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# EXOELECTRON EMISSION CRITERION OF THE YIELD LIMIT OF ALKALI METAL HALIDE CRYSTALS

By B. Sujak

Department of Solid State Physics, Institute of Experimental Physics, B. Bierut University, Wrocław*

and R. Pfranger

Institute of Physics, Częstochowa Technical University**

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This investigation deals with the relationship between the position of the maxima of tribo-photostimulated exoelectron emission intensity and that of the yield limit $\sigma_{0.2}$ determined on the basis of the most commonly used criterion. The objects used in this study were KCl and NaCl single crystals and mixed (K, Na)Cl and (Na, K)Cl crystals. The results obtained warrent a proposal of a new criterion of the yield limit of the examined crystals — the "exoelectron emission criterion".

## 1. Introduction

The yield limit in the case of uniaxial strain is determined in the basis of the character of the stress-strain relation

$$\frac{\Delta l}{l_0} = f(\sigma), \text{ where } \sigma = \frac{F}{S_0}. \tag{1.1}$$

In this relation $\Delta l/l_0$ denotes the relative contraction of the sample, $\sigma$ is the normal stress applied, $F$ is the value of the force applied, and $S_0$ is the area of the initial cross-section of the sample.

For substances exhibiting a distinct yield limit the relation (1.1) in graphical form features an inflexion point. This corresponds to a change in sample length without any change of load. The value of stress at this point is the distinct yield limit value [1, 2, 3].

Alkali metal halides are substances for which no such distinct yield limit appears [3, 4]. In the case of these halides plastic strains (permanent) occur together with elastic strains as the stress increases, the share of the former becoming larger and larger. For such materials

* Address: Instytut Fizyki Doświadczalnej, Uniwersytet Wrocławski, Wrocław, Cybulskiego 36, Poland.

** Address: Instytut Fizyki, Politechnika Częstochowska, Częstochowa, Deglera 35, Poland.

the yield limit is determined on the basis of a conventional criterion for a practical assessment of the yield limit, which is schematically shown in Fig. 1. For a strain of $\Delta l/l_0 = 0.2\%$ the straight line drawn parallelly to the initial rectilinear segment of the graph inersects it

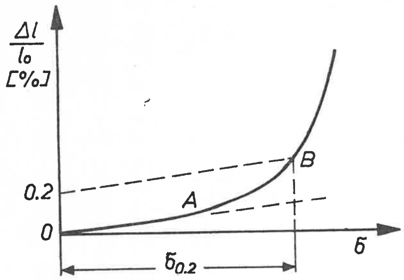


Fig. 1. Approximate determination of conventional yield limit $\sigma_{0.2}$. $\frac{\Delta l}{l_0}$ is sample dilatation, and $\sigma$ is compressive strain. For $\frac{\Delta l}{l_0} = 0.2\%$ the contribution of plastic strains is 0.2%

at point $B$. This determines the conventional yield limit $\sigma_{0.2}$ [2, 3].

The measurements of Sujak and coworkers [5–9] made to date in the field of tribo-photostimulated exoelectron emission from NaCl and KCl crystals coloured with $X$-rays show that the exoemission kinetics depends on the way the examined samples are deformed. The position of the maximum of the intensity of tribo-photostimulated exoelectron emission is effected by the initial range of plastic deformation. For KCl and NaCl crystals kept in an exsiccator containing $P_2O_5$ before exoemission measurement the position of the maximum in the curve of tribo-photostimulated exoelectron emission intensity against applied stress appears in the vicinity of the point where the strain leaves the elastic range into the plastic range [9].

In the work presented here we give the results of measurements of tribo-photostimulated exoelectron emission from "pure" NaCl and KCl crystals and mixed (K,Na)Cl and (Na,K)Cl crystals. An analysis of the relation between the position of the maximum intensity of tribo-photostimulated exoelectron emission and the magnitude of the yield limit determined on the basis of the above-mentioned criterion $\sigma_{0.2}$ has been made. This permitted us to propose a new criterion for determining the yield limit alkali metal halides, which we have called the "exoemission criterion".[1]

## 2. *The samples*

The "pure" NaCl and KCl single crystals and the mixed (K, Na)Cl and (Na, K)Cl single crystals were drawn by the well-known Kyropoulos method from analytically pure sodium chloride and potassium chloride, respectively.

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[1] This problem is elaborated in details in the doctor's dissertation of R. Pfranger at the Faculty of Mathematics, Physics and Chemistry of the Wrocław University (1971).

Samples of the dimensions 2×2×10 mm were cleaved from the middle parts of the obtained single crystals. In order to have the samples free of internal stress arising during cleaving, they were annealed at 893 K (KCl and (K, Na)Cl crystals) and 923 K (NaCl and (Na, K)Cl crystals). The samples were annealed for 10 hours and then cooled slowly to room temperature within the next ten-odd hours.

The crystals and cleaved samples were stored in an exsiccator containing $P_2O_5$ until it was time for performing the measurements.

The samples were coloured in a "Stablil 250" $X$-ray unit having a tube with a tungsten cathode; $I_a = 8$ mA and $U_a = 85$ kV. Samples were coloured for 15 minutes. About an hour after conclusion of sample irradiation the measurements were initiated.

## 3. *Measuring arrangement*

The crystals were submitted to uniaxial compressive stress in a device analogous to the one described earlier by Sujak and coworkers [5, 8, 9]. The intensity of tribo-photo-stimulated exoelectron emission was recorded by means of a typical electronic unit with automatic recording of the counting rate at the integrator output.

## 4. *Results of measurements*

Investigations concerned the relative strain and intensity of tribo-photostimulated exoelectron emission as a function of the compressive stress applied to the sample. The results of measurements for several samples are presented in Figs 2, 3, 4 and 5. Each point of measurement in these plots is the arithmetic mean calculated for the results obtained for ten samples.

It is seen from these plots that there is a distinct relationship between strain and the associated tribo-photostimulated exoelectron emission. The maximum in exoemission

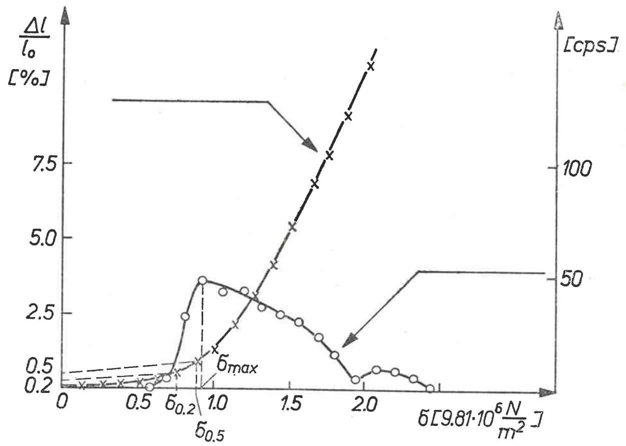


Fig. 2. Dependence of relative strain $\Delta l/l_0$ and intensity of tribo-photostimulated exoelectron emission $N/t$ upon compressive stress applied to sample ($\sigma$) for crystals of (K, Na) Cl containing 1.0 mol% of NaCl. Deformation rate was 0.49 N/s

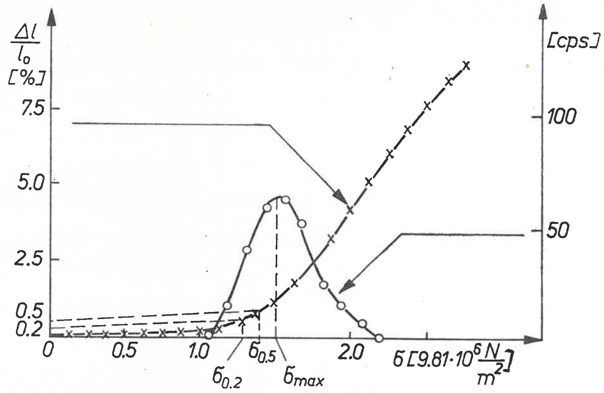


Fig. 3. Dependence of relative strain $\Delta l/l_0$ and intensity of tribo-photostimulated exoelectron emission $N/t$ upon compressive stress applied to sample ($\sigma$) for crystals of (K, Na)Cl containing 2 · 2 mol% of NaCl. Deformation rate was 0.49 N/s

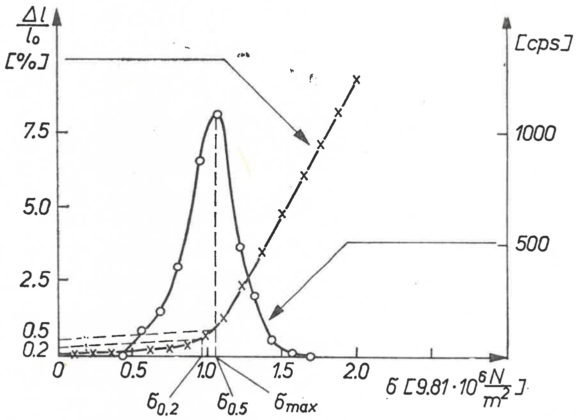


Fig. 4. Dependence of relative strain $\Delta l/l_0$ and intensity of tripo-photostimulated exoelectron emission $N/t$ upon compressive stress applied to sample ($\sigma$) for crystals of (Na, K) Cl containing 0.52 mol % of KCl. Deformation rate was 0.49 N/s

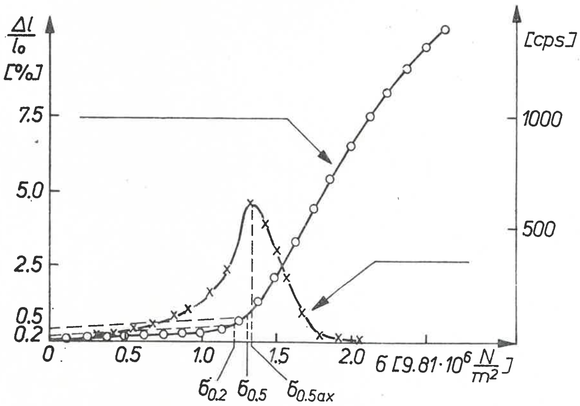


Fig. 5. Dependence of relative strain $\Delta l/l_0$ and intensity of tribo-photostimulated exoelectron emission $N/t$ upon compressive stress applied to sample ($\sigma$) for crystals of (Na, K) Cl containing 0.81 mol % of KCl. Deformation rate was 0.49 N/s

intensity marks the beginning of the range of plastic deformation of the crystals. The dashed line marks out the yield limit as found by applying the criterion $\sigma_{0.2}$ mentioned in the Introduction. Similarly, dashed lines mark the stress $\sigma_{0.5}$ corresponding to relative permanent strains of $\Delta l/l_0 = 0.5\%$. A comparison of $\sigma_{0.2}$ and $\sigma_{0.5}$ with the position of the maximum of the intensity of tribo-photostimulated exoelectron emission shows that the value od $\sigma_{0.5}$ corresponds to the value of stress at which this peak occurs.

## 5. *Comparison of exoemission criterion of the yield limit with the conventional criterion $\sigma_{0.2}$*

We shall now compare the "exoemission criterion" $\sigma_{max}$ of the yield limit with the conventional criterion $\sigma_{0.2}$ used hitherto.

Figure 6 shows curve *a* as the dependence of the stress value corresponding to maximum intensity of tribo-photostimulated exoelectron emission $\sigma_{max}$ upon the percentage of NaCl

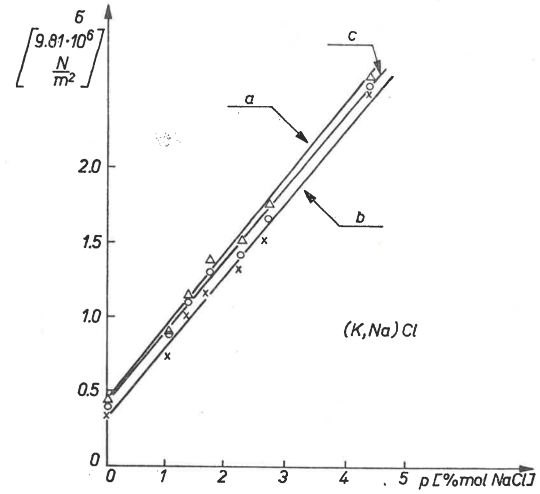


**Fig. 6.** Dependence of stress corresponding to maximum intensity of tribo-photostimulated exoelectron emission $\sigma_{max}$ and yeld limit $\sigma_{0.3}$ and $\sigma_{0.5}$ upon NaCl content for mixed (K, Na) Cl crystals: $\Delta$ — $\sigma_{max}$ (curve *a*); × — $\sigma_{0.2}$ (curve *b*); ○ — $\sigma_{0.5}$ (curve *c*)

in the mixed (K, Na)Cl crystals. In the same figure, curve *b* illustrates the dependence of $\sigma_{0\ 2}$ and curve *c* of $\sigma_{0.5}$ upon the NaCl content in the mixed crystal. As is seen, not only are these dependences rectilinear, but they run almost parallelly with respect to each other. The respective equations found from the obtained results by the least squares method [10, 11] are

$$\sigma_{max} = (0.51 \pm 0.06)p + (0.44 \pm 0.12) \tag{5.1}$$

$$\sigma_{0\ 2} = (0.47 \pm 0.07)p + (0.33 \pm 0.12) \tag{5.2}$$

$$\sigma_{0.5} = (0.48 \pm 0.07)p + (0.42 \pm 0.11) \tag{5.3}$$

where $p$ is the NaCl content in mol %.

The dependence of the stress corresponding to maximum intensity of tribo-photo-stimulated exoelectron emission $\sigma_{max}$ upon the KCl percentage in mixed (Na, K)Cl crystals is shown in Fig. 7 as curve *a*. Here also, curve *b* presents the dependence of $\sigma_{0.2}$ and curve *c* of $\sigma_{0.5}$ upon the KCl content in the mixed crystals. As before, these dependences

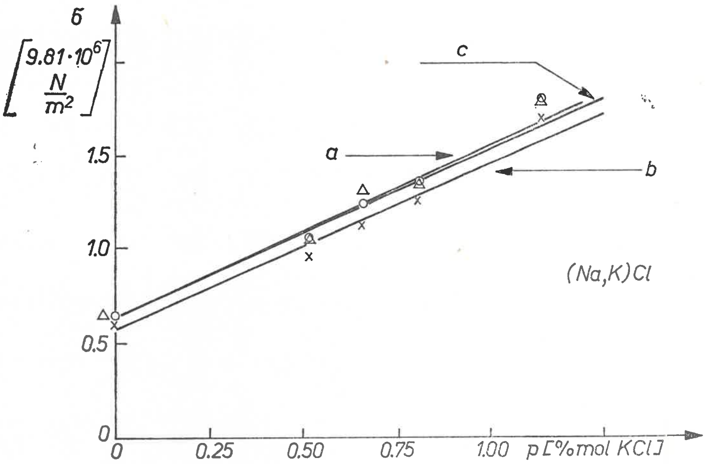


Fig. 7. Dependence of stress corresponding to maximum intensity of tribo-photostimulated exoelectron emission $\sigma_{max}$ and yield limits $\sigma_{0.2}$ and $\sigma_{0.5}$ upon KCl content for mixed (K, Na) Cl crystals: $\Delta$ — $\sigma_{max}$ (curve *a*); $\times$ — $\sigma_{0.2}$ (curve *b*); $\bigcirc$ — $\sigma_{0.5}$ (curve *c*)

are rectilinear and run almost parallelly, and they may be described by equations found by the least squares method:

$$\sigma_{max} = (0.92 \pm 0.06)p + (0.63 \pm 0.05) \tag{5.4}$$

$$\sigma_{0.2} = (0.86 \pm 0.06)p + (0.57 \pm 0.05) \tag{5.5}$$

$$\sigma_{0.5} = (0.90 \pm 0.05)p + (0.64 \pm 0.04) \tag{5.6}$$

where $p$ is the KCl content in mol %.

From the plots in Figs 6 and 7 and their equations it is easily seen that there is conformity between the value of $\sigma_{max}$ to which corresponds the position of maximum tribo-photostimulated exoelectron emission intensity and the value of $\sigma_{0.5}$ corresponding to the stress value of the conventional yield limit determined for relative plastic strains $\Delta l/l_0 = 0.5\%$.

The phenomenon of exoelectron emission is commonly thought to be associated with emissively active centers generated and occupied by electrons at the near-surface layers of the samples. The appearance of a a maximum of exoemission for $\sigma_{max}$ should be ascribed to the motion of dislocations in the crystals. Such motion, as is known, appears at the initiation of the process of plastic deformation of crystals. It is possible, therefore, to propose an "exoemission criterion" for determining the yield limit, at least in the case of alkali metal halide crystals. According to this criterion, the yield limit is determined by the stress at which the maximum intensity of tribo-photostimulated exoelectron emission appears.

At the same time, the yield limit determined thus corresponds to the value of yield limit determined by the method described in the *Introduction* of this paper at an assumed plastic strain of 0.5%.

Subsequent studies will show the extent to which the exoelectron emission criterion of the yield limit can be generalized and introduced into general practice in researches on strengths of materials.

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