Time-Resolved Far-Infrared Studies of Superconducting $Nb_{0.5}Ti_{0.5}N$ Film in a Magnetic Field

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Abstract. Time-resolved, optical pump-probe measurements on a thin $Nb_{0.5}Ti_{0.5}N$ film in applied magnetic fields were performed at the National Synchrotron Light Source, Brookhaven National Laboratory. Despite the presence of normal cores from vortices in the films, we find that the relaxation time of photoexcited quasiparticles does not decrease with magnetic field as one might expect. The change in the far-infrared transmittance due to the applied magnetic field is also discussed.

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When a superconductor is exposed to an external light source having energy greater than the superconducting energy gap 2Δ, excess quasiparticles are produced. These photoexcited quasiparticles relax primarily through the emission of phonons and eventually recombine into Cooper pairs. The emitted phonons have energies > 2Δ and can break other Cooper pairs unless they decay or escape the superconductor. This cycle leads to a bottleneck in the return to equilibrium superconductivity after photoexcitation. When a magnetic field is applied in a type II superconductor, the quasiparticles may diffuse toward vortices where there is no gap and hence potentially no bottleneck. Thus, vortices would seem to open a new "channel" for the energy relaxation of the photoexcited quasiparticles, and should yield a faster relaxation time.

Our sample was a ~10 to 20 nm thickness film of $Nb_{0.5}Ti_{0.5}N$ on 0.5 mm thick sapphire with T_c approximately 10 K. The far-infrared transmission through the films was measured for both the normal and superconducting states. Figure 1 shows the magnetic field dependence of the superconducting-state transmittance, normalized by the normal state transmission. The superconducting data were measured at 3 K in magnetic fields up to 10 T. The normal state was measured at 12 K at zero magnetic field. Behavior typical of $Nb_{0.5}Ti_{0.5}N$ was observed, e.g. H_{c2} is greater than 10 T at 3 K. The peak transmittance occurs near 28 cm^{-1} (3.47 meV), which agrees with $2\Delta_0 \sim 26.5$ cm^{-1} [1].

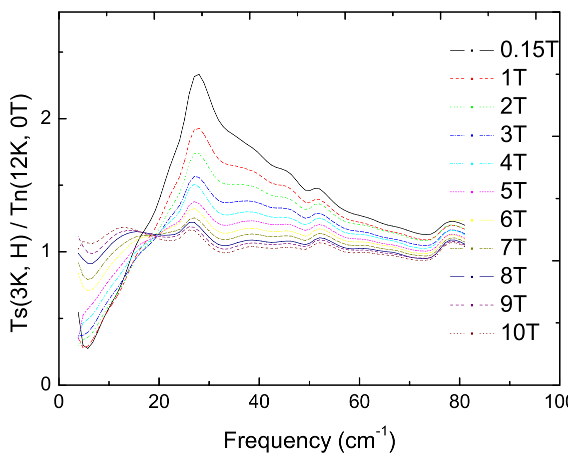

FIGURE 1. Measured ratio of T_S/T_N for a $Nb_{0.5}Ti_{0.5}N$ film at magnetic fields between 0 and 10 T.

Time-resolved pump-probe spectroscopy [2] was performed at the U12IR beamline of the National Synchrotron Light Source (NSLS), Brookhaven National Laboratory. A mode-locked Ti:sapphire laser producing two picosecond duration near-infrared pulses was used as the pump source. Those pulses were synchronized to the far-infrared pulses from

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U12IR that served as the probe source. For high sensitivity to spectroscopic changes, the pump-probe delay time was dithered and a lock-in amplifier then measured the derivative of the photoinduced transmittance signal. This differential was integrated to yield the time-resolved change in transmission. The synchrotron pulse width was about 350 picoseconds and determines the measurement resolution. Figure 2 shows the integrated signal (squares) for a $Nb_{0.5}Ti_{0.5}N$ sample along with a fit.

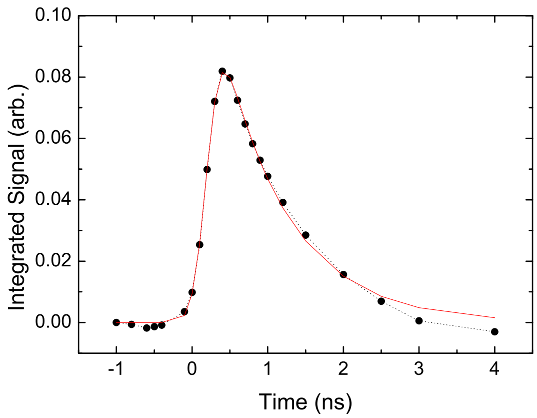

FIGURE 2. Plot of the integrated signal and the fit for the $Nb_{0.5}Ti_{0.5}N$ film, measured at 0 T and 3 K.

The fitting function used is given in Eq. (1) and represents a single exponential, convolved with a Gaussian to account for the width of the probe pulse.

$$S(t) = \frac{A}{T\sqrt{\pi}} \int_{0}^{+\infty} e^{-\frac{t'}{\tau}} e^{-(\frac{t-t'}{T})^2} dt' \qquad (1)$$

Here, S is the measured temporal response, A is the measured signal magnitude, T is probe pulse duration and τ is the lifetime. For the applied magnetic fields up to 5 T, the fitting parameters are shown in Table 1. It indicates that the lifetime τ does not decrease with increasing magnetic field, in contradiction to our expectation that the vortices would speed up the relaxation dynamics of the photoexcited quasi-particles.

In the dither (derivative) method of measuring the photoinduced signal, one can show that the maximum signal value is approximately inversely proportional to the probe pulse width while the minimum signal is inversely proportional to the quasiparticle relaxation time. By sweeping the magnetic field and collecting maximum and minimum date points for every field, the lifetime can be estimated. The results are shown in Figure 3. The error bars are statistical, from the variations of two trials. At 4.5 K, the lifetime does not show a decrease as the magnetic field increases, in agreement with the results in Table 1.

TABLE 1. Fitting Parameters

T (K)	H (T)	A (arb.)	τ (ps)
3	0	0.114±0.003	880±30
3	1	0.069±0.001	1100±20
3	2	0.063±0.002	1030±50
3	3	0.051±0.001	1050±20
3	4	0.055±0.001	1040±20
3	5	0.048±0.001	1360±50

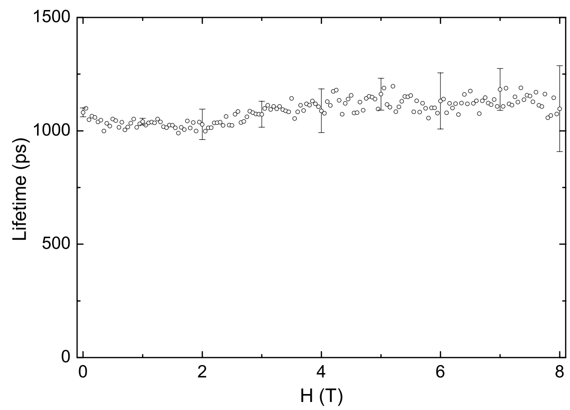

FIGURE 3. Quasiparticle relaxation time from swept measurements for a $Nb_{0.5}Ti_{0.5}N$ sample at 4.5 K.

The data indicate that the vortices do not have a significant effect on the measured lifetime. There are two possible explanations. Either the additional scattering channels made available by the vortex and its core are not an efficient route for relaxing the system back to the true equilibrium state or the excess quasiparticles simply do not interact with the vortices to any appreciable extent.

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