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Title: FAR-INFRARED CARRIER DYNAMICS IN SUPERCONDUCTING MgB_2

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Abstract: We have performed optical-pump terahertz-probe measurements in transmission on MgB_2 thin films in the superconducting state. The initial optical perturbation of the superconducting condensate and subsequent pair recovery display a strong fluence dependence.

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1. Introduction

The announcement in January 2001 of the discovery of bulk superconductivity in MgB_2 at $T_c \sim 39$ K [1] has generated a great deal of excitement for several reasons. Most importantly, T_c is higher by nearly a factor of two in comparison to other previously known simple intermetallic superconductors (e.g. Nb_3Ge, $T_c \sim 23$ K). This discovery has fueled the search for other simple metallic compounds that have a comparable or even higher transition temperature than MgB_2 [2]. Indeed, an important fundamental issue that has resurfaced is determining the upper limit for T_c permitted by conventional phonon-mediated pairing (see also [3] in this regard). It is important in characterizing MgB_2 to employ techniques that probe the bulk low energy electronic states. Far-infrared spectroscopy is especially useful since the gap can be directly observed. Recently, the superconducting gap in MgB_2 has been studied using terahertz time-domain spectroscopy [4].

All-optical ultrafast time-resolved spectroscopy has also proven to be sensitive to the low energy states of correlated electron materials [5]. Our recent work has emphasized combining ultrafast optical and far-infrared techniques to directly probe the low energy dynamics by measuring the photoinduced changes in the complex conductivity with picosecond resolution. In particular, optical-pump terahertz-probe spectroscopy has allowed us to simultaneously measure the dynamics of quasiparticles and superconducting pairs in high-T_c superconductors [6]. Time-resolved far-infrared studies of superconducting pair breaking have been performed on lead which is a conventional superconductor with $T_c = 7$ K [7]. However, given the low value of T_c in Pb, it is difficult to perform temperature and fluence dependent studies in the superconducting state. MgB_2, having a considerably higher T_c, offers the exciting possibility to look at the time-resolved far-infrared dynamics of a BCS-like superconductor in considerable detail. In the following we present our preliminary time-resolved studies of the pair breaking and recovery in MgB_2.

2. Experiment

The MgB_2 films used in these studies had thicknesses of approximately 50 nm and 100 nm with $T_c \sim 32$ K [8]. The experiments were performed using 1-mJ 150-fs 1.5-eV pulses at 1kHz from a commercial regeneratively amplified system. The 1.5 eV pulses were used to photoexcite the sample and generate and detect the terahertz (THz) pulses in ZnTe. Further details of the film growth and experiment are described elsewhere [6,8].

3. Results and Discussion

Figure 1(a) shows the THz pulses transmitted through the MgB_2 film at 35 K (above T_c) and at 7 K. The phase shift is the so-called kinetic inductance due to superconductor pairing (i.e. the conductivity due to the superconducting pairs is purely imaginary with a $1/\omega$ dependence that results in the observed phase shift in the time domain). The increase in amplitude below T_c is due to the increase in transmission above the superconducting gap compared to the normal state transmission. This is evident in Fig. 1(b) which shows the amplitude of the Fourier transform in the superconducting state divided by the amplitude in the normal state (35K). Below 30 K a gap opens up and increases in magnitude with decreasing temperature. The inset shows the gap Δ as a function of temperature as determined from data analysis using Mattis-Bardeen formulae [9] – the dashed line is a fit showing the BCS-like behavior of MgB_2. These results are in reasonable agreement with [4].

The photoinduced change in the THz transmission at 7 K at several fluences is shown in Figure 2. The optical pump line was scanned and chopped while sitting at the null point of the electric field as shown by the arrow in Fig. 1(a). This is where the maximum signal was obtained meaning that induced change is primarily a phase shift and we are probing the dynamics of the superconducting pairs. Furthermore, the photoinduced change decreases with increasing temperature (not shown) and vanishes just below T_c. The solid lines are fits with a two-exponential rise followed by a single exponential decay. At 20 μJ/cm², the pair recovery is > 3 ns indicating complete destruction of the superconducting state. However, at lower fluences, the pair recovery time is approximately 500 ps. The dynamics are much slower than in high-T_c materials which is consistent with the observation that the lifetime goes as $1/\Delta$ [5] (MgB_2 has a much smaller gap). Fig 2(b) shows an expanded view of (a) showing more clearly that the risetime is also fluence dependent. The rise consists of a fast resolution limited component (~1 ps) and a slower (~15 ps) component. At 20 μJ/cm² there is only a resolution-limited risetime while the slower rise is especially pronounced on the 0.5 μJ/cm² data. This slow risetime at lower fluences may be associated with the dynamics of the gap closing. This is consistent with the fact that at higher fluences, where the superconductivity is destroyed (and the gap completely closed), there is only a resolution-limited rise. To more extensively elucidate this possibility a more complete experimental analysis in which the dynamics of the real and imaginary conductivity are directly measured is required (see [6] for examples on high-T_c superconductors).

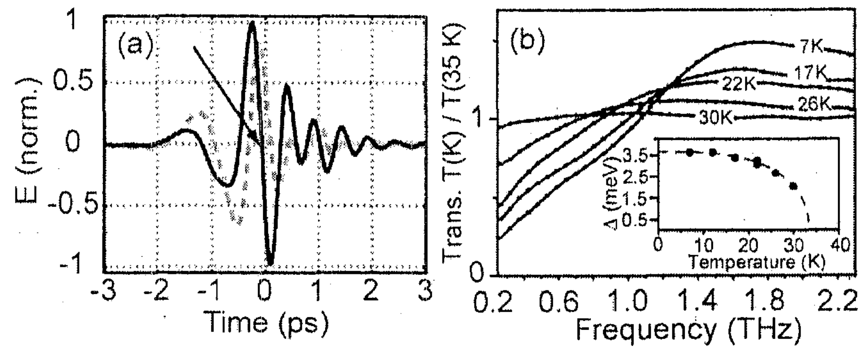

Fig. 1 (a) Electric field transmitted through MgB_2 thin film at 35 K (dashed line) and 7 K (solid line). (b) The amplitude of the Fourier transform in the superconducting state divided by the amplitude in the normal state (35K). The inset shows the gap Δ as a function of temperature.

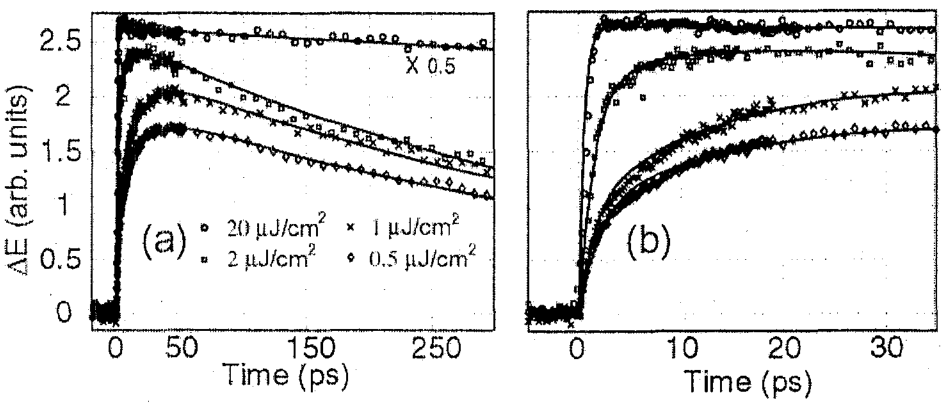

Fig. 2. (a) Photoinduced change in electric field transmission at 7 K at various fluences. (b) An expanded view of (a) showing more clearly that there is also a fluence dependent risetime.

4. Conclusions

In conclusion, we have performed the first time-resolved far-infrared studies on the new superconductor MgB_2. We have observed a strongly fluence dependent pair recovery time that, at the lowest fluences used, is approximately 500 ps. In addition, at the lower excitation fluences where superconductivity is not destroyed, a risetime in the dynamics is observed that may be due to photoinduced gap fluctuations.

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