

Electron and Hole Dynamics by Microwave Detected Photoconductivity Transients of $AgBr_{1-x}I_x$-Tabular Crystals

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Abstract

Intrinsic tabular formed emulsion $AgBr_{1-x}:I_x$ crystals were investigated with microwave detected photo induced current transient spectroscopy (PICTS). PICTS signals were observed at room temperature after strong exposure of the films. The transients obtained at room temperature in a time scale of about 100 µs are due to thermal activation of carriers from traps. The temperature dependence of the current transients yield a trap level of 70 meV. At 77 K a nearly persistent photoconductivity was found. It is interpreted to be due to an efficient hole trapping. Consequently the trap level analysed must be a hole trap. The microscopic structure of this trap is still unknown.

Introduction

As it was shown in many experiments the investigation of microwave detected photoconductivity transients provide valuable pieces of information about the dynamics of electrons in photographic materials [1,2]. In these experiments the main source of information is the lifetime of electrons in the conduction band as detected by the decay time of the photoconductivity response after the light has been switched off. Typical decay times at room temperature are in a range below microsecond and the mechanisms behind are recombination or trapping of charge carriers.

By, however, optimising the microwave detection system for high sensitivity and extending the time scale up into the millisecond range under certain conditions a rather faint and slow residual decay of the conductivity is observed. This effect is due to thermal activation of carriers out of different traps. Evaluating this decay in detail provides new information about defect levels which is usually not available by other experimental means. For high resistive semiconductors such experiments are known as photo induced current transient spectroscopy (PICTS) [3]. However, in the case of semiconductor crystals, the photoconductivity is measured very conventionally using ohmic contacts and a DC voltage source. The information obtained by PICTS is similar to that from the well known DLTS which is, however, only feasible for low resistive semiconductor material. The application of microwave detected PICTS to emulsion crystals is new.

Experimental

Observing the time dependence of very weak signals over relatively long time periods by microwave absorption provides a challenge because of signal-to-noise ratio and baseline stability problems of the spectrometer. The basic principle of the apparatus is depicted in Fig. 1.

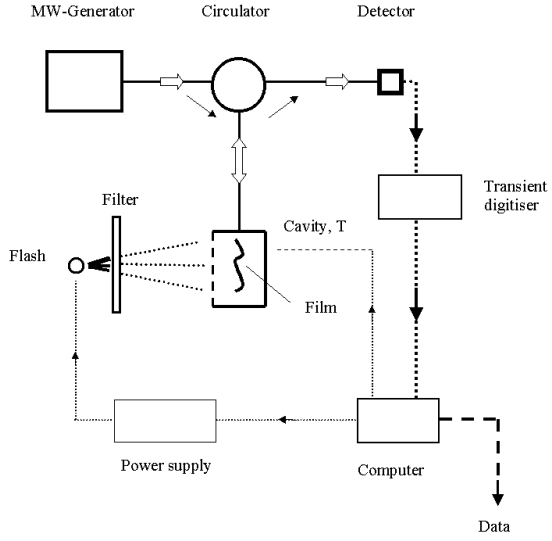

Figure 1. Schematic diagram of the apparatus for microwave detected PICTS

The microwave generator, the circulator, and the detector are the most essential building blocks of the microwave spectrometer. This spectrometer employs design concepts similar to those of high performance ESR and ENDOR spectrometers [4]. The microwave frequency used is 9.6GHz. The cavity has a Q-value of about 6000 leading to a time resolution of the entire microwave spectrometer of 1μs. As flash lamp a high power Xenon lamp was used with an electrical input power of 1 Joule/ pulse filtered by an interference filter at λ = 425nm and focused onto the film strip of about 5x30mm². The time response of this flash is shown in Fig. 2. For the measurements intrinsic tabular formed emulsion AgBr:I crystals were used with a volume of 0.75 μm³ and 2%I content.

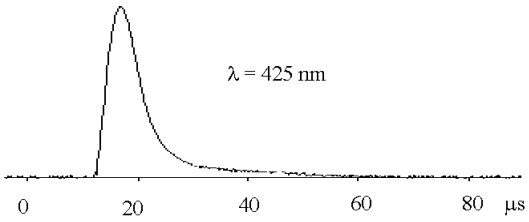

Figure 2. Time response of the flash used for photo excitation

Results and discussion

Using an unexposed film the time response of the microwave absorption signal for a single pulse nearly follows the time dependence of the flash light intensity. This is seen in the upper trace in Fig. 3.

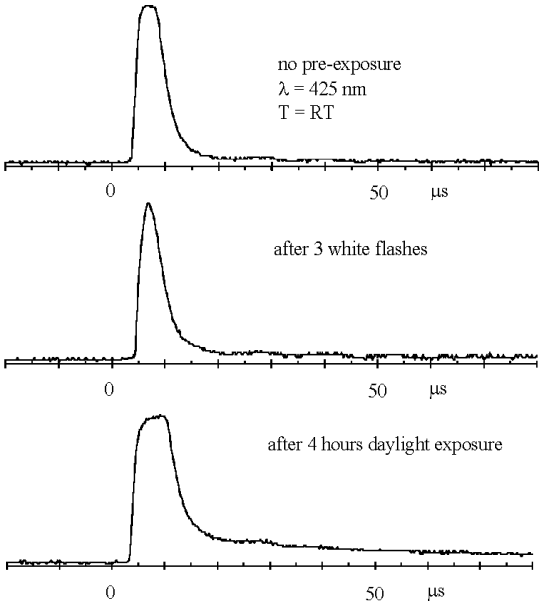

Figure 3. Time dependence of absorption signal after different exposures of the film

This reflects the well known fact that under these conditions the lifetime of the photo-generated electrons in the conduction band is much smaller than 1 μs. This situation, however, changes with increasing exposure of the film. As can be seen from the lower traces in Fig. 3, after intense exposure there appears a slowly decaying tale of the microwave absorption at a long time after the decay of the light intensity. This relatively slowly decaying signal is due to thermal activation of carriers out of traps where these traps are gradually emptied. Assuming a constant recombination rate of these carriers, it can be easily shown that the concentration of the carriers in the corresponding band as detected by microwave absorption decays exponentially with time. The rate at which carriers are activated out of the traps again depends exponentially on the depth of the corresponding trap and on the temperature. This is demonstrated in Fig. 4.

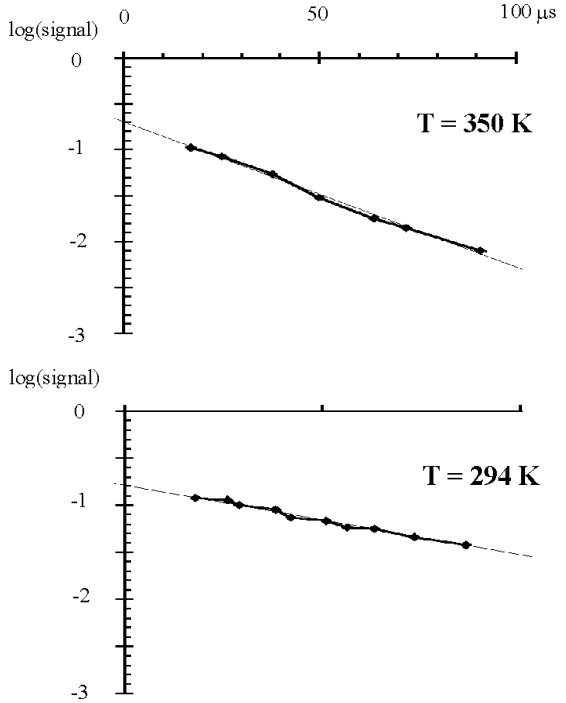

Figure 4. Logarithm of the tail signal (Fig. 3, lower trace) for two different temperatures

It shows the logarithm of the tail signal as in the lower trace of Fig. 3 versus time for two different temperatures. The slope of the resulting straight line and at the same time the emission rate is clearly smaller at 294K than at 350K. These two slopes at the two temperatures yield a trap level depth of about 70meV.

So far it is on open question whether electrons or holes are activated out of a trap with 70meV depth. Following a so far widely accepted assumption that only the light electrons can give rise to a microwave absorption signal rather than the heavy holes one would suppose that the observed signals are due to an activation of electrons out of an electron trap into the conduction band until the electron concentration in the conduction band disappears by recombination. It could, however, as well happen that electrons generated during the light pulse cannot recombine because all corresponding holes are trapped. In this case, the concentration of electrons in the conduction band is determined by the rate holes are thermally activated out of a hole trap. Consequently, the trap depth of 70meV corresponds to a hole trap. This

interpretation is supported by results obtained at 77K shown in Fig. 5.

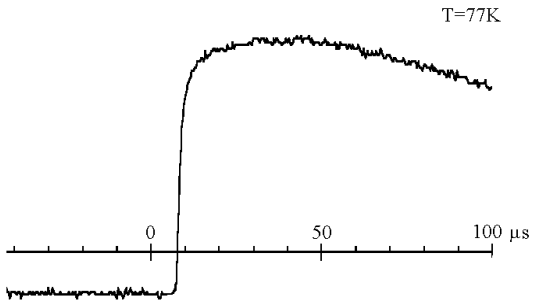

Figure 5. Time dependence of the microwave absorption signal at 77K for the sample as in Fig. 3, lower trace

The surprising fact is that the microwave conductivity and thus the electron concentration in the conduction band persists for a likewise long time after the light has been switched off. It should be stressed that in good approximation the full peak intensity persists, there is no longer a fast initial decay to a low value followed by a slow decay as at room temperature (see Fig. 3). If really only electrons in the conduction band are detected by 10 GHz microwaves (as generally assumed) then the observed persistent photoconductivity can only be explained by an effective hole trapping mechanism. Since the effect of persistent photoconductivity was only observed after an intense exposure of the film the generation of the hole traps must be somehow linked to the generation of latent image specks. However, there is so far not yet sufficient experimental information to clarify details of the mechanism.

Further experiments must include PICTS experiments where the conductivity is detected by the absorption of electromagnetic radiation with frequencies much lower than 10 GHz, e.g. 100 MHz to compare the hole concentration in the valence band directly to that of the electrons in the conduction band.

References

1. Th. Muessig, J. Imaging Sci. 41, 118 (1997)
2. Th. Muessig, G. Hagenbart, A. Russow, H. Fuess, J. Imaging Sci. Technol. 38, 526 (1994)
3. P. Blood and J.W. Orton, The Electrical Charakterization of Semiconductors: Majority Carriers and Electron States, Academic Press London 1992
4. J.-M. Spaeth, J. R. Niklas, R. H. Bartram Multiple Magnetic Resonance Spectroscopy for Structural Analysis of Point Defects in Solids, Springer (Heidelberg) 1991.