Supralinear Current-Voltage-Dependence in Irradiated Fused Silica

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The measured field- and temperature-dependence of γ-ray induced current in synthetic fused silica is explained by a field dependent electron capture cross section. The comparison with a model gives a constant mobility within the region of 8 to 300 °K. With high electric fields the acousto-electric effect is observed.

The lifetime of free electrons excited by light or irradiation can be increased by reducing the electron cross section of attractive Coulomb centers in an electric field [1]. The capture cross section s may be written as [2]

$$s = \pi r_0^2, \qquad \text{for} \quad \lambda_p < r_0, \qquad (1\text{ a})$$

$$s = 2\pi r_0^3/\lambda_p, \qquad \text{for} \quad \lambda_p \geqq r_0. \qquad (1\text{ b})$$

r_0 and λ_p are the capture radius and the mean free path loss of phonon, respectively. With an applied field F the electron near an attractive Coulomb center is subjected to the potential

$$V(r) = (e/K r) + F r \qquad (2)$$

where K and e are the dielectric constant and the electronic charge. This is valid as long as the mean distance of the capture centers is larger than the capture radius. r_0 can be obtained by asking what is the minimum in the probability distribution of an electron around the center [2]. From this we find [3] using (2)

$$r_0 = \frac{k\,T}{e\,F}\left\{-1 + \left[1 + \frac{e\,F}{K(k\,T/e)^2}\right]^{1/2}\right\}. \qquad (3)$$

T is the absolute temperature and k the Boltzmann constant. Contrary to other assumptions [1] the capture radius (3) may be approximated by [2] $r_R = e/(2\,K\,k\,T)$ [as derived from $V(r) = e/K\,r$] or by $r_M = (e/K\,F)^{1/2}$ [extreme value of (2)], only if $F \leqq 10^{-2}\,F_1$ or $F \geqq 10^2\,F_1$, respectively. $F_1 = 4(k\,T/e)^2\,K/e$ gives the order of magnitude in field, at which the influence of the field on the capture cross section (1) should become significant. To demonstrate the effect, low temperatures and materials with small dielectric constants are favourable.

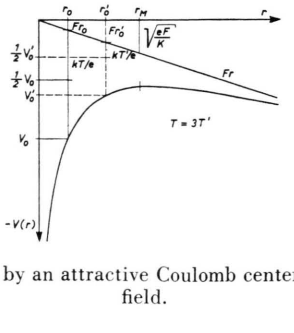
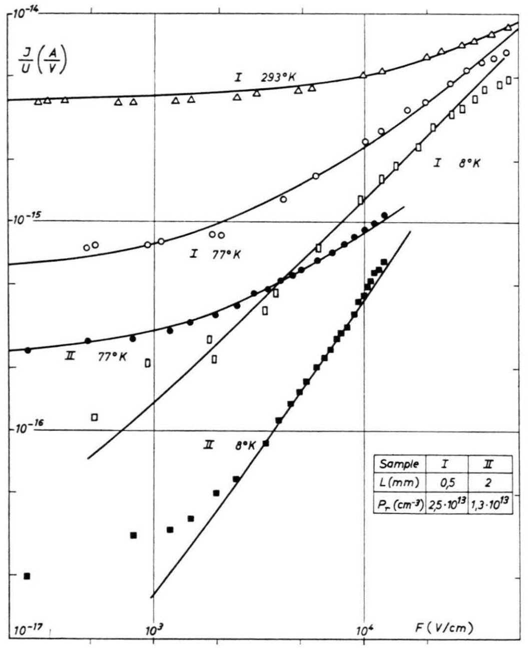


Fig. 1. Capture by an attractive Coulomb center in an electric field.

In Fig. 1 the radii r_M and r_0 and the respective potentials are represented.

We have measured the gamma-ray induced current in disks of synthetic fused silica (containing water), 0.2 to 4 mm thick, at applied voltages up to 2500 V in the temperature range 8 to 300 °K and at a low dose rate of about 10 mr/sec (Fig. 2). Since the close lying localized states in the forbidden band, affected by the amorphous structures of these glasses, are extensively compensated by hydroxylgroups [4, 5], only a small number of positive centers is effective in capturing the excited electrons [6]. Therefore Eq. (3) is adequate for this case.



Sample	I	II
L (mm)	0,5	2
P_r (cm^{-3})	$2{,}5\cdot10^{13}$	$1{,}3\cdot10^{13}$

Fig. 2. γ-ray induced conductivity in synthetic fused silica as function of the applied field at different temperatures.

With p_r positive centers the electron lifetime is $\tau = (p_r\,v\,s)^{-1}$, and the radiation induced current density is

$$j = e\,g\,\tau\,v_D = g\,e\,\frac{\mu\,F}{p_r\,v\,s}. \qquad (4)$$

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g, v_D, μ and v are the number of excited electrons cm^{-3} sec^{-1}, the drift velocity, the mobility and the thermal velocity, respectively. In Fig. 2 the lines are theoretical curves according to equations (4), (1) and (3). As to the four upper curves there is good agreement of the measured data with a field- and temperature dependence according to (1 a). The parameter p_r/μ is adjusted to fit the data. While recording such a set of measurements the density p_r of positive centers is increased by the irradiation [3, 7], and thus p_r is somewhat different from curve to curve even for the same sample. Taking that into account, we get temperature independent values for p_r/μ. The density p_r is assumed to be constant, since most of the states are as deep as or deeper than 2 eV below the conduction band edge [6]. We arrive at the conclusion that the mobility μ is not or nearly not temperature dependent. Our measurements agree with Goodman's value of $\mu = 29$ cm^2/Vsec [8], measured at 300 °K. Therefore we conclude that the mobility in fused silica is determined by elastic scattering at about $3 \cdot 10^{19}$ cm^{-3} neutral impurities. Mean values of p_r are given in Fig. 2.

In Fig. 2 the lower curve at 8 °K is calculated with cross section (1 b), with a value of p_r/μ derived from the 77 °K-curve of this sample, and with $\lambda_p = 106$ Å. The rate of energy loss derived from this mean free path for loss of a phonon is much greater than that for crystalline SiO_2, estimated from the formulas for piezoelectric or acoustic deformation potential scattering [9]. It is assumed that in disordered solids a different energy loss mechanism is present.

At high voltages two saturation effects appear, limiting the further increase of the induced current. Besides the schubweg saturation, found in photoconductors with blocking contacts when the schubweg τv_D (4) becomes comporable with the sample thickness, the drift velocity v_D becomes constant on the level of the velocity of sound v_s. This effect known as acoustoelectric effect from piezoelectric semiconductors [9, 10] starts at about $v_s/\mu = 1.9 \cdot 10^4$ V/cm. In some samples especially at lower temperatures the effect is accompanied with fluctuations of the induced current and with charge redistributions within the sample. Further results and details of the measurements will be published elsewhere [3].

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Die Zustandsgleichung isotoper Äthylene

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The second virial coefficients of C_2H_4 and C_2D_4 have been measured at 236.04 °K. The experimental isotope effect of 1.07% can be separated into one contribution from a translational quantum effect and one contribution which is due to the different molar volumes of the isotopes. In this temperature region the isotope effect is shown to be mainly a volume effect. This explanation is confirmed by results from molar volume measurements of the liquid isotopes.

Im Rahmen einer Untersuchung über die Zustandsgleichung isotopensubstituierter Substanzen wurden die 2. Virialkoeffizienten der deuterierten Äthylenisotope gemessen. An dieser Stelle wird über die ersten Ergebnisse für die Isotope C_2H_4 und C_2D_2 berichtet.

Vergleichende Messungen der 2. Virialkoeffizienten isotoper Gase liegen lediglich für die Paare H_2-D_2 [1] und CH_4-CD_4 [2] vor.

Experimentelles

Für die Messungen wurde im Prinzip das Verfahren von BURNETT [3] verwendet. Hierbei wird ein Gas in einen von zwei über ein Ventil verbundenen Metallbehälter eingelassen und der Druck p_1 gemessen. Nach Expansion in das zweite Volumen stellt sich ein Druck p_2 ein, der zum Druck p_1 in einem Verhältnis steht, das bei idealen Gas-Bedingungen dem umgekehrten Verhältnis der von dem Gas eingenommenen Volumina gleich sein wird. Verhält sich das Gas nicht ideal, so weicht p_1/p_2 von dem Verhältnis der Volumina ab. Die Abweichung des Druckquotienten bei einer Reihe von sukzessiven Expansionen ermöglicht eine sehr genaue Absolutbestimmung der Virialkoeffizienten des Gases. Wegen der Kleinheit der Effekte waren die Anforderungen an die Genauigkeit der Druckmessungen und an die Temperaturkonstanz während einer Expansionsserie sehr groß. So wurde der Druck bei 300 Torr auf sechs Stellen genau gemessen und die Temperatur auf $2 \cdot 10^{-3}$ °K genau über mehrere Stunden geregelt. Weitere Angaben über die technische Ausführung der Apparatur werden an anderer Stelle veröffentlicht.

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