Conditions of registration of acoustic emission pulses generated during surfacing of dislocations

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(Submitted 24 July 1981)
Zh. Eksp. Teor. Fiz. **82**, 504–508 (February 1982)

The zone of formation of transition sound emission accompanying the emergence of dislocations to the surface of a crystal is considered. A theoretical relation for the size of the zone l_f is obtained. This allows the analysis of the conditions of registration of the acoustic emission pulses that are generated upon emergence of individual dislocations to the surface. The registration of the emission should be carried out at frequencies for which $l_f < l_d$ (l_d is the mean distance between dislocations in the pileup at the moment of emergence to the surface). The surfacing velocity should be sufficiently high (the value of the minimum velocity is determined by the sensitivity of the recording apparatus). Acoustic emission accompanying the motion of a pileup of twinning dislocations near the surface has been investigated in calcite crystals. A zone of formation is observed whose size is consistent with the theoretical estimates. Discreteness of the acoustic emission signal is observed. Acoustic emission pulses generated during the emergence of separate dislocations to the surface can be recorded against the background of the signal from the dislocation pileup.

PACS numbers: 61.70.Jc, 62.65. + k

1. INTRODUCTION

The direct measurement of the dynamic characteristics of the elastic field of individual dislocations is a topic of fundamental interest. The observation of the emission fields of individual dislocations became possible after the analysis[1] of the transition radiation of sound from dislocations emerging at the surface. In experiments on the observation of the acoustic transition radiation, an elastic twin was used as a "collimated" stream of dislocations bombarding the surface.[2] It was shown in Ref. 3 that the spatial distribution of the radiation agrees with that predicted by theory. The integrated signal from a moving, elastic twin constituting a plane pile up of ~10^3 twinning dislocations[4] has been registered and analyzed in Refs. 2 and 3. Since individual dislocations are the sources of the studied emission, it is important to observe the discrete character of this signal. Such an experimental problem is not trivial. The possibility of its solution requires a discussion of the problem of the connection of the dimensions of the zone of emission formation with the characteristic distances between moving dislocations.[1)] Since the problem of the formation zone of acoustic transition radiation has not been discussed previously, we pause to discuss it in greater detail.

By the zone of formation of acoustic transition radiation, in analogy with electromagnetic transition radiation,[6] we mean the region bordering on the surface of the crystal, in which the elastic field carried along by the moving dislocations and the radiator field become separated. As in Ref. 6, we define also the size l_f of the zone of formation of the acoustic transition radiation. Using the results of Ref. 1, we obtain

$$l_f=\frac{2\pi V}{\omega}\left(1-\frac{V}{c_t}\right)^{-1}, \tag{1}$$

where V is the velocity of the dislocation (we assume that $V =$const), ω is the cyclic frequency of the emitted waves, and c_t is the speed of sound.

The registration of the pulses from individual dislocations is possible only in the case in which a small number of dislocations are simultaneously located in the zone of formation. Since l_f is inversely proportional to the recorded emission frequency, in the experiments of Refs. 2 and 3, where the characteristic registration frequencies can be estimated at 10^3 Hz and the characteristic dislocation velocities at about 10^2 cm/s, we obtain the following estimate for the zone of formation of the signal: $l_f \sim 0.1$–1 cm. In this case the zone of formation is of the order of the size of the twin, i.e., it contains ~10^3 dislocations. It is natural that it is impossible to discern the discrete character of the acoustic emission under such conditions.

The aim of the present work was the experimental observation of the zone of formation of transition radiation of sound by a pile up of dislocations and the determination of its dimensions, which allows us to test the applicability of the relation (1) and to formulate the requirements for an experimental situation in which the sound pulses from individual dislocations can be separated. Two such experimental situations were selected—the approach of an elastic twin to the surface from the interior of the crystal under the action of external loading, and the emergence of an elastic twin to the surface under the action of forces of surface tension.[2)] In both cases, a discrete character of the acoustic emission has been observed. The temporal parameters of the signals support the assertion that it is possible to separate the pulses of the sound transition emission generated upon the appearance of individual dislocations at the surface.

2. EXPERIMENT

The experiment was carried out on calcite crystals with the use of the method developed previously.[2,3] The twin, which was a plane pile up of screw twinning dislocations, moves to the surface and its migration is registered by high-speed motion picture photography,

 0038-5646/82/020291-03$04.00

in parallel with measurement of the sound emission. It was observed in Ref. 2 that, with accuracy to within several milliseconds, the sound emission is observed at the instant of the twin's reaching the surface. In the present work, we succeeded in increasing the resolving power of the experiment severalfold. A comparison of the data from the motion picture film of the displacement of the twin with the synchronously recorded signals of the acoustic emission (Fig. 1) shows that the sound emission appears 1–2 ms before the pile-up of the dislocations touches the surface.[3)] At the same time, the distance from the end of the pile-up to the surface amounts to 0.15 cm at this instant, that is, $l_f \sim 10^{-1}$ cm in the experiment. As will be shown below, the theoretical estimate gives this same order of magnitude.

It should be expected that a more detailed study of the character of the signal directly before and after the touching of the surface by the twin should reveal, against the background of a smooth section due to the emission of an assembly of dislocations located in the formation zone, signals from dislocations that have already reached the surface and are successively emerging on it. In this case, when the size of the formation zone is of the order of the mean distance between dislocations $\bar{l}_d$, condition are set up for observation of the discrete structure of the signal. Since $\bar{l}_d \sim 1/\rho \sim 10^{-3} - 10^{-4}$ cm (ρ is the linear density of dislocations in the pile-up), even if signals of frequency $\sim 10^{-5} - 10^{-6}$ Hz are recorded one can hope to observe a discrete signal. Therefore, the bandwidth of the detecting apparatus was extended to 5 MHz for the experiments described below.

Analysis of the oscillograms of the emission signal at sweep rates of tens and hundreds of microseconds per centimeter reveals a smooth initial section in all investigated cases, of duration ~1 ms, which gives way to oscillations (Fig. 2). The minimum scale division on the horizontal in Fig. 2(a) is 8 μs, which enabled us to obtain a picture of the signal as a whole. In Fig. 2(b), the minimum scale division was 1.6 μs, which made it possible to represent the discrete part of the signal more clearly.

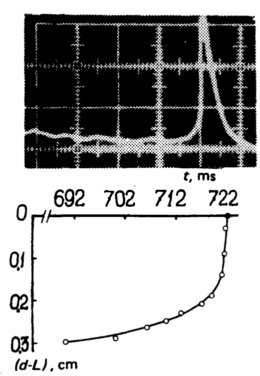

FIG. 1. Time dependence of the distance from the tip of the twin to the surface of the crystal ($d-L$) juxtaposed with the oscillogram of the sound emission in the same time scale. The scale of the oscillogram along the abscissa is 5 μs/cm.

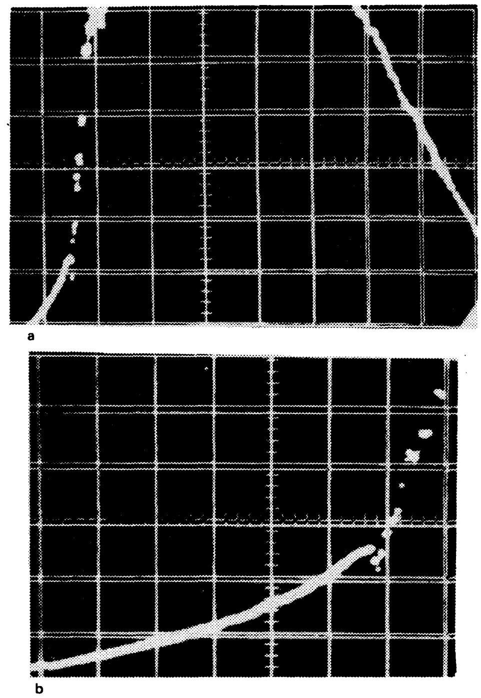

FIG. 2. Oscillogram of the signal of acoustic emission accompanying the approach of the pile up of dislocations from the interior of the crystal to the surface with its subsequent emergence to the surface: a) the minimum scale division along the abscissa in 8 μs; b) the minimum scale division along the abscissa is 1.6 μs.

In the case of the emergence of an elastic twin from the crystal under the action of surface tension forces, the change in the smooth part of the discrete signal is well seen from Fig. 3. The reproducibility of the experiment is good: the noted features of the signal took place in crystals that differed appreciably in size (by up to a factor of two), when different piezodetectors and different twins were used, and when entire blocks of the detecting apparatus were replaced. At the same time the recorded emission signals did not differ qualitatively from one another, although the distances between the separate emission bursts could change somewhat from experiment to experiment.

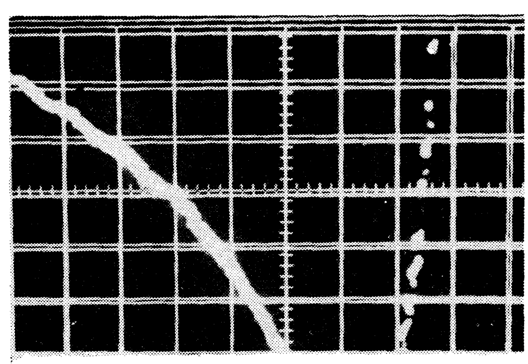

FIG. 3. Oscillogram of the signal of acoustic emission accompanying the emergence of a dislocations pile-up formed with the surface to this surface. The minimum scale division along the abscissa is 8 μs.

3. DISCUSSION

Thus, for the registration of emission pulses from separate dislocations, it is necessary, on the one hand, that the distances between the dislocations successively emerging to the surface be greater than the zone of formation of the signal at the registration frequency, and on the other hand, the surfacing rate of the dislocations should be sufficiently large that the emission can be recorded with the apparatus employed (we recall that the characteristics of the radiation are proportional to the rate of surfacing of the dislocations[1)]). These requirements can be satisfied if the surface intersects the tip of the twin, since according to the theory of twins (Ref. 4) the tip of the twin should have a zero aperture angle. Electron-microscope studies[7] have shown that there is a region of size ~10 μ on the tip of the twin where

$$l_d(x) \sim 1/\rho(x) \propto (L^2-x^2)^{-1/2}$$

(x is the coordinate of a point inside the twin, L is the coordinate of the end of the twin), while at large distances from the end of the twin,

$$l_d(x) \sim 1/\rho(x) \propto (L^2-x^2)^{1/2}.$$

In the case of a twin approaching from the interior of the crystal, the surface first intersects the tip, where the density of dislocations begins from zero. Under these conditions, $l_f < l_d$ and at frequencies that can be handled by the receiving equipment there is a possibility of resolving pulses from the individual dislocations against the background of the signal from the pile-up. In the case of a rate of approach of the twin to the surface ~10^2 cm/s, we find that this region will be crossed in a time $\Delta t \sim 10^{-5}$ s, which agrees with the data of Fig. 2(a). The number of dislocations in the end region is ~10^2, and $\bar{l}_d \sim 10^{-5}$ cm. Consequently, the mean time interval between arrival of the separate dislocations should amount to ~10^{-7} s. According to the data of Fig. 2(b), the time between separate emission bursts ~10^{-7}–10^{-6} s.

Upon emergence of the elastic twin from the crystal under the action of surface tension forces, the events take place in reverse order. The intersection of the surface with the near-end section is accompanied by an increase in the dislocation flux emerging to the surface, which is recorded as the smooth part of the signal. In the case of intersection of the surface with the tip itself, the dislocation density decreases and falls to zero. At precisely this moment, the signal becomes discrete (see Fig. 3).

The conclusions on the character of the motion of the dislocations in the end region of the twin cannot be regarded as sufficiently rigorous, because of its semimicroscopic dimensions. Nevertheless, all the experimental information obtained enables us to assert that in the given region acoustic emission pulses can be recorded against the background of the signal from the pile-up of the dislocations. This emission is generated upon in the emergence of individual dislocations to the surface. By the same token, the dislocation origin of the observed emission predicted in Ref. 1 is confirmed.

The fact that the zone of formation of the sound transition radiation from a dislocations pile-up has macroscopic dimensions can be used for the diagnosis of the state and structure of the near-surface layers of the crystal by the method of acoustic emission.

We take this opportunity to express our gratitude to V.D. Natsik for a discussion of the results.

[1)] We note that the importance of allowance for the formation zone of electromagnetic transition radiation in the organization of experiments aimed at its observation was discussed in Ref. 5.

[2)] The twin location relative to the surface in these cases has been considered in detail in Ref. 2.

[3)] It could be assumed that this fact is due to the presence of emission connected with the accelerated motion of the dislocations. But this would produce a signal of opposite polarity in comparison with the transition radiation, since the latter is equivalent to a rapid slowdown and stopping of the dislocations at the surface.

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Translated by R. T. Beyer