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A new kind of electrostatically driven forced-torsion pendulum

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Abstract

A sensitive system for measurement of internal friction as a function of both temperature and vibration frequency is proposed. The system is a special vibrating-reed arrangement producing shear stress in specially shaped specimens.

In this sense it can be seen as a new "forced-torsion pendulum". the available frequency range goes from 10^{-4} up to 10 Hz and damping values corresponding to phase lags as low as 10^{-5}–10^{-4} radian can be readily obtained. the apparatus, of small overall dimensions, can operate on very small and brittle samples.

Some results obtained in Y–Ba–Cu–O superconducting specimens are presented as illustrations of the method.

1. Introduction

The advantages of isothermal friction measurements, conducted as a function of the vibrating frequency, were recognized a long time ago especially in the field of polymer sciences. However, such measurements have been successfully applied to crystalline materials only since the introduction of a specially devised forced-torsion pendulum [1, 2], owing to the low damping levels of such materials.

This torsion pendulum is characterized by a great mechanical complexity and large dimensions and is not appropriate for measurements on very small specimens. Furthermore the accuracy of damping measurements, by direct phase-lag determination, is still inferior to that obtained by classical free-decay methods.

For these reasons a much simpler arrangement, offering a better accuracy and appropriate for tests on very small specimens, is proposed here.

2. Experimental arrangement

A vibrating reed ($20 \times 10 \times 1$ mm^3 in the present arrangement) with two slits as shown in Fig. 1(a) and (b) is electrostatically driven by two electrodes located close to the sample surface. the working part of the specimen, between the slits, is submitted to shear stresses. Thus, despite the fact that the motion of the reed corresponds to a flexural mode, the strain mode of the working area corresponds to a torsional mode. the maximum strain amplitude is smaller than or comparable with that obtained with a forced or classical pendulum.

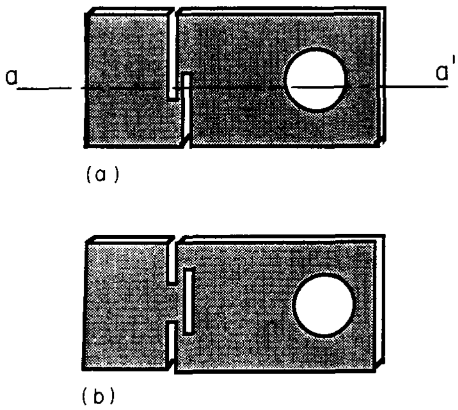

Fig. 1. Specially shaped specimens. The working area between the slits is submitted to shear stresses. The white circle corresponds to the metallization in an insulating sample.

With this arrangement it is possible to fix accurately the rigidity of the reed by simply adjusting the shape and position of the slits. It must also be noted that low extra damping levels can be obtained since the specimens are clamped in a non-strained part, for the same reason it is also possible to use very brittle samples.

The behaviour of the reed has been modeled with a finite element method and some results appear in Fig. 2, confirming that the stress is localized between the slits and is mostly of torsional type.

The features of the measurement head are shown in Fig. 3. Flexural vibrations are transmitted to the reed through two conducting electrodes located close to the specimen surface, the gap being typically 0.2 mm.

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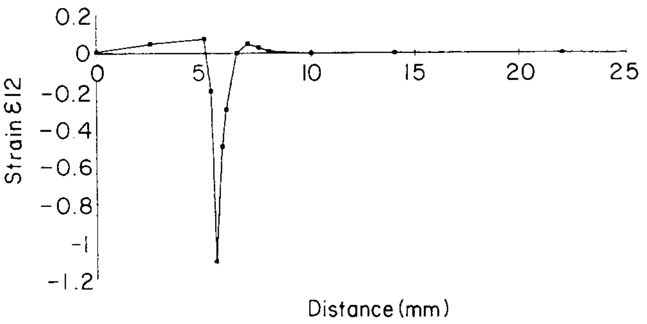

Fig. 2. Modelling of the sample in Fig. 1(a) by finite element calculus: shear strain is along the *a–a'* axis.

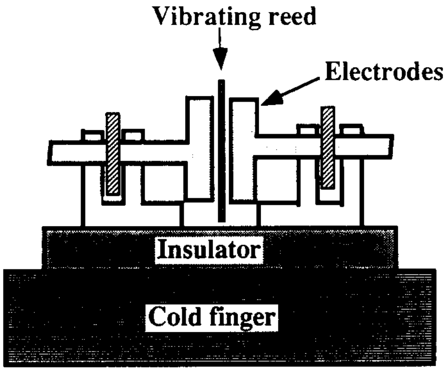

Fig. 3. Details of the measuring head showing the vibrating reed and the driving electrodes.

One electrode is submitted to a high d.c. voltage (500–2000 V) and a moderate superimposed alternating voltage (100–200 V). The other electrode is submitted to the same d.c. voltage and to an alternating voltage opposing the preceding signal.

The resulting force applied to the sample is in phase with the applied alternating voltage and has the following amplitude:

$$F = \frac{2\epsilon_0 S}{e} V_0 v$$

ϵ_0 being the dielectric permittivity of vacuum, S the electrode area, e the gap between the electrodes and the specimen, V_0 the d.c. voltage and v the amplitude of the alternating voltage.

In the special case of an isolated sample, the sample area facing the electrodes must be metallized. The resulting force is in this case reduced to

$$F = \frac{\epsilon_0 S}{2e} V_0 v$$

The driving electrodes are also used to detect the reed vibrations: a 1 MHz carrier frequency is modulated by the capacitances formed between the reed and the electrodes. The modulation is then extracted thanks to a full-wave rectifier. The resulting low frequency signal is amplified and converted into 18 words. The amplitude and the phase of this signal, giving the complex shear modulus, are finally obtained by comparison with the driving voltage. Numerical filtering of the two signals allows accurate measurements in the presence of a large amount of mechanical noise. The intrinsic accuracy of the electronic part corresponds to errors in phase-lag measurements less than 10^{-6} radian, an accuracy better than 10^{-4} radian being maintained in final measurements, despite large parasitic mechanical vibrations.

The measuring system does not require expensive parts and has been automated using a personal computer with an Intel 80486 DX processor. The programs were written in FORTH language.

3. Experimental results

Owing to its small dimensions, it was possible to mount the measuring head on the cold finger of a helium cryogenerator allowing tests at temperatures down to 13 K, located in the field of an electromagnet delivering a magnetic field of 0.6 T.

The arrangement was slightly modified to allow the study of vortex pinning in small specimens of superconducting Y–Ba–Cu–O. The corresponding results are reported elsewhere [3].

One of the advantages of the new method presented here is to also allow internal friction measurements as a function of temperature and not only, as with some forced pendulums [2], as a function of the vibrating frequency. Measurements as a function of temperature were necessary to describe the non-thermally activated damping peak associated with the "melting" of the vortex network [4–6] and presented in Fig. 4(a). The occurrence of a non-thermally activated damping peak was confirmed by tests at vibration frequencies between 10^{-1} and 10 Hz.

Figure 4(a) and (b) relate to an epitaxed Y–Ba–Cu–O thin film specimen obtained by laser ablation in the Laboratoire Matériaux Céramique et Traitement de Surface (Limoges). In such a specimen the *c* axis is normal to the plane of the film, the applied field being parallel to that plane and perpendicular to the direction of motion.

The high accuracy of damping determination was also confirmed by the "melting" peak obtained in a small textured bulk Y–Ba–Cu–O specimen [3], as shown in Fig. 4(b).

4. Conclusion

The new internal friction measurement method presented here offers the following advantages compared with previous methods: reduced dimensions and me-

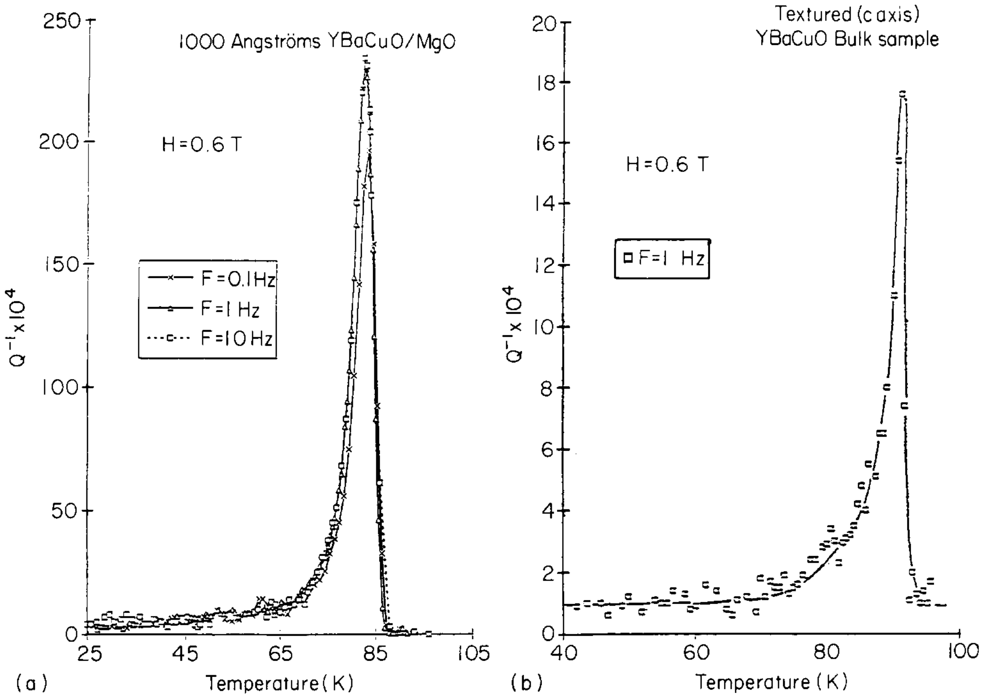

Fig. 4. Damping of the vibrating reed with a superconducting sample fixed on it in a 0.6 magnetic field: (a) thin Y–Ba–Cu–O film (100 nm) tested at three different frequencies; (b) textured Y–Ba–Cu–O bulk sample.

chanical simplicity; use of small and brittle specimens; improved accuracy for damping measurements.

Development of a high temperature version of such equipment is in progress (room temperature–800 °C) designed for the study of the mobility of dislocations in elementary and composite semiconductors.

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