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ELECTRON SPIN-ECHO MEASUREMENTS OF E_1' CENTERS IN CRYSTALLINE QUARTZ

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A standard spin-echo technique has been employed to determine the electronic phase-memory time of radiation-produced E_1' centers in crystalline quartz at 4.2, 77, and 300°K. The phase-memory time was found to be independent of temperature.

Radiation-produced E_1' centers in crystalline quartz have been the subject of considerable study,[1] and the spin-lattice relaxation time of this center has been reported to vary from the order of minutes at 4.2°K to a value of approximately 0.2 msec at 300°K.[2] These relatively long spin-lattice relaxation times make this defect a prime candidate for the observation of electron spin echoes at liquid-nitrogen or ambient temperatures. Spin echoes have been observed at these temperatures, and the spin-echo technique has been utilized to determine the phase-memory time of this material at 4.2, 77, and 300°K.

The experimental arrangement which is employed in these investigations involves a standard X-band superheterodyne spectrometer with i.f. detection at 45 MHz plus a 10-W traveling wave tube (TWT) which has been inserted after the signal klystron. With reference to Fig. 1, the signal klystron is left to run cw while two identical microwave pulses are produced by gating the grid of the TWT. The microwave pulse width and peak power are then varied to give the maxium echo signal on the oscilloscope. Related parameters (which vary slightly with temperature) are the following: peak pulse power incident on the cavity, 0.8 W; pulse width, 1 μsec; loaded-cavity $Q \sim 1000$; effective cavity volume, ~5 cm^3; operating frequency, ~9.5 GHz; gyromagnetic ratio, 1.76×10^7 G^{-1} sec^{-1} ($g = 2$). These values correspond to the two 120° pulses which are required to produce the maximum echo signal.[3] Spin-echo signals at various temperatures are shown in Fig. 2.

By varying the separation between the microwave pulses a decay envelope for the echoes is obtained from which one can estimate the conventional $1/e$ phase-memory time T_2. Similarly, the value of T_1 was determined by varying the repetition rate of the echo-producing pulses until the amplitude of the second echo was $1-1/e$ of the initial echo. These values were found to be in agreement with those determined by Castle et al.[2] Values of T_1 and T_2 are listed in Table I along with the spin-lattice relaxation time and

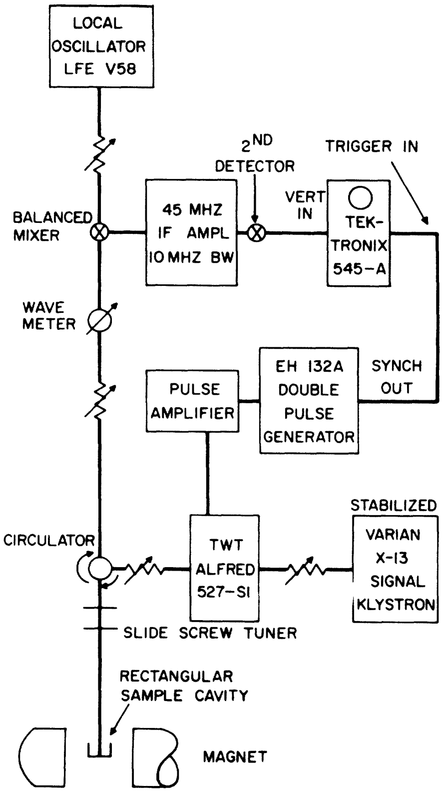

FIG. 1. Block diagram of spin-echo spectrometer.

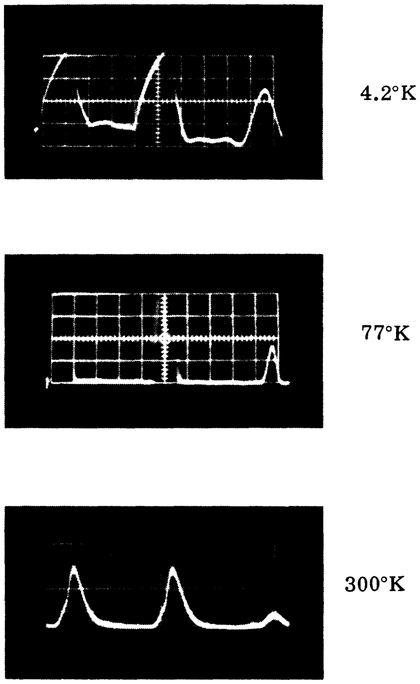

FIG. 2. Oscilloscope presentation showing two identical 120° pulses followed by the spin-echo signal due to the E_1' center in crystalline quartz at 4.2, 77, and 300°K. Horizontal sweep is 2 μsec/cm. At 4.2 and 77°K the receiver is saturated during the two 120° pulses; at 300°K this saturation was overcome by inserting a −30 dB switch in the receiver arm which was gated on during the time of the echo.

the resonant linewidth at the different temperatures. Because T_1 is always greater than T_2, it is concluded that the phase-memory time is determined by the spin-spin relaxation time.[4] The 40-μsec value obtained for T_2 was observed to be independent of temperature, over the temperature range covered, and corresponds to a E_1' concentration of $3\times10^{16}/\text{cm}^3$ as determined independently by comparison with the signal from a known amount of diphenyl picryl hydrazyl contained in the same cavity. Reference 4 points out that T_1 can still affect the phase-memory time even when T_1 is an order of magnitude greater than the spin-spin relaxation time. This is because T_1 is merely a measure of the return to the equilibrium population of the two levels. However, it does not tell us what effect spin-lattice relaxation has on the destruction of phase memory. No such information is contained in T_1. Still, such an effort would cause T_2 to be temperature dependent which was not the case in this particular experiment.

Table I. Critical data for E_1' center in crystalline quartz at 4.2, 77, and 300°K.

Temperature (°K)	Linewidth (G)	T_1 (sec)	T_2 (μsec)
4.2	0.1	10^{-2}	40 ± 10
77	0.2	10^{-2}	40 ± 5
300	0.2	2×10^{-4}	40 ± 5

In summary it should be mentioned that radiative defects, because of their inherently long spin-lattice relaxation times, resulting from loose coupling to the lattice, lend themselves well to the observation of electron spin echoes at ambient temperatures.

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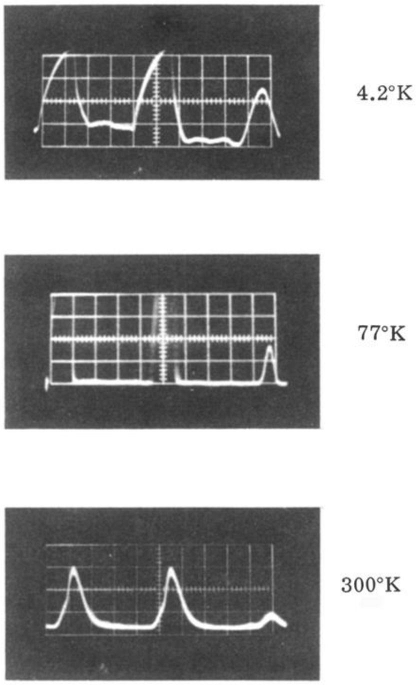

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