TWO-ELECTRON-TRANSITIONS IN Ge*

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The high-energy photon-emission from Ge is investigated at liquid nitrogen temperature. There appeares a peak at $h\nu = 2E_g$ which is attributed to two-electron-transitions between the bands. The transition probability is of the same order as in the case of Si. To lower energies there appeares a broad continuum, which is attributed to partially thermalized Auger-particles.

IN A PREVIOUS letter[1] high-energy photon-emission from a Si injection-diode was reported at an energy of about $h\nu = 2E_g$. This emission was attributed to a two-electron transition between conduction band and valence-band.

This explanation is supported by new results obtained by injection-laser excitation.[2] The best argument, that this is a very general effect, would be its observation in different materials with similar conditions. Therefore we have investigated Ge in the same manner.

The difficulty in the case of Ge is the appearence of a high energy photon-emission due to Auger-recombination as reported in a previous paper.[3] This emission has the same density dependence as the expected $2E_g$-photon-emission and at room-temperature it obviously covers up a possible $2E_g$-emission. But since the high-energy-emission in the case of Auger-recombination is caused by thermalized Auger-particles, it should be possible to observe $2E_g$-emission at lower temperatures. Therefore we have carried out the experiment at liquid-nitrogen-temperature with shorter injection pulses.

Holes were injected into n-type Ge via an alloyed $p–n$ junction with an area of $7 \cdot 10^{-8} m^2$. The injection was performed in pulse-technique with a current-density of $3 \cdot 10^8 Am^{-2}$ and a duty-cycle of 0.5 per cent. The radiation was observed from the side of the probe, where the $p–n$ junction reached the surface. It was analyzed by a double-monochromator Zeiss MM 12 and it was detected by an EMI 9684B photomultiplier with S 1 response, which was cooled to liquid-nitrogen-temperature. The registration of the radiation was carried out in the same digital boxcar-integration method as described in the Si experiment.[1] Because of the very low intensity a completely metal-enclosed optical system was used. Each obtained measuring-value corresponds to a measuring-time of 24 hr.

Figure 1 shows the energy dependence of the high-energy photon-emission from Ge at an estimated temperature of about 100 K. A peak appears at an energy of $2E_g = 1.45$ eV.[4] The low-energy increase can be explained by thermalized Auger-particles. Between these two regions there appears a broad continuum, which we attribute to partially thermalized Auger-particles. Their spectrum is expected to reach up to $2E_g$, but this effect can not cause the peak at $2E_g$, since this spectrum is a monotonously decreasing function of energy as verified by Pankove et al. in the case of GaAs.[5]
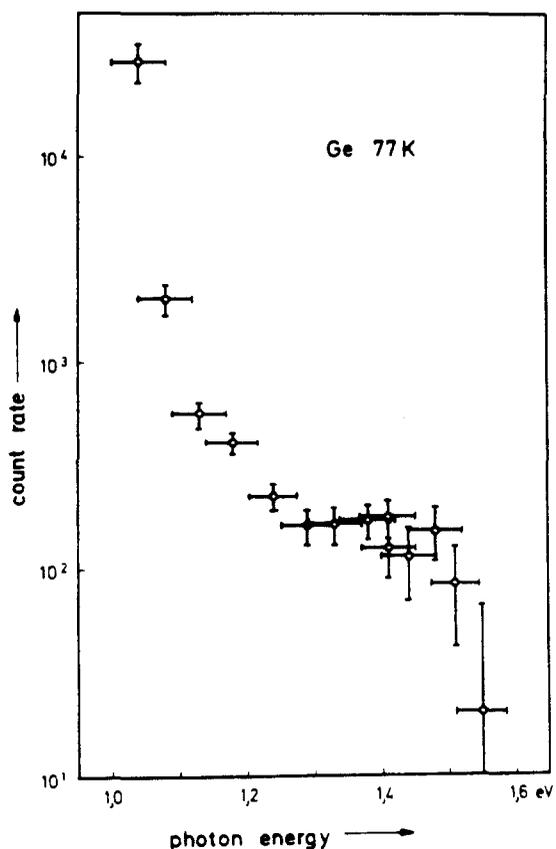
FIG. 1. Energy dependence of the high-energy
photon emission from Ge at 100 K.

We explain the $2E_g$-peak as a two-electron band-to-band-transition. An approximate calculation leads to a transition coefficient of the same order as in the case of Si, i.e. of the order of 10^{-63} cm^9 sec^{-1}.[1]

REFERENCES

1. BETZLER K. and WELLER T., *Phys. Rev. Lett.* **26**, 640 (1971).

2. BETZLER K, WELLER T. and CONRADT R., to be published.

3. CONRADT R. and WAIDELICH W., *Phys. Rev. Lett.* **20**, 8 (1968); CONRADT R., *Z. Phys.* **209**, 445 (1968).

4. MACFARLANE G.G., MCLEAN T.P., QUARRINGTON J.E. and ROBERTS V., *Phys. Rev.* **108**, 1377 (1957).

5. PANKOVE G.F., TOMASETTA L. and WILLIAMS B.F., *Phys. Rev. Lett.* **27**, 29 (1971).

Die Hoch-Energie Photonenemission von Ge wird bei der Temperatur des flüssigen Stickstoffes untersucht. Bei $h\nu = 2E_g$ wird ein Maximum beobachtet, das zwei-Elektronen-Ubergängen von Band zu Band zugeordnet wird. Die Ubergangswahrscheinlichkeit ist von der gleichen Größenordnung wie im Fall des Si. Zu niedrigeren Energien erscheint ein breites Kontinuum, das teilweise thermalisierten Auger-Teilchen zugeordnet wird.