Long-lived stimulated echo in a superconducting $YBa_2Cu_3O_x$ powder

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A two-pulse echo and a stimulated echo have been observed in a superconducting $YBa_2Cu_3O_x$ powder in a static magnetic field. A stimulated echo has been detected an hour after the removal of exciting pulses (the memory effect). The field and temperature dependences of the echo amplitude are presented.

At a frequency of ~20 MHz we have observed in $YBa_2Cu_3O_x$ powders with $\sim 10^6$ particles ~100 μm in size in the superconducting phase an rf echo whose frequency does not depend, in contrast with an ordinary spin echo, on the static magnetic field. Such echo signals have been observed previously in powdered piezoelectric materials, powdered normal metals, and powdered type-II superconductors (see the review by Mason and Thurston[1]). In a preprint[2] recently received by us, the authors report the observation of an effect of this sort in powdered $YBa_2Cu_3O_x$.

To observe the echo signal, we used the standard pulsed NMR technique at frequencies of about 20 MHz. The rf circuit coil, filled with powdered $YBa_2Cu_3O_x$, was inserted into a superconducting magnet in such a way that its axis would run perpendicular to the static field. The rf circuit was placed in a container filled with gaseous helium. The temperature of the sample was varied by means of a wire heater placed inside the cell holding the sample and was measured by a semiconductor thermometer inside the same cell.

A strong echo signal was detected when a resonant circuit with powdered $YBa_2Cu_3O_x$ received two ~100-W, 5- μs-long rf pulses. The echo amplitude increased with increasing magnetic field, beginning with 3 kOe, and reached ~5 mV in a 24-kOe field (Fig. 1), a much higher amplitude than that of the NMR signals measured in these compounds. The echo amplitude decayed when the pauses τ between the exciting pulses with a time constant $T_2 = 30$–40 μs increased at a temperature of 4.2 K. When the delay between the two exciting pulses was short, we detected a second and third echoes. The echo signal decayed rapidly as the temperature was raised and remained only in the superconducting phase (Fig. 2). The echo signal is caused by the oscillations of the diamagnetic moments of single grains of powder which induce a voltage in the rf circuit.

If a third pulse with a delay even much greater than T_2 is sent to the rf circuit, we will see a stimulated echo signal (Fig. 3). The stimulated echo signal remains if two pulses of the three-pulse train are removed. The stimulated echo amplitude in this case

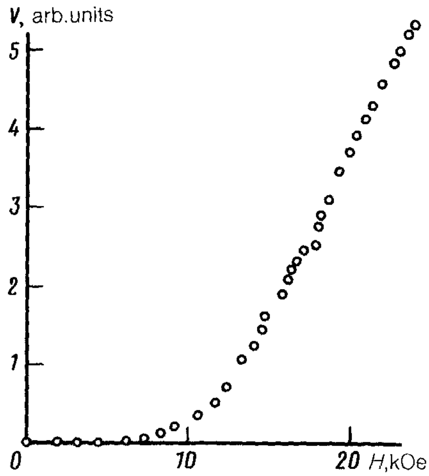

FIG. 1. Two-pulse echo amplitude vs the magnetic field. The temperature is 4.2 K.

decays by half in several seconds and then remains essentially constant at least for an hour. The stimulated echo signal increases within a similar time frame when a pair of exciting pulses is applied. The system under study thus has a long-time memory of the time-varying train of exciting pulses. If the time delay τ between the writing pulses is changed during the buildup of pulses, a new signal will appear along with the one recorded earlier. Accordingly, when the third pulse is used as a reading pulse, we see a sequence of echoes corresponding to different delay times between the writing pulses.

A long-lived stimulated echo vanishes when either the magnetic field or the temperature is changed slightly and is not restored completely upon return to the initial values.

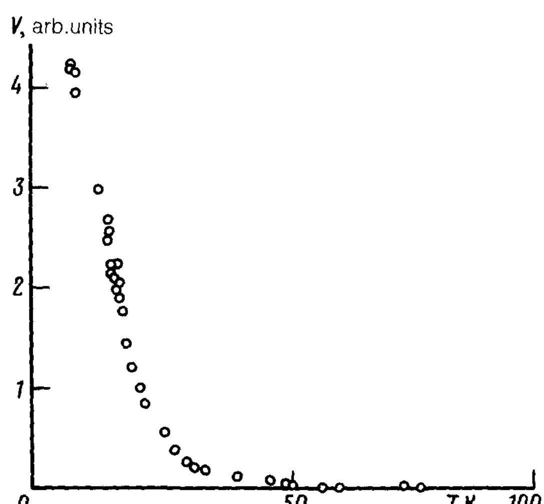

FIG. 2. Temperature dependence of the amplitude of a two-pulse echo in a 24-kOe magnetic field.

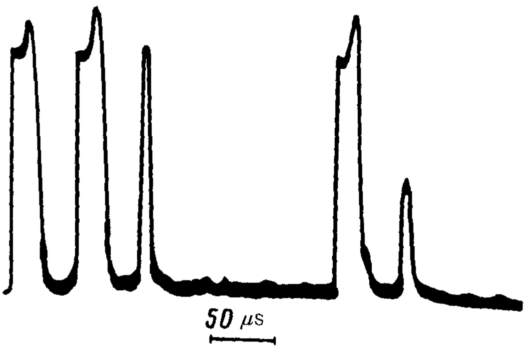

FIG. 3. The oscilloscope trace of a three-pulse echo signal.

The pressure of gas (helium in our case), in which the powder is placed, affects appreciably the formation of an echo. Upon increase in the pressure from 1 torr to 10^3 torr, the amplitude of a two-pulse echo decreases by a factor of ten and the amplitude of a stimulated echo decreases by a factor of thirty. The dependence of the echo signal on the gas pressure suggests that the pressure is produced as a result of mechanical vibrations of the powder particles.

The presence of memory which was previously observed in ferrite and piezoelectric powders can be explained by the fact that the second rf pulse generates a macroscopic magnetic moment as a result of rotation of the moments of the individual particles in the direction of the alternating magnetic field. The strongest reversal of orientation occurs in those particles whose phase matches that of the second rf pulse at the time it is applied. Accordingly, if an rf pulse is applied to such a system of oriented but no longer oscillating particles, the particles will oscillate in phase after its application at instants of time which are multiples of τ, and a stimulated echo will be produced.[3]

As was noted above, the appearance of an echo in a powdered high-T_c superconductor is a consequence of the mechanical vibrations of powder particles which have a frozen diamagnetic moment. It cannot be attributed to the vibrations of fluxoids in a type-II superconductor, as was assumed in Ref. 4.

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