

Two-Pulse and Stimulated Echoes in Yttrium and Bismuth Based HTS C Powders[†]

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Experimental data on a two-pulse and a stimulated echoes in a superconducting YBaCuO and BiSrCaCuO powders in a static magnetic field at a frequency ~ 20 MHz are presented. The field, filling helium gas pressure and temperature dependence of the echo intensity and relaxation time were measured. A stimulated echo has been even detected some hours after the removal of exciting pulses (the memory effect). The echoes are practically disappeared at *temperatures 50 K for yttrium powder* and at 30 K in the case of Bi-powder. Experimental results are in a qualitative agreement with a supposition that the phase coherence arises due to the movement of lattice imperfections by vortex lines.

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PACS.74.72.Hs - Bi-based compounds.

The phenomenon of powder echo (PE), which is also called polarization or phonon echo, was discovered in 60-s and has up to now attracted considerable interest of experimentalists as well as theoreticians. The PE in powders is an electromagnetic response of a sample, placed in a static magnetic field, by two or three electromagnetic pulses. The PE has been observed in powdered segnetoelectric, piezoelectric, ferromagnetic, normal and superconducting metal materials (see the review [1]). It follows from the experimental results obtained that in all cases the phenomenon is conditioned by acoustic vibrations of powder particles which are resonantly excited with radiofrequency pulses. It is also well known that acoustic waves are easily electromagnetically excited in HTSC [2].

The signals from two- and three-pulse PE were named dynamic echoes. Besides, in powders of different materials the stimulated or static echo is also observed that originates under the influence of a read pulse even if the pair of write and store pulses is switched off. This effect of the memory of the time-sequence of exciting pulses is conserved in a sample during a very long time - hours and even days. In powders of the II type low-temperature superconductors the PE was discovered as early as in 60-s. After the discovery of high- T_c superconductors similar echoes were also observed in their powders [3-5].

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All echo phenomena are inherently nonlinear, but in each case the nature of nonlinearity has its own origin. In superconductors the PE is seen *only* in superconducting phase with the echo amplitude that is three orders of magnitude higher than the NMR signal in these compounds. The question arises as to a cause of such a strong amplification of the PE effect in superconductors as well as to a connection of superconducting and acoustic properties of the material. In the paper the results of a detailed experimental study of the two-pulse (dynamic) and stimulated echoes in yttrium and bismuth based HTSC are presented.

To observe the echo signal, we used the standard pulsed NMR technique at frequency of about 20 MHz. 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. A strong echo signal was detected when a resonant circuit with a powder received two ~ 100 W, $5 \mu\text{s}$ -long rf pulses. The rf coil, filled with powdered high- T_c superconducting material ($\sim 10^6$ particles $\sim 100 \mu\text{m}$ in size), 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.

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 intensity of two-pulse echo decreases by a factor of ten and the intensity of a stimulated echo decreases by a factor of thirty. This pressure dependence clearly indicates that the echo signal really results from mechanical vibrations of the powder particles. The echo intensity decayed when the pauses τ between the exciting pulses with a time constant $T_2 \simeq 40 \mu\text{s}$ increased at a temperature of 4.2 K. The T_2 of the PE is slightly decreased with temperature (approximately at twofold rate at 50 K in the field 2.4 T for YBCO).

When the delay between the two exciting pulses was short ($\sim T_2$), we detected a second and even third echoes. If a third rf pulse with a delay even much greater than the relaxation time T_2 is sent to the rf circuit, we saw a stimulated echo signal. The stimulated echo signal remains even if two pulses of the three-pulse train are removed — it is initially reduced approximately by half in 10-20 seconds, and then, after some minutes, becomes constant that equals 0.4 of its preliminary value. In our experiments the stimulated echo has been detected some hours after the removal of exciting pulses, and which means that the system under study has a long-time memory of the time varying train of exciting 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.

If the time delay τ between the write and store pulses is changed during the buildup of pulses, a new signal will appear along with the one recorded earlier. Figure 1 illustrates such a situation: after the third rf pulse we see a sequence of echoes corresponding to different delay times between the write-store pulses and in this case the two primary rf pulses act both as the write-store and read pulses.

There is an accumulating effect of an amplitude of the stimulated echo, as it is shown in Fig. 2: if the third delayed pulse is switched on (or off) with the availability of two write-store rf pulses the stimulated echo signal initially rapidly increases (decreases) and then it continues slowly to enhance with characteristic time constant of tens of seconds.

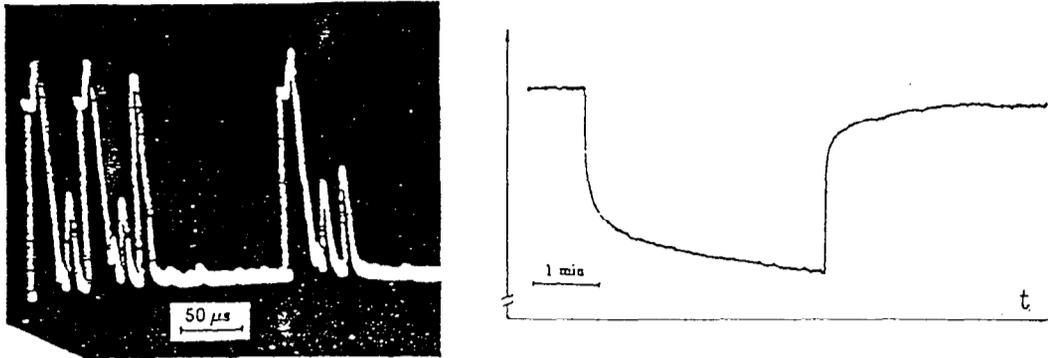


FIG. 1. The oscilloscope trace of a three-pulse echo signal. After every rf pulse the stimulated echo signal appears, demonstrating the memory of the previous write-store pulse-sequence.

FIG. 2. Time-dependence of a stimulated echo signal with switching on and off of two exciting rf pulses

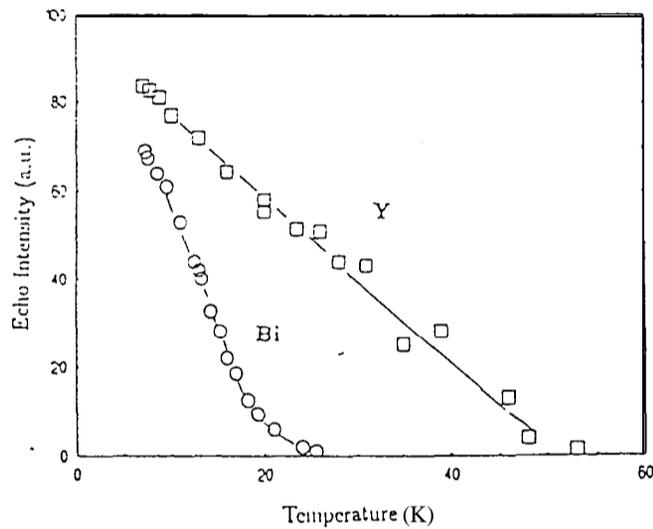


FIG. 3. Temperature dependence of the amplitude of a two-pulse echo in 24-kOe magnetic field for YBCO and BiSCCO powders.

It is impossible to expand this accumulating curve only in two exponents, that indicates that probably there is a distribution of time constants characterizing this process. This feature reflects different values of internal friction and defect of module due to a nonuniform deformation in different parts of a grain.

Besides the memory effect, there is another remarkable feature of the echo in HTSC — temperature dependence of the echo intensity, that is shown in Fig. 3. Two-pulse

and stimulated echoes exist only in superconducting phase of a powder, but they vanish well before reaching the critical temperature T_c (≈ 90 K for both materials), and besides, a significant difference in temperature dependence of the amplitude exists for Y- and Bi-based HTSC.

As it was underlined above, the properties of the echo are determined to a great extent by the nonlinear mechanisms of their formation. According to the theoretical approach to the problem, that has been recently developed by Ya. Asadullin [6], a nonlinearity in PE occurs due to the frequency and damping dependence of the acoustic particle vibrations on the structure of imperfections in the material under investigation.

An unusual temperature dependence of the echo-signal can be understood on the basis of recent studies of vortex dynamics in HTSC. The key elements determining the nature and the physical behaviour of the vortex system are the thermal and quantum fluctuations and the quenched disorder [7]. The coupling of the vortices to external currents and fields allows to exert forces on these interacting elastic strings, opening up the wide field of the dynamical behaviour of the vortex system.

Novel phenomena of HTSCs include, in particular, the existence of a distinct irreversibility line far below H_{C2} which is often associated with a melting- or glass-transition. The phase diagram for the anisotropic high-temperature superconductors (YBCO) and for a strongly layered one (BiSCCO) are essentially different. The irreversibility line $B_{irr}(T)$ can be moved to significantly higher fields and temperatures by strong pinning in YBCO which is a good three-dimensional material over a wide temperature and field range.

On the other hand, many experiments which appear to indicate a melting transition, can be explained conventionally by a rather abrupt onset of thermally activated depinning when T or B are increased [8,9,10]. In conventional superconductors this effect is observed only close to the transition temperature T_c as flux creep. A novel feature in HTSC is that this effect may be seen at temperatures that are rather far from T_c . It appears that experimentally observed features in some physical properties of HTSC (susceptibility, acoustic impedance, frequency and damping anomalies of vibrating reed) do not necessarily mean that there is a melting transition but only indicate that the displacements of sufficiently distant flux lines are uncorrelated in the relevant length and time scales. The "melting lines" in the (B, T) plane coincide with the "depinning lines" obtained on the same materials. It is also necessary to underline that analogous data were obtained with measurements of sound velocity and its damping [11] that is very essential for our consideration.

The simple estimations of the irreversibility line for a particle $100 \mu\text{m}$ in size and for 20 MHz excitation frequency show that its position approximately coincides with the curve of temperature dependence of echo intensity (Fig. 3), and the difference of YBCO and BiSCCO behaviour is qualitatively understandable on the basis of given above arguments.

Although new experiments as well as theoretical considerations are needed for a full quantitative explanation, we can definitely say that the echo phenomena in HTSC are closely connected with vortex dynamics and can serve as an effective tool for its study.

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