Low-frequency acoustic measurements on the metallic glass $\text{Zr}_{46.8}\text{Ti}_{8.2}\text{Cu}_{7.5}\text{Ni}_{10}\text{Be}_{27.5}$

Sebastian Craft, ●Arnold Seiler, Georg Weiss

Low-temperature properties of amorphous materials

The properties of amorphous solids at low temperatures are well known to be dominated by atomic two-level tunneling systems (TS). While the standard tunneling model successfully describes thermodynamic properties of insulating glasses it fails to predict the elastic properties of metallic glasses in some important aspects.

Standard tunneling model

Atoms or groups of atoms tunnel between two metastable positions

Predictions [1-3]

- low T : resonant interaction
- intermediate T : relaxation interaction

internal friction

- low T : $Q^{-1} \propto T^3/\omega$
- intermediate T : $Q^{-1} = \pi/2 C$

with material constant $C_{l,t} = P_{l,t}^2 / \rho v_{l,t}^2$

sound velocity

- low T : $\delta v/v_0 = C \ln(T/T_0)$
- intermediate T : $\delta v/v_0 = -1/2 C \ln(T/T_0)$

Improvement [4]

renormalization by conduction electrons

Our vibrating reed

material

splat cooled bulk metallic glass

advanced geometry

- to reduce loss in clamping [5]
- to allow study at various frequencies
- still easy to fabricate

References

- [1] P.W. Anderson, Philos. Mag. **25** 1 (1972)
- [2] W.A. Phillips, J. Low Temp. Phys. **7** 351 (1972)
- [3] Enss, Hunklinger, *Low temp. Physics*, Springer (2005)
- [4] Kagan, Prokof'ev, Solid State Com. **65** 1385 (1988)
- [5] J. Classen, Ann. Phys. **3** 315-335 (1994)

Results

2nd mode: torsional mode at 642 Hz

- non-linear response of TS for stronger drive - similar to other metallic glasses but distinct from insulating glasses [5]

4th mode: torsional mode at 2922 Hz

- superconducting, and normal conducting in a magnetic field of $B = 4$ T

9th mode at 12495 Hz

- $-1/2 \ln(T/T_0)$ decrease superimposed with onset of electron interaction

Conclusions

- $\delta v/v_0$ ratio of slopes below and above maximum deviates from 2 to -1 prediction
- low T : slope of resonant interaction gives $C_{\text{res}} \approx 5 \cdot 10^{-5}$
- intermediate T : transition to relaxation gives $C_{\text{rel}} \approx 3.4 \cdot 10^{-5}$ while $C_{Q^{-1}} \approx 5 \cdot 10^{-5}$
- above 200 mK onset of renormalization due to quasiparticles in accordance with [4]
- nonlinear behaviour seems universal for metallic glasses - role of quasiparticles?
- general shape in accordance to renormalized STM