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Plastic deformation in glasses: Composition dependence and implications

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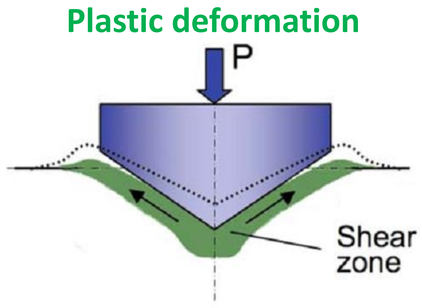
Introduction

Although glass is considered an ideally brittle solid, permanent deformation will occur under gigapascal range shear as evidenced by microindentation studies. This work aims to quantify the two contributions to permanent deformation: Plastic deformation and densification.

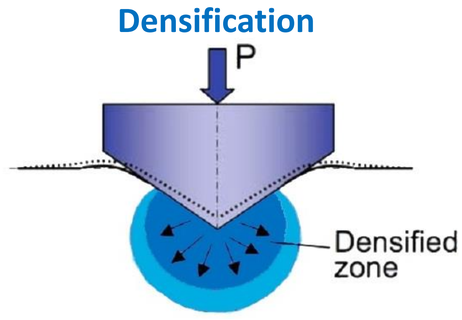
Method

Step 1: The glass is indented, and plastic deformation and densification cause permanent deformation.

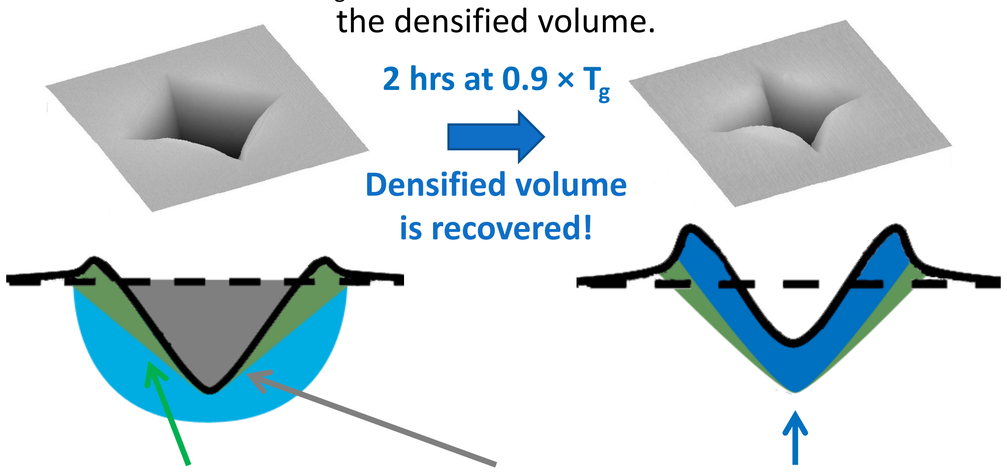
Plastic deformation



Densification

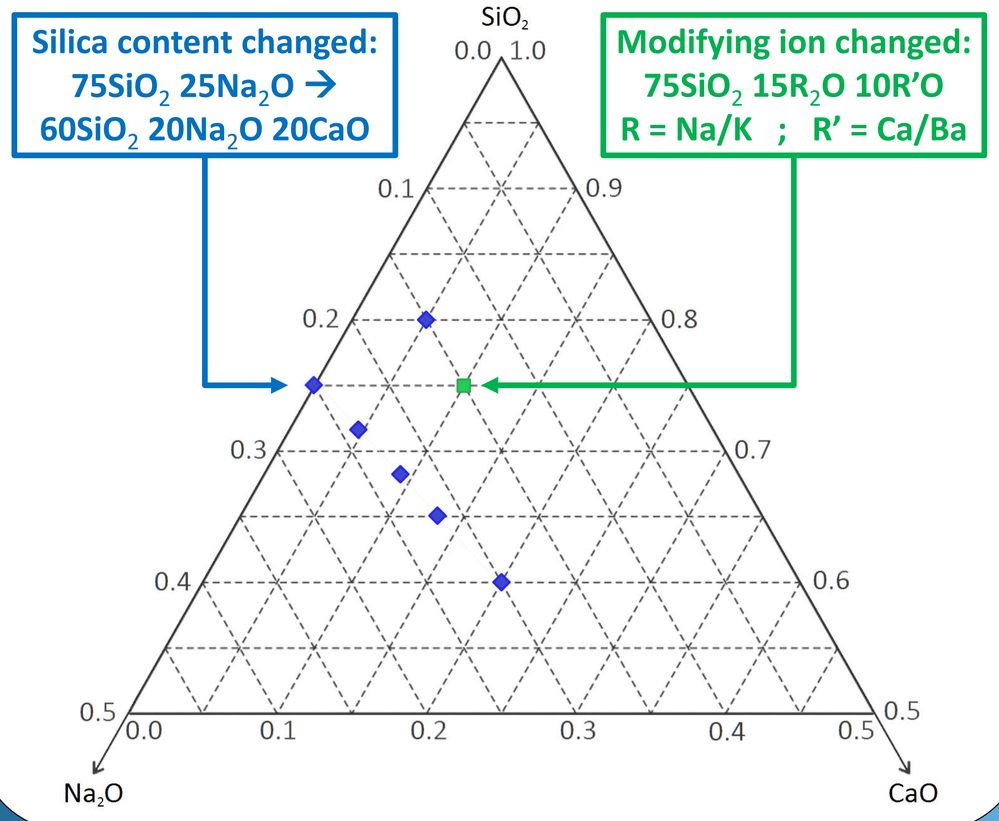


Step 2: The indent is mapped by AFM before and after annealing at 0.9 × T_g for 2 hours. The annealing fully recovers the densified volume.



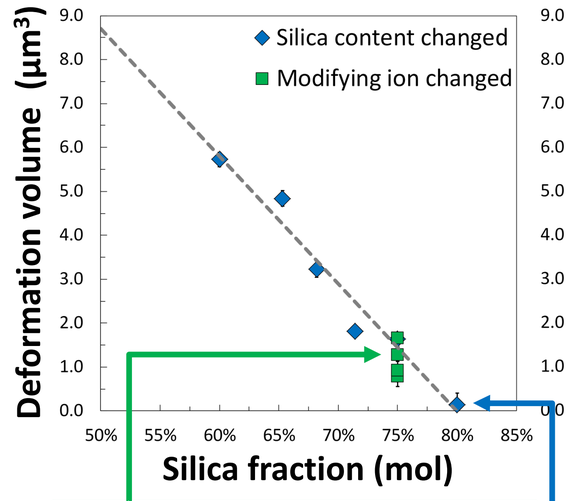
Plastic deformation = Indent volume - Densified volume

Compositions

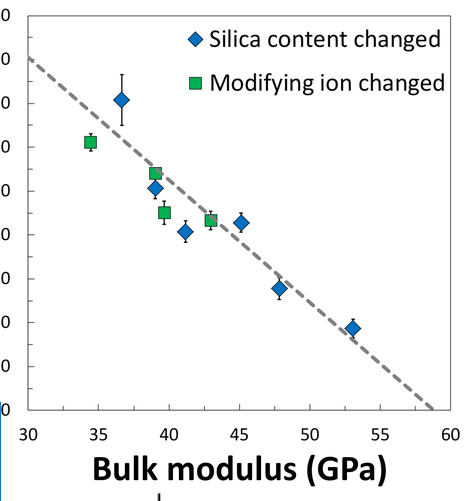


Results

Plastic deformation



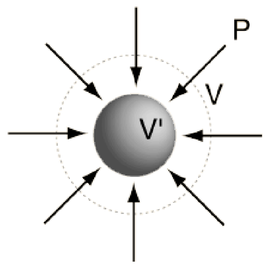
Densification



Modifying ion ➡ NO effect

More than 80% silica

NO plastic deformation!



Bulk modulus:

$$B = \frac{\Delta P}{\Delta V/V}$$

P = pressure
V = volume

Discussion

Plastic deformation

- Negligible effect of modifying ion
- Decreases linearly with silica mole fraction
- No plastic deformation above 80mol% silica

Interpretation:
Depolymerization beyond a critical value (80% silica) allows for plastic deformation.

Densification

- Decreases linearly with bulk modulus

Interpretation:
A densificative yield pressure.

Conclusion

For the first time strong quantitative relations of plastic deformation and densification to other properties of glasses have been found. This result is expected to lead to the development of glasses with improved scratch and fracture resistance.

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