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Persistent photoconductivity spectrum of $GdBa_2Cu_3O_{6.3}$ in the IR to UV region

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We measured the spectral dependency of persistent photoconductivity (PPC) in $GdBa_2Cu_3O_{6.3}$ from the near infrared to the ultraviolet energy range. For a photon energy of 4.1 eV there is a strong enhancement in the excitation efficiency. Photons with this energy create electron-hole pairs close to oxygen vacancies in the Cu-O chain layers. This increases the probability of the excited electron to get trapped at an oxygen vacancy, and thus leads to a strong enhancement of the excitation efficiency of the PPC.

1. INTRODUCTION

Illumination of oxygen deficient $YBa_2Cu_3O_{7-\delta}$ thin films decreases their resistivity[1] and, if the film is superconducting, increases its superconducting temperature[2]. This effect is persistent at temperatures below 100 K and relaxes within several days at room temperature. It has been shown, that the persistent photoconductivity (PPC) needs oxygen vacancies [3] and that its magnitude increases with decreasing oxygen content[4].

We extended measurements of the spectral efficiency from the previously measured visible range[1] into the UV energy region. Compared with excitations with visible light there is a strong enhancement of the excitation efficiency of PPC at photon energies of 4.1 eV. This can be directly attributed to electronic excitations in the Cu-O chain layers.

2. RESULTS

The experiments were performed on a 1000 Å c-axis-oriented $GdBa_2Cu_3O_{6.3}$ thin film grown on a (100) $SrTiO_3$ substrate, since it is close to the metal-insulator transition, and therefore shows a large PPC effect[1]. The resistance was measured with a four point method in a He-flow cryostat equipped with optical quartz windows. For the optical excitation we used a 1000 W mercury-xenon arc lamp with wavelengths from 300 to 900 nm (4.1 to 1.4 eV) selected by using interference bandpass filters (bandwidth 10 nm). The light intensity at the sample varied, depending on the wavelength, between 0.2 and 5 mW/cm^2. During excitation, the sample was kept at 95 K. After each excitation the sample was relaxed back to its original state at room temperature.

For a given wavelength the excitation of PPC in $YBa_2Cu_3O_{7-\delta}$ depends only on the number of photons per surface area[1]. Therefore we converted for our excitation measurements the measurement time t into photon numbers per surface area n using

$$n = (I \times t)/\hbar\omega, \quad (1)$$

where I is the light intensity at the sample and $\hbar\omega$ the photon energy. Figure 1 shows the resistance change $R(n)$ versus photon number for a few different photon energies. $R(n)$ during the excitation, can be fitted phenomenologically to a stretched-exponential[1]:

$$R(n) - R(\infty) = [R(0) - R(\infty)] \exp(-n/n_c)^{\beta} \quad (2)$$

Here $R(n)$ is the resistance after the illumination, $R(0)$ is the initial resistance, $R(\infty)$ is the saturation resistance, n_c is a critical photon number, and β is a dispersion parameter ($0 < \beta < 1$). Figure 1 shows as an example a fit for the data at 4.1 eV.

Figure 2 shows the dependence of n_c and β on the energy of the excitation. Clearly, the excitation efficiency, which is proportional to $1/n_c$, is enhanced by an order of magnitude at 4.1 eV compared with excitations in the visible range (1.5 to 3.2 eV).

3. DISCUSSION

It is very interesting to compare the spectral dependence of PPC with the dielectric function of

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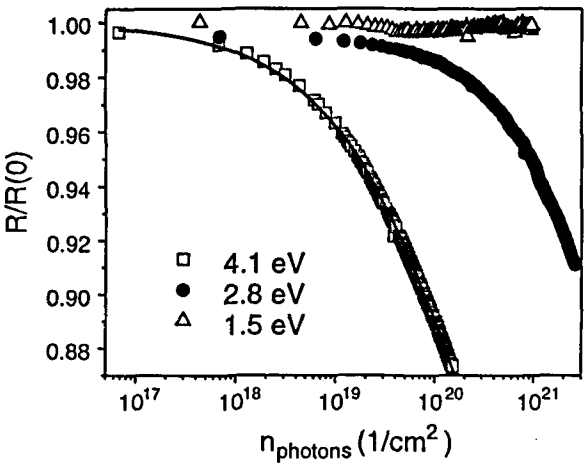

Figure 1: Excitation of PPC for a few representative photon energies $\hbar\omega$. The resistance is normalized to the resistance in the relaxed state $R(0)$. The solid line is a fit to the data at $\hbar\omega = 4.1$ eV using Eq. (2).

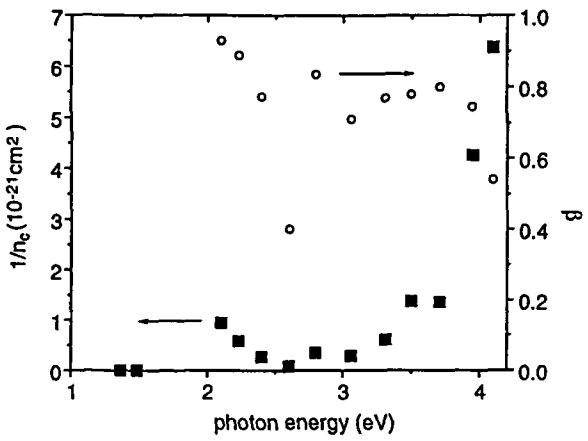

Figure 2: Spectral efficiency of the PPC excitation. $1/n_c$ and β vs. photon energy. $1/n_c$ and β is determined by fitting the data from Fig. 1 to Eq. (2).

$YBa_2Cu_3O_{7-\delta}$. The imaginary part of the dielectric function shows a large peak at 4.1 eV, which is strongly dependent on the oxygen content of the sample[5]. However, the enhanced absorption alone is not sufficient to explain the strong enhancement of excitation of PPC at 4.1 eV. At an oxygen content of 6.3, the intensity of the absorption peak at 4.1 eV is at most a factor of two higher than in the visible region[5]. On the other hand, the PPC shows an enhancement of an order of magnitude.

The key to understand this strong enhancement is the origin of the absorption peak at 4.1 eV. This peak has been assigned to a $3d_{3z^2-1}$ to $4p_x$ electronic transition of Cu(1) atoms in an O(4)-Cu(1)-O(4) dumbbell[5]. These Cu(1) atoms are located in the Cu-O chain layers and have an oxygen vacancy on both sides. On the other hand the excitations with photons in the visible light region have been all attributed to charge transfer excitations in the CuO_2 plane layers[1]. This implies that the PPC is enhanced as soon as an electron-hole pair is created in close proximity to an oxygen vacancy.

This observation supports a recent model of PPC[4]. In this model, the incoming photon excites an electron-hole pair. Subsequently the electron is trapped at an oxygen vacancy in the Cu-O chain layer, while the hole is transferred to the CuO_2 plane layer. When an electron-hole pair is created with visible light (1.5 to 3.2 eV), they are both in the CuO_2 plane layer. For the electron to become trapped at an oxygen vacancy, it needs to be transferred into the Cu-O chain layer. Therefore the probability for an excitation with visible light to contribute to the PPC is small. When the electron-hole pair is created with 4.1 eV photons, the electron is close to the oxygen vacancy and therefore has a much higher probability to get trapped. This easily explains the strong enhancement of the excitation of PPC at 4.1 eV.

4. CONCLUSIONS

In conclusion, we measured the spectral dependence of PPC in $GdBa_2Cu_3O_{6.3}$ from the IR to the UV energy region. The efficiency of the excitation is strongly enhanced for 4.1 eV compared with the visible region (1.5 to 3.2 eV). Comparison with optical measurements implies that this enhancement at 4.1 eV is due to the creation of an electron-hole pair in the Cu-O chain layer next to two oxygen vacancies, while in the visible region the electron-hole pair is created in the CuO_2 plane layer. This results for excitations at 4.1 eV in an higher probability for the electron to get trapped at an oxygen vacancy.

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