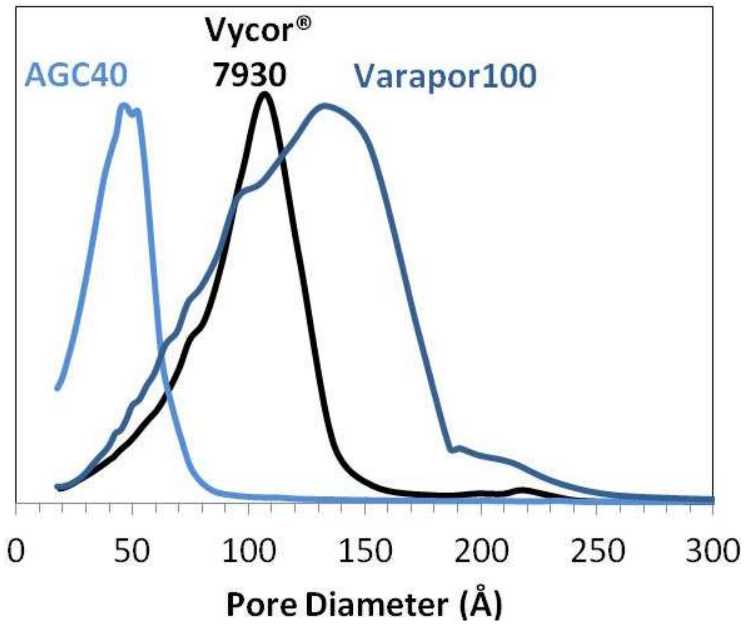




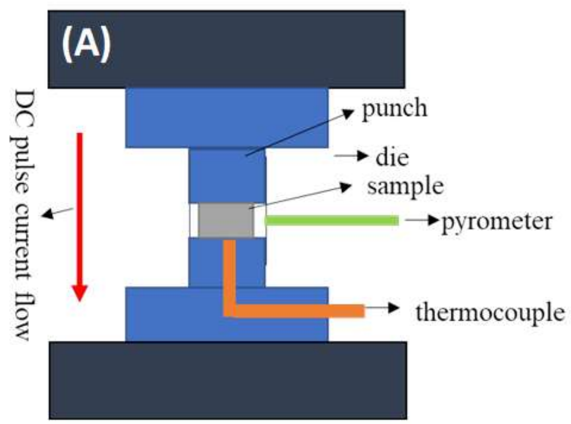


SPS Consolidation of Porous Silica

Varapor 100: >99% SiO_2, **1.6** g/cc; **AGC 40**: 95% SiO_2, 5% B_2O_3, **1.3** g/cc

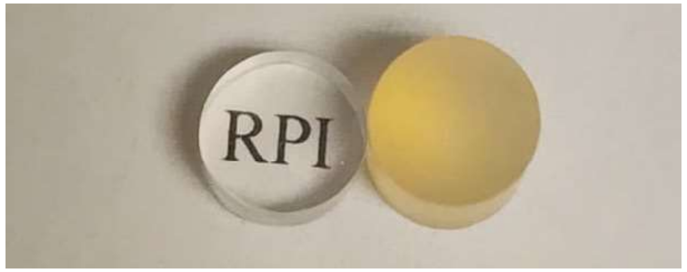


	AGC-40	Varapor100
Surface Area, m²/g	215	116
Pore Volume, cm³/g	0.2	0.3
Porosity, %	31	40
Average Pore Diameter, angstrom	37	98



Varapor 100, **2.18** g/cc

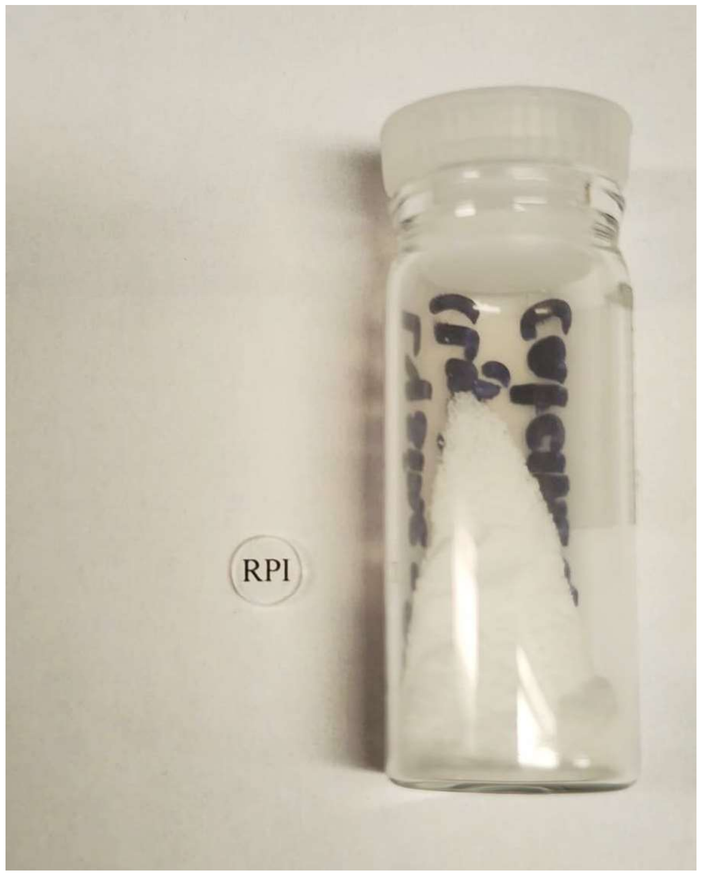
AGC 40, **2.21** g/cc

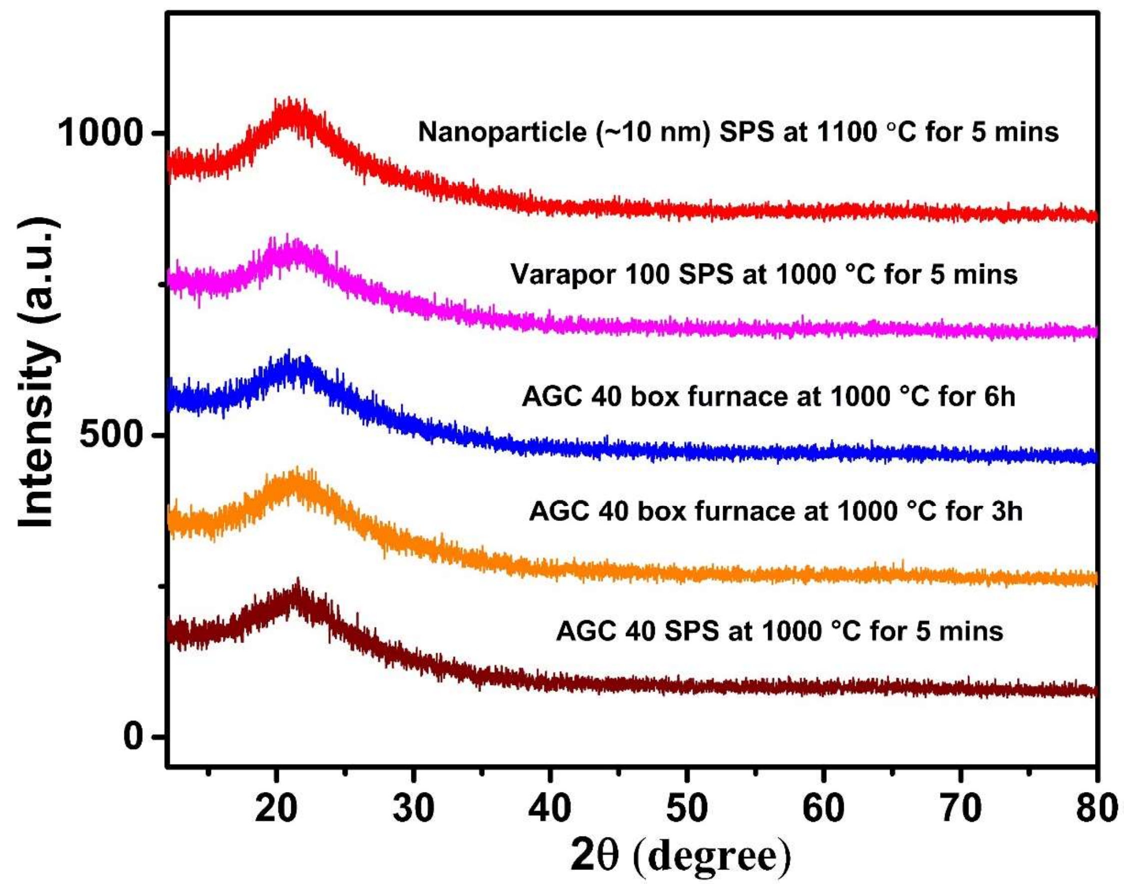


SPS Sintering at 1000 °C 45 MPa for 5 mins

SPS Consolidation of Silica Nanoparticles

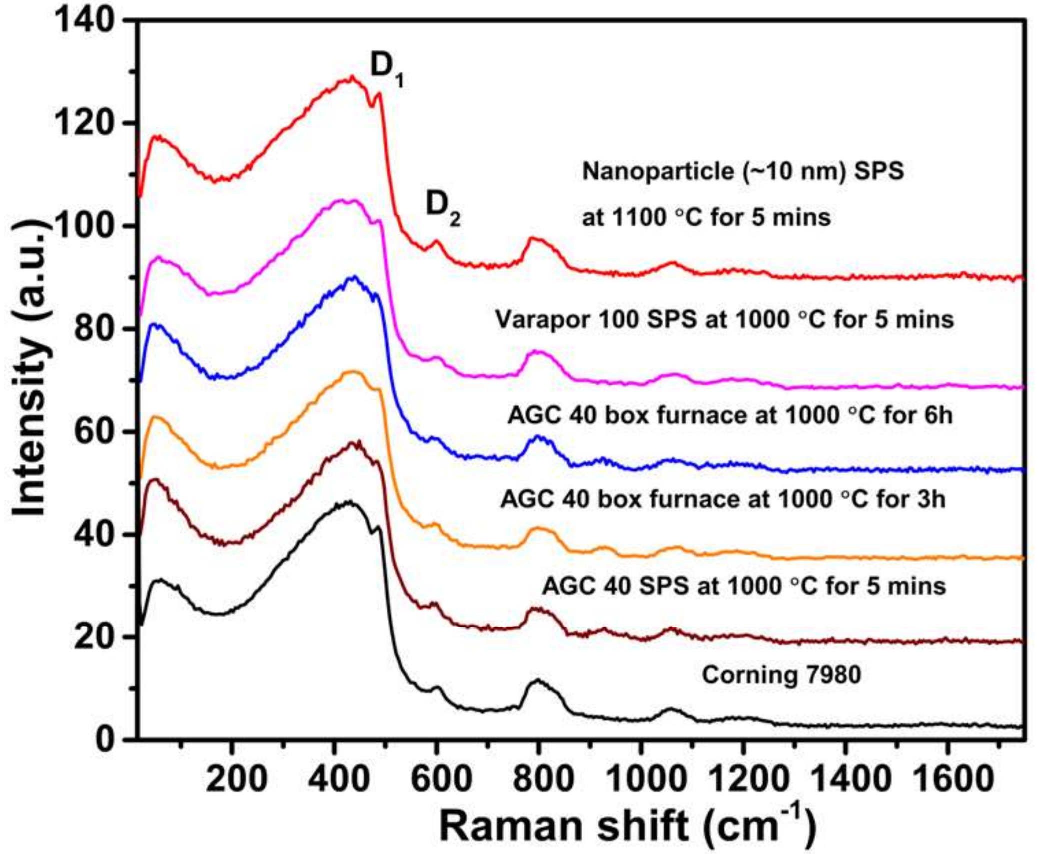
SPS Sintering at 1100 °C 45 MPa for 5 mins

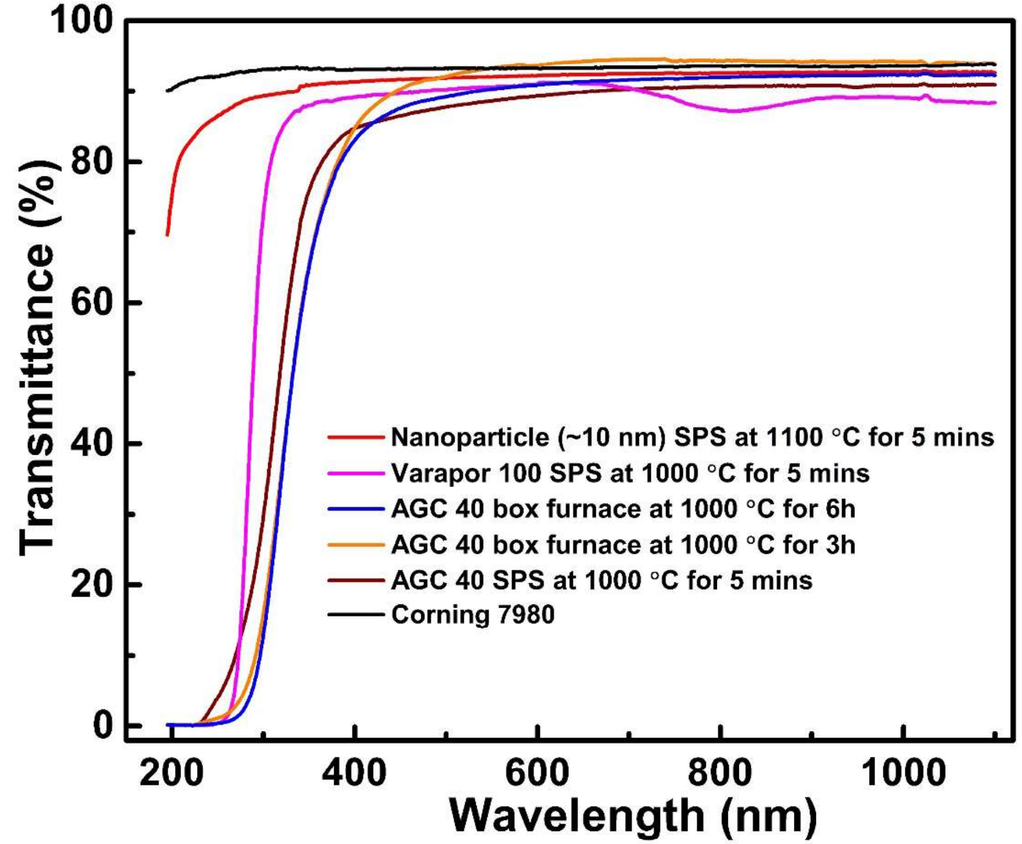




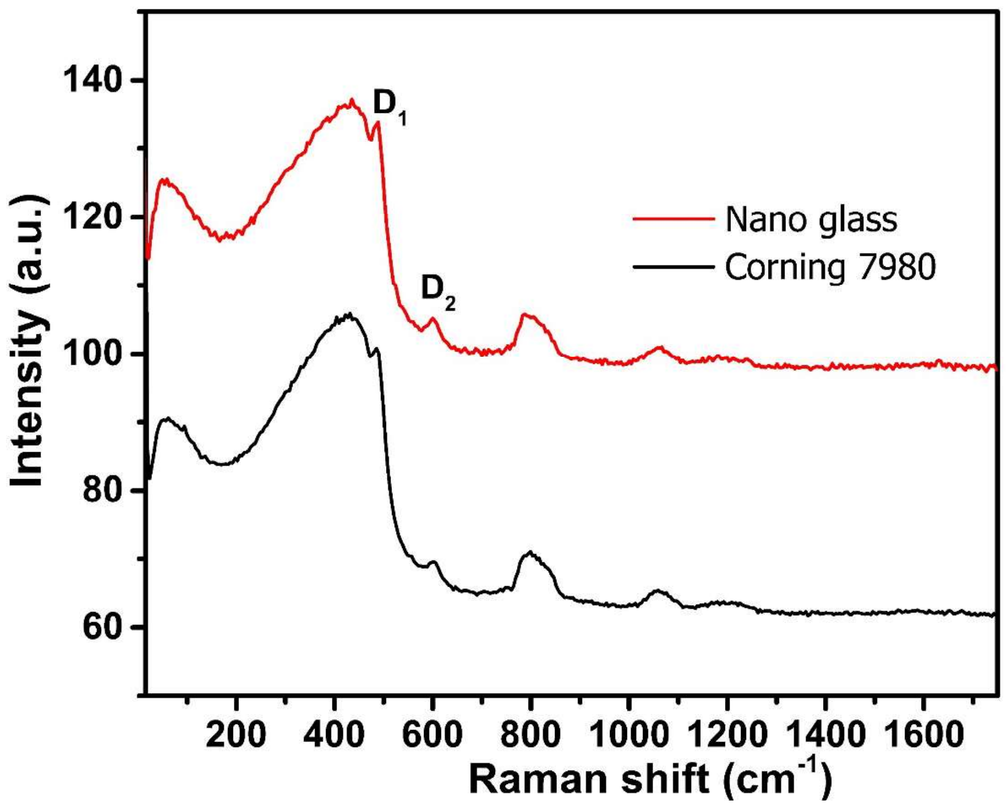
In collaboration with Dr. Joel Destino at Creighton University

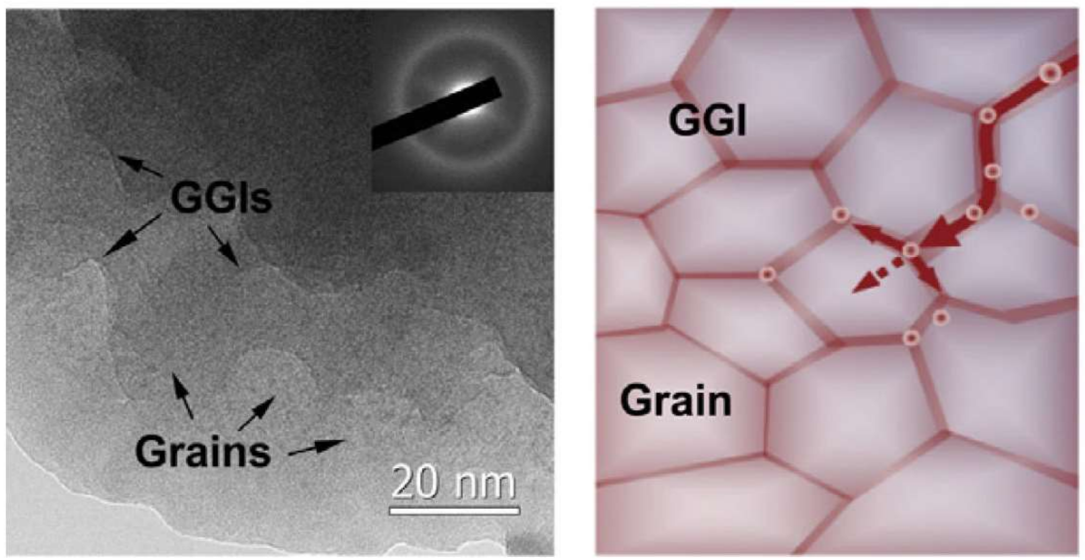
Structure and Property of SPS-Consolidated Silica Glass





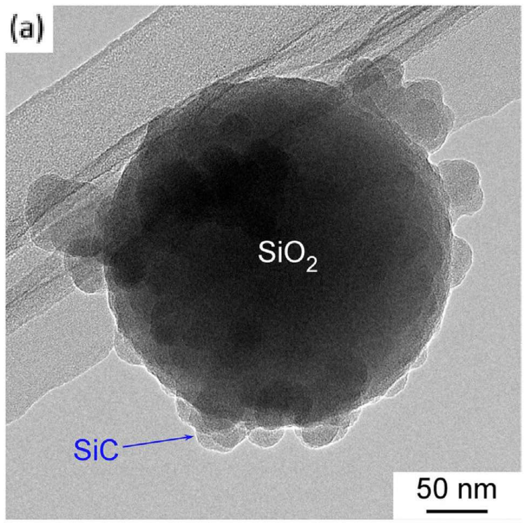
SPS-consolidated Nano-Silica Glass

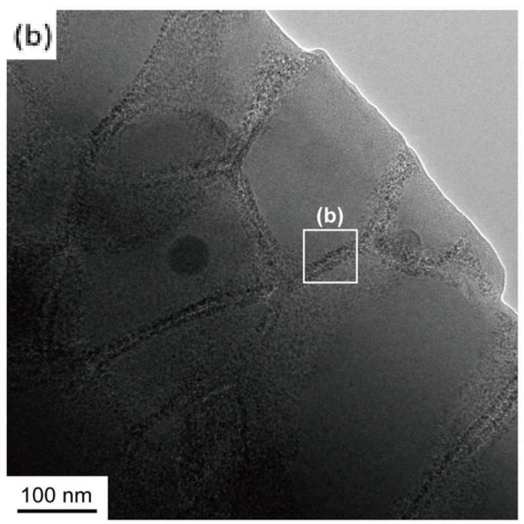




D. Danilov et al., *ACS Nano,* **10**, 3241 (2016)

Design of Chemical/Structural Heterogeneity





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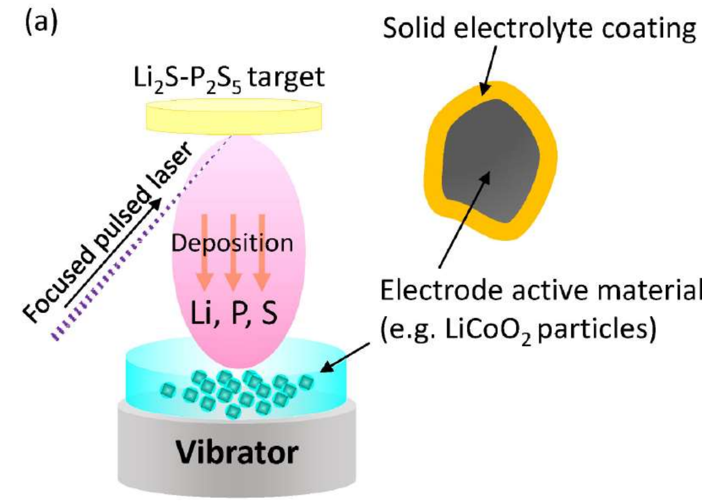
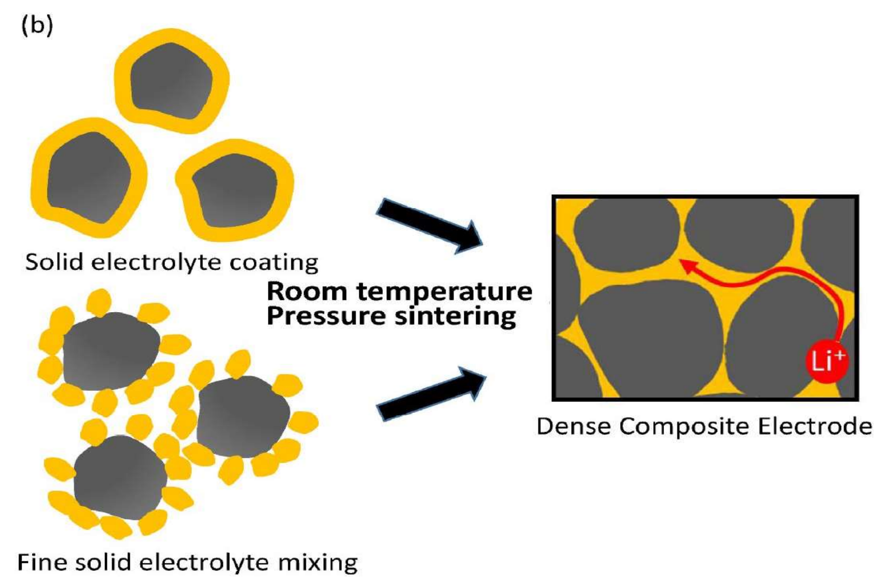
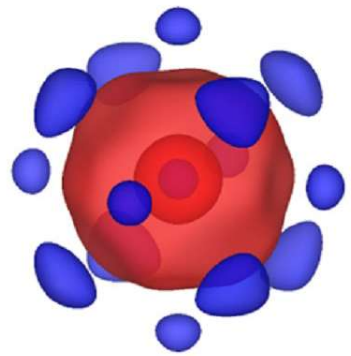


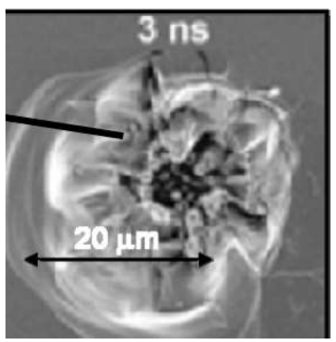


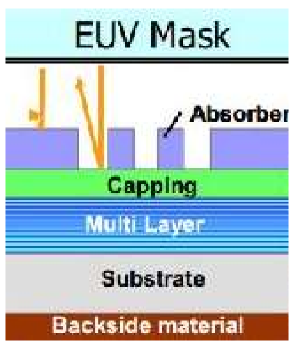
A. Sakuda et al., *Journal of the Ceramic Society of Japan,* **126**, 675 (2018)

“New” Periodic Table under Pressure



1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesi...											13 Al Aluminium	14 Si Silicon	15 P Phosph...	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Mangan...	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germani...	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybde...	43 Tc Techneti...	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Caesium	56 Ba Barium	57 La Lanthan...	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89 Ac Actinium	104 Rf Rutherfo...	105 Db Dubnium	106 Sg Seaborg...	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitneri...	110 Ds Darmsta...	111 Rg Roentge...	112 Cn Coperni...	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovi...	116 Lv Livermo...	117 Ts Tenness...	118 Og Oganes...





Summary

- Pressure processing can lead to unique structure and properties that cannot be achieved by the traditional melt-quenching method.
- Structure and properties of the hot-compressed glass are distinct from those of the cold-compressed counterpart at room temperature.
- Consolidation of glassy nanoparticles can form nanoglass with composition/structure variation on a much longer length scale than in bulk samples, leading to unique properties.