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COHERENT ELECTRIC ECHOES IN FUSED SILICA GLASS

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Résumé.— Des échos électriques cohérents ont été observés entre 15 et 45 mK dans de la silice vitreuse contenant des impuretés OH. On en déduit des temps $T_1$ et $T_2'$ considérablement plus longs que pour les échos de phonons.

Abstract.— Coherent electric echoes are observed at temperatures between 15 and 45 mK in bulk fused silica glasses containing OH impurities. The deduced lifetimes $T_1$ and $T_2'$ are appreciably longer than those observed for phonon echoes.

The anomalous thermal/1/ and acoustic/2/ low-temperature properties of glasses can be explained by the existence of two-level systems (2LS) having a broad distribution of their energy-splitting. It has been proposed/3/ that tunneling particles (of still unknown nature, but probably groups of atoms) give rise to these 2LS. Recent experiments have demonstrated/4/ that not only elastic waves, but also microwave electric fields can resonantly excite 2LS in glasses provided that a dipolar impurity, such as OH, is incorporated into the glassy structure. The mechanism which couples the electrical dipoles of the impurities to the 2LS is still unknown. In order to describe the dynamics of the 2LS two characteristic times $T_1$ and $T_2'$ have to be introduced. $T_1$ is the radiative lifetime and reflects the coupling of the 2LS to the amorphous network. $T_2'$ is the homogeneous lifetime and is determined by the interaction between the 2LS.

In the present paper, we report the observation of coherent electric echoes in bulk fused silica glass. /5/ These echoes are the electric dipolar analog of magnetic spin echoes and very similar to phonon echoes observed in fused silica recently /6/. Our experiments were carried out in the temperature range between 15 and 50 mK using two different samples of vitreous silica, Suprasil I contains about 1200 ppm of OH impurities whereas only 180 ppm are found in Herasil /7/. The echoes are excited by introducing 710 MHz microwave pulses (duration $\tau$ between 0.3 and 0.9 μs) into a microwave cavity in which the sample is located in a uniform electric field region. Spontaneous (2-pulse) and stimulated (3-pulse) echoes are generated, allowing the direct determination of $T_2'$ and $T_1$, respectively.

Figure 1 shows the dependence of the spontaneous echo amplitude upon the product of the microwave field and the duration $\tau$ of the two pulses. $\tau$ was 0.3 μs for Suprasil I (1200 ppm OH) and 0.9 μs for Herasil (180 ppm OH).

As expected the amplitude varies as $(FT)^3$ for small power levels and passes a maximum with increasing power. The curve at higher power levels is difficult to determine since the echo splits into two parts. This feature is characteristic of large area echoes in inhomogeneously broadened systems and has been seen in EPR echoes /8/ and more recently in coherent phonon echoes in glass /6/. For identical pulses as in our measurement, the maximum is expected for a pulse area $\alpha = 2\pi/3$, where $\alpha = (\mu^2/3)\Pi t$. $\mu$ is the off-diagonal matrix element connecting the two tunneling levels ("induced dipole moment"). The factor $1/3$ takes into account the random orientation of the dipole moments, which smears out the effective coupling between the 2LS and the electric field. This leads to a maximum for pulse areas close to $\pi$ and to

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a minimum around $2\hbar$. From our experimental data we estimate $\mu'\% 5$ Debye, a value close to that of an OH impurity in crystals and also in good agreement with other experiments \cite{4}. The position of the maximum and of the minimum is independent of the OH-concentration of the sample indicating that a single OH-impurity determines the electric dipole moment of a 2LS. The decay of the spontaneous echo $E_{12}$ provides a direct measure of the homogeneous lifetime $T_{12}'$. Figure 2 shows the decay of $E_{12}$ at $15\, \text{mK}$ as a function of $T_{12}$ in Suprasil I. Here $T_{12}$ is the separation between the first and the second pulse. - If a third pulse is applied at time $T_{13}$, stimulated echoes are observed.

![Fig. 2](image)

Fig. 2: Relative amplitude of the spontaneous echo $E_{12}$ as a function of the pulse separation $T_{12}$. Insert shows the pulse sequence.

The decay of the echo $E_{123}$ occurring at $T_{13} + T_{12}$ is plotted in figure 3 as a function of $T_{13}$.

![Fig. 3](image)

Fig. 3: Relative amplitude of the stimulated echo $E_{123}$ as a function of the pulse separation $T_{13}$. Insert shows the pulse sequence.

The decay of $E_{12}$ as well as of $E_{123}$ is clearly non-exponential. Whereas $E_{12}$ falls off faster at larger times, the opposite behaviour is found for $E_{123}$. Considering only the initial decay, we deduce decay times which are proportional to $T^{-2}$ in both cases. Such a dependence has already been reported for the phonon echo experiments \cite{6} and has been interpreted in terms of spectral diffusion \cite{7}. This is supported by the fact that the decay curves of $E_{12}$ scale with the pulse separation $T_{12}$ \cite{9}. It should be pointed out, however, that we observe a power dependence of the decay curves - they become flatter with decreasing incident powers - and that the echoes seem to decay much faster in Heraasil, the sample containing less OH-impurities. These results can hardly be explained by spectral diffusion.

In the stimulated echo experiment the signal persists for extremely large values of $T_{13}$, much longer than in the phonon echo experiment. The most likely explanation is that the phonons couple preferentially to those resonant systems with the largest off-diagonal strain matrix elements. The electric field couples to those systems with the strongest off-diagonal, electric dipole moments. If it is assumed that there is a distribution of strain matrix elements and that they also determine the decay, then the electric echo involves the excitation of systems with a wider distribution of phonon couplings than the phonon echo and thus, more weakly decaying systems. The result is a slowly decaying tail.

References

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