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PHOTOTRANSFER STUDIES IN SYNTHETIC QUARTZ

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Abstract — The PTTL of high purity synthetic quartz was studied in the temperature range from 80 to 500 K. Main PTTL peaks appeared after LNT illuminations at 205 and 265 K and after RT illuminations at 380 K with a shoulder at ~430 K. PTTL excitation spectra have maxima at 275, 315 and 330 nm. Emission spectra of PTTL showed maxima at 330, 370 nm and a broad maximum centred at 460 nm. The same emission bands have also been recorded in the TL, indicating that the same luminescence processes are responsible for the emission in both cases. The finding that the PTTL peaks appear at the same temperatures and with the same thermal activation energies as the β, X and and some of VUV induced TL peaks, indicates that the carriers are released in these cases, from the same traps.

INTRODUCTION

Phototransferred thermoluminescence (PTTL) has previously been studied in various materials (e.g. Refs 1–3). The PTTL of quartz and its application to dating has recently also been investigated by various authors (e.g. Refs 4 and 5). For most previous studies natural quartz samples were used and the irradiations were carried out at RT. In a few studies also effects of low temperature UV illumination on β irradiated natural quartz were studied[6]. In the present work these studies have been extended to high purity synthetic quartz, as well as to X and vacuum UV (VUV) irradiations. PTTL excitation and emission spectra were measured. For comparison the thermoluminescence (TL) induced in the same samples by X, β and VUV radiations was also investigated.

EXPERIMENTAL TECHNIQUES

For our measurements, synthetic 'premium Q grade' quartz from Sawyer Research Products was used. For most experiments powder samples were used. The single crystals were crushed and ground to grains of the size of ~30 μm.

The irradiations were performed either with an X ray tube (Cu, 25 kV, 15 mA) or with a ^{90}Sr beta source at ~80 K (LNT) or at ~300 K (RT). For the VUV irradiation the sample was mounted in a windowless cryostat, attached to a normal incident VUV grating monochromator (McPherson 225, Rowland circle of 1 m diameter, linear dispersion 8.3 $Å.mm^{-1}$); a 1000 W hydrogen arc lamp was used as a light source. For the PTTL investigations the samples were X or β irradiated at RT and then illuminated with UV light at LNT; for PTTL measurements above RT the irradiated samples were heated to ~520 K, recooled to RT and UV illuminated at RT. The UV illuminations for the PTTL measurements were performed with a deuterium or halogen lamp and a double monochromator. The TL and PTTL were recorded with an EMI 6255B photomultiplier and a conventional set-up for TL measurements. For the low temperature excitation measurements the sample was kept in the vacuum cryostat and the heating was normally 20 $K.min^{-1}$. The TL and PTTL above RT were recorded at a heating rate of 5 $K.s^{-1}$. For measurements of the excitation spectra the incident photon flux of the UV source was measured with a pyroelectric radiometer.

The TL and PTTL emission spectra were measured with a Bausch and Lomb grating monochromator equipped with an electronically controlled fast scanning stepping motor[7]. For the detection and recording of the luminscence spectra an EMI 9789Q A photomultiplier was used. Spectra were normally scanned in both directions at a speed of 20 $nm.s^{-1}$.

EXPERIMENTAL RESULTS

In the present work the PTTL of synthetic quartz was compared with the TL induced in the same sample by various types of radiation, such as X rays, β rays and VUV. For the VUV excitation of the TL, the samples were irradiated by monochromatic light in the wavelength region 110–350 nm. Excitation spectra of TL and of photoluminescence (PL) in quartz have previously been measured in the spectral region between 115 and 180 nm and showed maxima at 128 and near 160 nm[7]. These wavelengths were now also found to be the most efficient for direct VUV excitation of TL peaks; no TL peaks could be excited with wavelengths longer than 175 nm. PTTL could, however, be excited with near UV light between 250–400 nm. Curves A and B of

Figure 1 show the TL induced at LNT in quartz by X and VUV irradiations respectively. Curve C of Figure 1 shows the PTTL of the sample. All these curves were recorded during heating from LNT to RT at constant rate of 20 $K.min^{-1}$. Main TL peaks appeared after X irradiation at 170 K, 205 K, ~260 K. The 170 K TL peak appeared also in the VUV induced TL, but in this case an additional strong peak appeared at 135 K; the higher temperature peaks did not appear after VUV irradiation. The 170 K, 205 K and 265 K peaks also appeared in the PTTL excited by 330 nm light; an additional weak PTTL peak appeared at ~240 K. After X and β irradiation at RT the TL peaks appeared at ~380, 430 and 480 K (Figure 2a) and after VUV irradiation at RT at slightly lower temperatures (curve B). The PTTL peaks above RT appeared at ~380 and 480 K (curve C).

Excitation spectra of the various PTTL peaks were measured and results are given in Figure 3. The excitation spectra of the low temperature PTTL peaks at 205 and 265 K, show both excitation maxima at 315 and 330 nm; a 380 K PTTL peak (not shown in Figure 1) has excitation maxima at 325 and 275 nm.

Emission spectra were measured for TL and

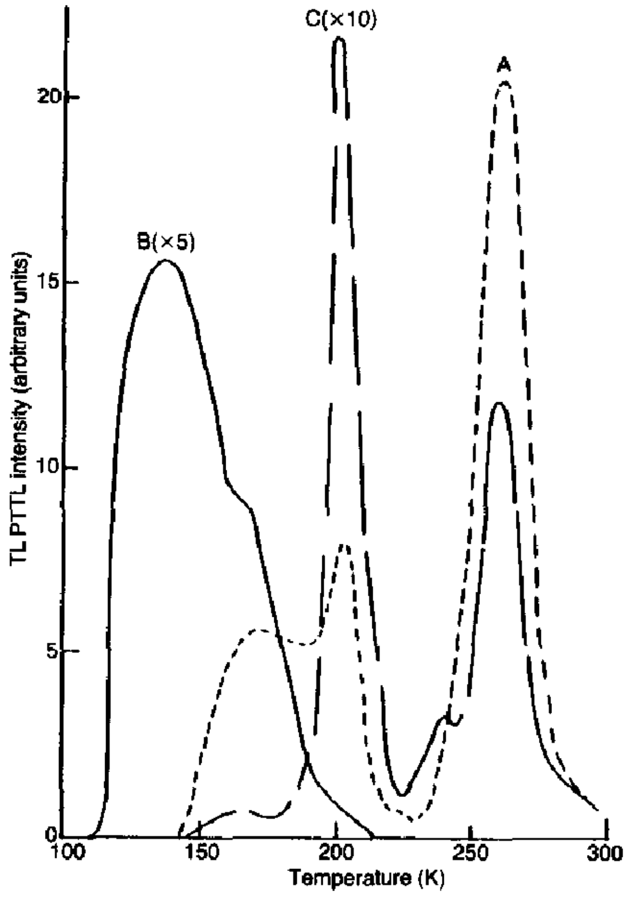

Figure 1. Curve A, TL induced by X rays at LNT. B, TL induced by 161 nm VUV radiation at LNT. C, PTTL recorded after X or β irradiation at RT and subsequent 330 nm illumination at LNT.

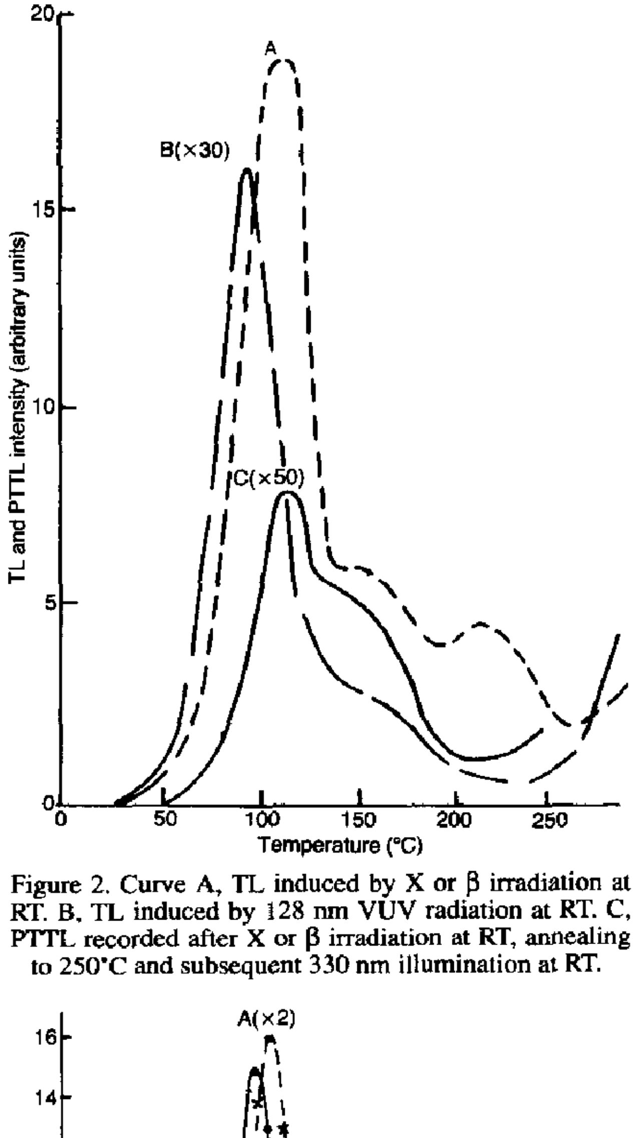

Figure 2. Curve A, TL induced by X or β irradiation at RT. B, TL induced by 128 nm VUV radiation at RT. C, PTTL recorded after X or β irradiation at RT, annealing to 250°C and subsequent 330 nm illumination at RT.

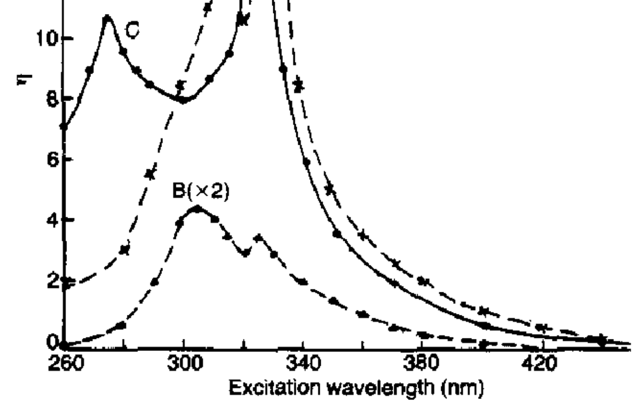

Figure 3. Excitation spectra of the PTTL peaks at: A, 205 K; B, 265 K; C, 380 K.

PTTL peaks at 205 and ~260 K. The TL emission at low temperature is dominated by a band at 370 nm and a broad band, centred at 460 nm; the same emission bands appeared for PTTL peaks at 205 and 265 K; and an additional weak band was recorded at ~330 nm (see Figure 4).

DISCUSSION

The experimental results have shown that the X and β induced TL peaks appear at nearly the same temperatures as the PTTL peaks. Some differences may, however, be noted. In the X induced TL the 210 K peak was the main one for low doses and reached fast saturations with increasing doses; for high X doses, the 260 K peak became dominant. In the PTTL the 205 K peak remained dominant over a wide range of X ray doses, indicating that during the phototransfer relatively few carriers are transferred from deep traps to a shallow trap responsible for the 210 K peak. In the TL induced by the 161 nm VUV irradiation at LNT, the main peaks were recorded between 100 and 180 K. The VUV irradiations at LNT also resulted in a strong phosphorescence with a lifetime of a few seconds. This phosphorescence is apparently due to shallow traps which become unstable near 80 K. The exciting radiation of 161 nm corresponds to a photon energy lower than the band gap of quartz, indicating that impurity levels within the gap are connected with the phosphoresence and the TL excited by the 161 nm radiation. The wavelength of the second VUV excitation maximum at 128 nm is located at the long wavelength tail of an exciton peak; this supports the assumption that the excitation in this case is due to an intrinsic process[7].

The fact that the intensity of the TL peaks above RT decreases mainly after UV irradiation with 275 or 330 nm light at LNT, indicates that these irradiations are most efficient for the transfer of carriers from deep to shallow traps. The PTTL excitation maximum at 275 nm has previously been attributed to Ge impurities in quartz and it has also been suggested that the TL peak at 600 K is due to the thermal release of electrons trapped at substitutional germanium atoms[3].

Different processes have previously been suggested for the emission bands near 370 and 450 nm which appeared in the X luminescence (XL) and TL (e.g. Refs 8–11)). The findings are that the same spectral bands are emitted at the main PTTL peaks as in the corresponding TL peaks, indicates that the same luminescence centres are responsible for the emission in both cases.

In the course of this work the thermal activation energies and geometrical symmetry factors were also evaluated by the the 'peak-shape method'[12]. The fact that the main PTTL peaks appear at nearly the same temperatures as the TL peak, have the same activation energies and approximately the same symmetry factors, indicates that in these cases the same traps are responsible for the corresponding PTTL and TL peaks.

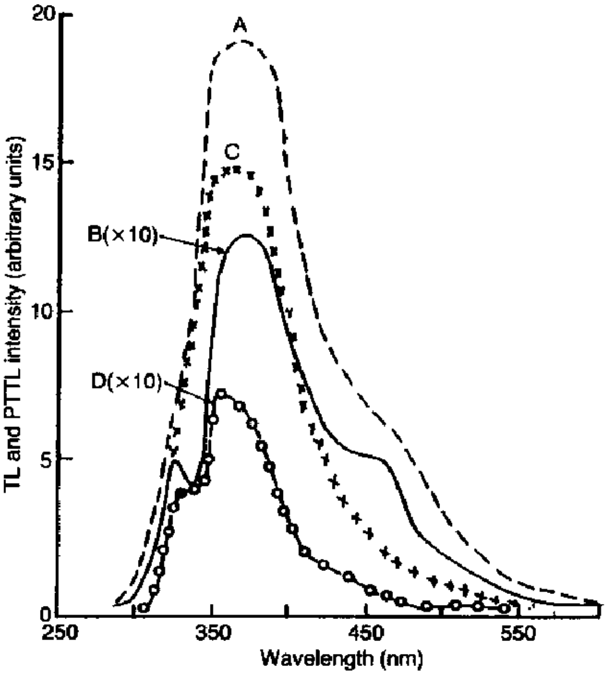

Figure 4. Emission spectra of TL and PTTL, recorded at: A, 205 K TL peak; B, 205 K PTTL peak; C, 260 K TL peak; D, 265 K PTTL peak.

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