Thermophysical Properties of Phosphor- containing Bulk Metallic Glasses

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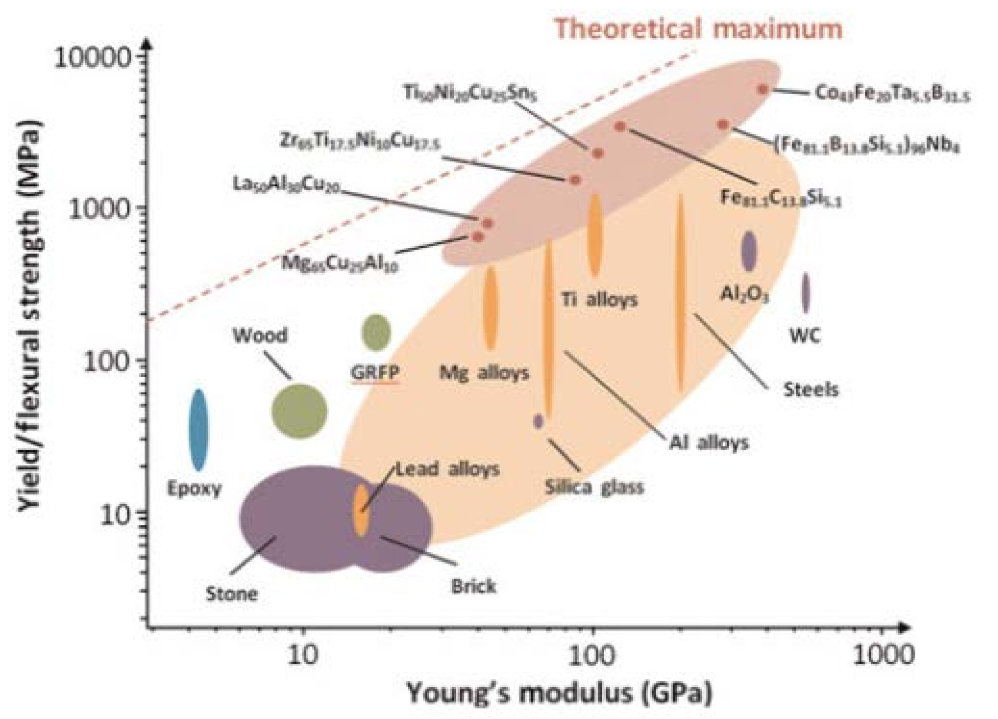
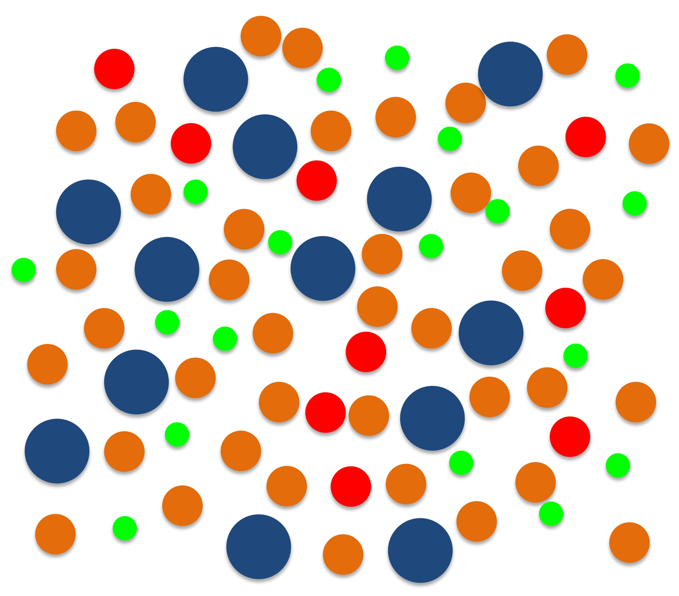
Bulk metallic glasses (BMGs) represent a new development in materials science with a major advantage of possessing superior mechanical properties that combine a high mechanical strength (about 2 GPa) and a 5 – 10 times higher elastic strain limit in comparison with conventional metals. They also show excellent wear properties and corrosion resistance due to the lack of grain boundaries.



Ferry, M. et al., MRS Communications, 3, 1-12, (2013).

First BMGs were produced in the '60s by fast quenching (as fast as 10^6 K/s) from the liquid phase into the glassy metastable phase thus avoiding crystallisation.
Even though several glass forming compositions have been discovered which require much less stringent quenching conditions ($1\text{-}10^3$ K/s), understanding of the underlying formation mechanisms is still required.

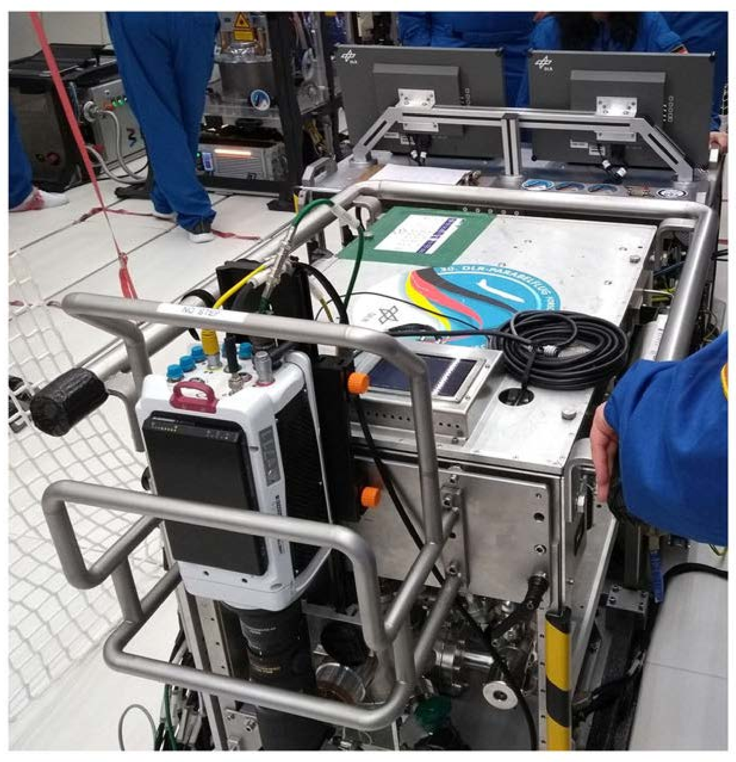
An amorphous metal



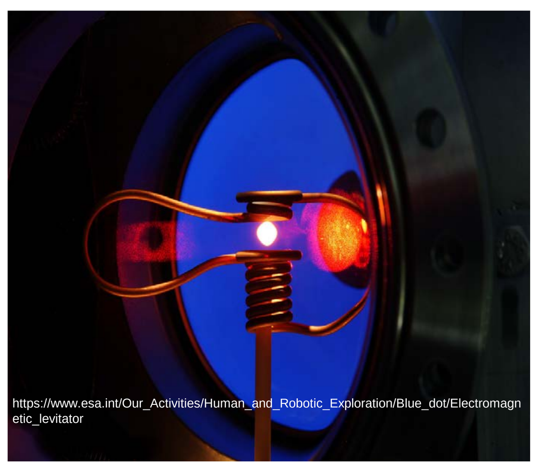
"Frozen liquid"

Since the synthesis conditions can have a major impact on the final structure and properties of the BMGs, within the **Thermoprop-II** (in collaboration with the European Space Agency **ESA**) project we aim at investigating the high temperature physical properties of the forming BMG phase.

The precise measurement of thermophysical properties such as surface tension and viscosity of metallic alloys in their liquid phase (at high temperatures) demand clean and high-vacuum conditions to avoid contamination of the surface or bulk of the measured sample by undesired elements. To avoid reaction with the sample container the method of electromagnetic levitation offers a quite unique containerless approach to access the high-temperature and liquid phase of the BMG.
However, under earth's gravitational normal conditions (1g), a liquid sample in its natural geometry or levitated by an electromagnetic positioning field will be considerably deformed and particularly difficult to control since the high input energy required to levitate the sample will tend to overheat the sample beyond the melting point.
Thus the necessity of employing micro-gravity conditions, either by means of **parabolic flights** (**PF**s) or the **International Space Station** (**ISS**).



ESA EML in action

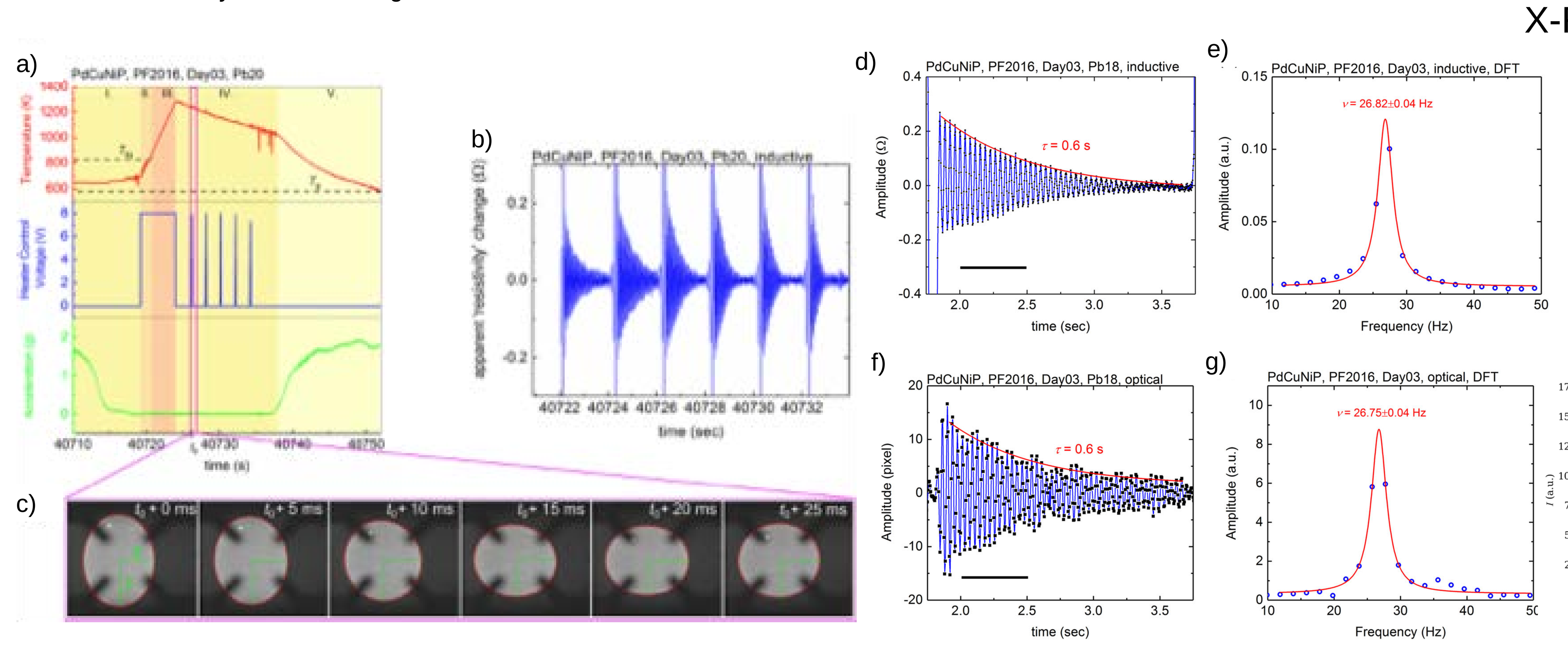


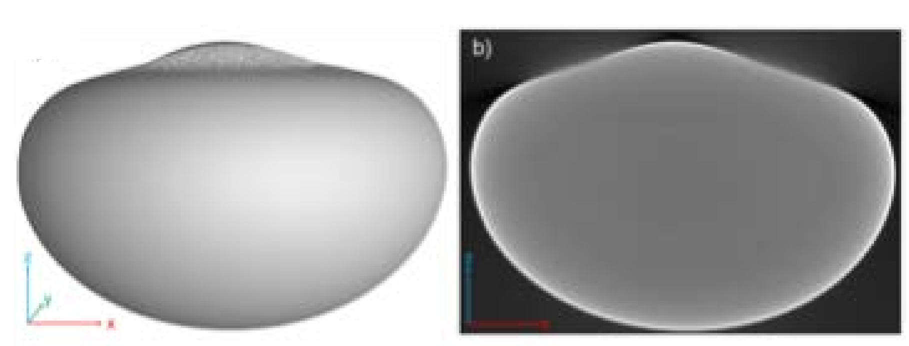
The TEMPUS facility for electro magnetic levitation

Macroscopic physical properties relevant for BMG processing

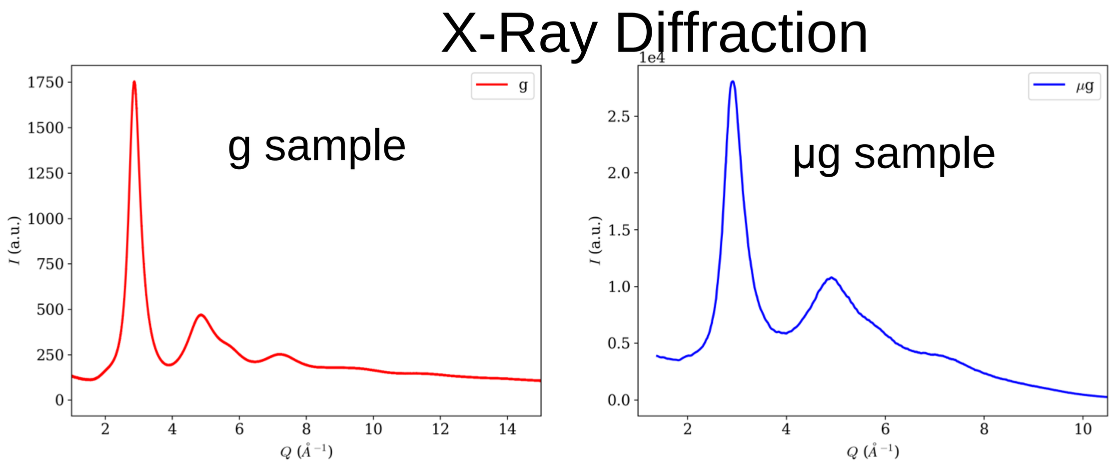
- surface tension: (γ,σ) in a liquid is the force per unit length, is the tendency of a fluid surfaces to shrink into the minimum surface area possible. $\sigma = \frac{3}{8}\pi\nu_R^2 M$
- viscosity: (η) of a fluid is a measure of its resistance to deformation at a given rate $\eta = \frac{3}{20\pi}\frac{M}{R}\frac{1}{\tau}$

X-Ray 3D computed Tomography of a µg sample





X-Ray Diffraction



a) Temperature-time profile of processing in the electromagnetic levitator on board a parabolic flight (red). The control voltage of the rf-heater (blue) shows pulses for the excitation of surface oscillations. The level of vertical acceleration (green) shows the ~20-s time window of µg. b) Variation of the high-pass filtered "apparent" electrical resistivity as a function of time, the exponentially decaying surface oscillations can be detected after heater turn-off and after every heater pulse. c) Series of frames recorded by the high-speed camera, showing the surface oscillations of the droplet. d) Oscillation amplitude, as detected by the inductive method as a function of time. e) Discrete Fourier transformation (DFT) spectrum of the amplitude variation between 2.0 and 2.5 s. f) Amplitude of the optically determined surface oscillations. g) DFT spectrum of a selected time slice.

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Mohr, Markus and Wunderlich, Rainer K. and Zweiacker, Kai and Prades-Rödel, Silke and Sauget, Romuald and Blatter, Andreas and Logé, Roland and Dommann, Alex and Neels, Antonia and Johnson, William L. and Fecht, Hans-Jörg, npj Microgravity, (2019), 5, 4

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