1/*f* noise and recombination processes in polycrystalline samples

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An interrelationship between the intensity of the $1/f$ noise and the lifetime of minority carriers has been observed experimentally in polycrystalline samples.

Establishing the nature of the low-frequency $1/f$ noise in semiconductors remains the topic of a lively debate, despite the long history of the study of this effect. Some interesting facts which have recently come to light indicate that there may be an extremely profound relationship between the behavior of the $1/f$ noise and that of generation–recombination noise.[1] These new facts force us to take a closer look at some ideas which were raised years ago regarding an effect of a long-term relaxation of a crystal lattice accompanying generation–recombination processes on the mechanism responsible for the $1/f$ noise.[2] That entire discussion, however, dealt with single-crystal semiconductors; there has been essentially nothing in the way of a corresponding systematic study of polycrystalline semiconductors.

We have carried out a study of the relationship between the shot noise and the intensity of recombination processes in *p–n* junctions, Schottky diodes, and resistors made from polycrystalline silicon. A remarkable feature of the structure of these samples is that they contain such defects as grain boundaries, which in many cases completely determine the properties of structures made from them.

The *p–n* junctions were produced by diffusing boron into platelets of polycrystalline silicon grown by a casting method.[3] Schottky diodes were produced by depositing gold on the same platelets. Resistors were made from the same platelets and also through the use of silicon films deposited on oxidized silicon substrates.[4]

Spectra of the shot current noise observed on the test samples can be approximated by a function $S_i(f) \sim a/f + b/f^2$, where $S_i(f)$ is the spectral power density of the current noise, f is the frequency, and a and b are coefficients which depend on the lifetime τ of the minority carriers in the samples. At $\tau \leqslant 3\times 10^{-9}$ s, these coefficients are $b=0$ and $a \sim 1/\tau^{2.5-3}$. At $\tau \geqslant 3\times 10^{-9}$, these coefficients change: we find $a \sim 1/\tau^{1/2}$, with b becoming slightly different from zero and slightly dependent on τ. In other words, slight deviations from linearity, reminiscent of generation–recombination slope changes, arise in the spectra of the $1/f$ noise.

Strictly speaking, an attempt to characterize the observed $1/f$ noise by means of a parameter α equivalent to the Hooge constant α_H is not completely legitimate in the case of such an inhomogeneous material as polycrystalline silicon. Nevertheless, a calculation of α by a method like that of Ref. 5 reveals $\alpha \approx \alpha_H$ at dopant concentrations $N \leqslant 4\times 10^{17}$ cm^{-3}. With increasing N, however, the parameter α decreases so rapidly

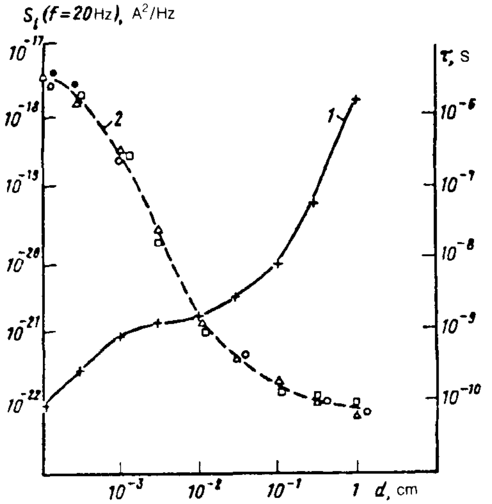

FIG. 1. Electrical properties versus the grain size d in the polycrystalline platelets. *1*—The lifetime τ versus d; *2*—the dependence of $S_i(f)$, i.e., of the spectral power density of the current noise, measured at a frequency $f=20$ Hz on d. △) p–n junctions; ○) Schottky diodes; □) resistors made from platelets; ○) deposited resistors.

that at $N=10^{19}$ cm^{-3} it is nearly two orders of magnitude smaller than α_H.

Figure 1 shows plots of $S_i(f)$, measured at the frequency $f=20$ Hz (curve *1*), and of the lifetime of the minority charge carriers, τ (curve *2*), in the structures versus the grain size d in polycrystalline silicon samples. The lifetime was measured by a conductance modulation method during injection from a point contact. The lifetime τ was also calculated from measurements of the photomagnetic effect. The value of S_i in the diodes was measured at high currents, at which the noise is due to fluctuations in the resistance of the base of the diodes, as has been established previously.[3] We would like to call attention to the circumstance that the data in Fig. 1 are evidence of a correlation between the behavior of S_i and that of τ.

With regard to a possible effect of the state of the crystal lattice on the mechanism responsible for the shot noise, we note the following. The difference between the crystal lattice of a polycrystalline sample and that of a single-crystal material, including the difference with regard to recombination activity, is characterized primarily by the presence of grain boundaries, by the dimensions of the grains, and thus by the size of the boundaries between grains. The mechanical strength of semiconductor platelets, which generally depends on the total length of the defects (e.g., cracks) which develop in these platelets, may be extremely sensitive to such factors.[6] In a polycrystalline material, we would logically expect the mechanical strength to depend on the grain size. Figure 2 shows the mechanical strength of the platelets used in these experiments versus the grain size d. We see that the results indicate that the behavior of the mechanical strength of the samples as a function of the grain size, which reflects the degree of imperfection of the crystal lattice of polycrystalline samples,[6] is similar in nature to the plots of $S_i(f)$ and τ versus d. We are thus forced to believe that the ideas expressed earlier regarding an interrelationship between the state of the crystal lattice and the magnitude of the $1/f$ noise in a polycrystalline sample are governing factors in shaping the current noise.

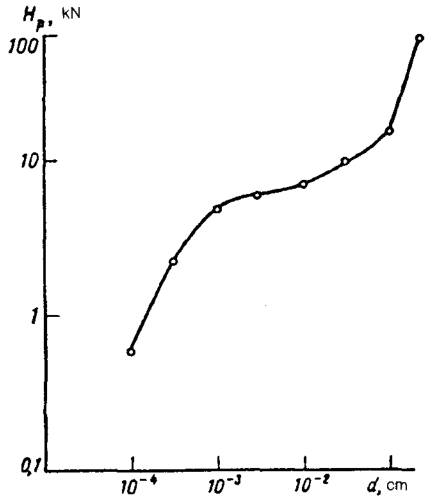

FIG. 2. Destructive load H_p versus the grain size d in the platelets of polycrystalline silicon.

The relationship between the noise characteristics and the recombination characteristics of silicon structures of various types observed in this study rekindles interest in ideas regarding an effect of the state of the crystal lattice—the presence of grain boundaries and the occurrence of a post-recombination relaxation of the lattice—on the nature of the $1/f$ noise. The correlation established between the noise, recombination, and strength characteristics of these test samples suggests some profound reasons for the interrelationship between the nature of the $1/f$ noise and structural properties of polycrystalline materials.

Because of the complexity of the structure of these test samples, i.e., because of their grain boundaries, the potential barriers at these boundaries, and the onset of a complex structure in the noise spectra, we cannot assert that the Hooge model is realized in full measure in these polycrystalline test samples. Nevertheless, the agreement between the effective Hooge parameter, calculated here for lightly doped test samples, and the customary value of the Hooge constant for a single-crystal material means that we cannot rule out a generation of noise in accordance with the Hooge model at low doping levels in polycrystalline samples.

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