New technique to measure the mechanical quality factor of metals using spherical samples

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Abstract

We developed a new technique for measuring the mechanical quality factor of metals from room temperature down to 10 mK. Spherical resonators with a diameter of 150 mm were suspended from the center with a copper rod. Since a sphere has a large number of resonant modes it is always possible to find some which are practically unaffected by the suspension and it can be assumed they are representative of the 'intrinsic' values. With this method we measured a Q-factor of 120 million in Al5056, the highest published value for a metal.

Keywords: Mechanical quality factor; Internal friction; Gravitational wave detectors

1. Introduction

This research was done in order to determine which material could be used for spherical gravitational wave detectors to optimize their performance. The sensitivity of the resonant detector depends on the material, among others, through the effective temperature T_{eff}, which contains the term $\frac{T}{\beta Q}$, with β the ratio of the energy deposited in the antenna to that converted into electromagnetic energy in the transducer, T is the thermodynamical temperature of the detector and Q the mechanical quality factor [1]. For quantum-limited sensitivity T/Q should be $\simeq 10^{-9}$K, which can be achieved with $T = 10$ mK and $Q = 10^7$ [2].

2. Experimental techniques

Spherical samples, with a diameter of about 150 mm, were suspended from the center by a copper rod ($\phi = 2 - 3$ mm) which was screwed to the mixing chamber of a dilution refrigerator. Several different suspension contacts were used [3], screwed or conical with small and large angle, but this didn't seem to influence the quality factor. From room temperature down to 4.2 K the resonant modes of the spheres were excited by a low temperature hammer activated by a superconducting coil. The temperature was measured using a commercial RuO_2 resistor (Philips 2000 Ω SMD). The detection was done with a piezoelectric ceramic transducer, glued with cyanoacrylate instant glue on small flats filed on the surface of the sam-

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ples. The amplitude was measured with a low noise pre-amplifier and a Stanford spectrum analyzer (SR770). At temperatures below 4.2 K excitation of the resonant modes was done with a function generator using piezo-ceramic transducers. For the excitation and detection, transducers of different sizes were used, without any significant effect on the results. The mechanical quality factor Q was determined by $Q = \pi\nu\tau$, with ν the frequency of the resonant mode and τ the relaxation time.

3. Results

The temperature dependence of the mechanical quality factor of several alloys has been measured from room temperature down to 15 mK, in the frequency range from 12 to 60 kHz. In Fig. 1 we plotted the resonant modes with the highest Q for each material. For Al5056 (5.2% Mg, 0.1% Mn, 0.1% Cr) a higher order mode was measured (35 kHz). At the lowest temperature, 44 mK, the Q-factor was 120 million, the highest value ever published for this alloy and for a metal in general. As a comparison we plotted the results of Suzuki et al. [4], using a disk with a diameter of 12.5 cm and a thickness of 3.3 cm, supported on a center post, and the results of Coccia et al. using a small bar with a diameter of about 2 cm and a length of 7.5 cm machined with a narrow ring in the center, supported by a three beams clamping ring [5]. The Be(5%)Cu showed an absorption peak around 8 K and has a Q-factor as high as 30 million at the lowest temperature. The CuAl(6%)Fe(0.8%) sample showed an absorption peak with the maximum around 3 K and a minimum around 1.2 K. It turned out that the $S = 0$ mode, the so called 'breathing mode' was least effected by the suspension and had the highest Q-factor. For the CuAl(6%)Fe(0.5%) the absorption peak disappeared for this mode.

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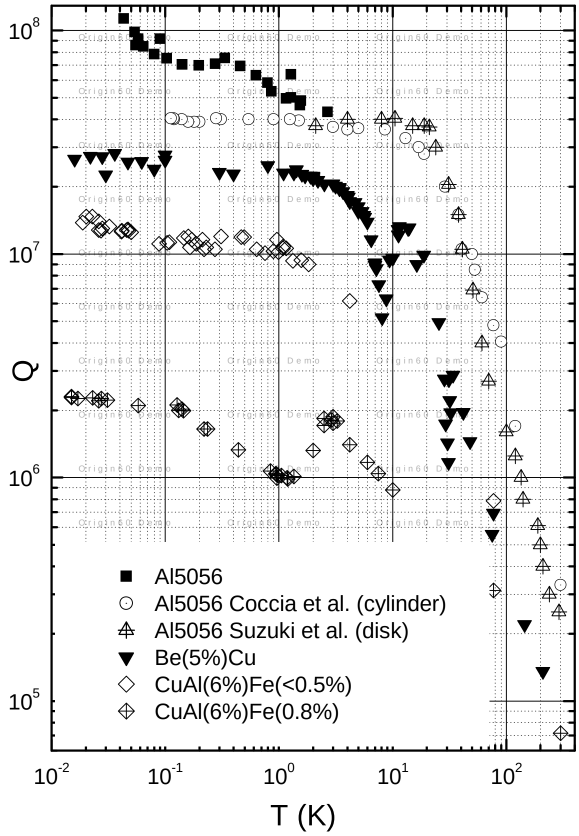

Fig. 1. Temperature dependence of the mechanical quality factor Q of several alloys using spherical samples. For the Al5056 sample a comparison is made with measurements using a cylindical sample and a disk.

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