We used thermal mechanical analysis (TMA, Perkin-Elmer Model TMS-2) to measure the thermal expansion of Kovar, titanium, borosilicate glass, and a low-T_g glass. We used the same instrument to measure the viscosity of the low-T_g glass at elevated temperatures. The outputs of the TMA are the change in the length and the temperature of the sample; the precision of the measurements is ±0.1 µm in length and ±0.1°C in temperature. We measured the lengths of the samples at room temperature using a digital caliper; the precision of the caliper is ±0.1 mm. We used a temperature ramp-rate of 20°C/min and chose a temperature range of 60°C to 600°C. Higher temperatures would be needed to observe the softening of borosilicate glass but we restricted the temperatures range to avoid reactions between the probe and the borosilicate glass sample. The probe was loaded by a 5 g (49 mN) weight to ensure stable mechanical contact with the sample. We made two additional runs with the low T_g glass sample using higher applied forces of 98 mN and 196 mN. We also made measurements of the dimensional changes of the low T_g glass at a constant temperature of 600°C.

We used cylindrical rods of each material with aspect ratios > 20 for determining the Young's modulus of the samples by the method of resonant vibrations. We measured the dimensions of the rods with a digital caliper and Venier caliper with precisions of ±0.1 mm , and the mass of the rod with a balance with a precision of ±0.1 g. To detect the vibrations of the rod, we placed a microphone (MXL Studio USB) at the end of the rod and pointed the microphone in the direction of the length of the rod. Figure 1 illustrates the configuration of the rod and microphone. We struck the rod using a steel ball mallet in accordance to standard ASTM C623 and measured the frequencies of two resonances: longitudinal and transverse. For the longitudinal frequency, the rod was struck in the axial direction; for the transverse frequency, the rod was struck in the radial direction. For the measurement of the longitudinal resonance frequency, the rods were placed on top of two polyurethane foam holders to prevent the rod from moving and colliding with the microphone. For the measurement of the transverse resonance frequency, the rod was hung by wires.

We analyzed the wave-form of the sound detected by the microphone using Audacity, an open-source program. The fundamental resonant frequency was found by identifying the peak with the largest amplitude. For the transverse frequency of the Kovar sample, band pass filters were used to select the frequency range that included the expected frequency of the transverse vibration. We also used a fast Fourier transform routine in Matlab for comparison.