Optical suppression of 1/f noise in silicon

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In view of the exceptional importance of silicon in modern semiconductor electronics, most of the experiments on the 1/f noise in semiconductors have been made using Si. However, even in the case of Si the results obtained in different investigations are contradictory. The value of the Hooge parameter α (Ref. 1) varies by about four orders of magnitude and ranges from $\sim 10^{-6}$ (Ref. 2) to $\sim 5 \cdot 10^{-3}$ (Ref. 3). Moreover, there are qualitative differences between the temperature dependences of α (Refs. 3 and 4). For example, it is reported in Ref. 4 that the value of α increased by about two orders of magnitude as a result of cooling from 300 to 100 K. On the other hand, according to Ref. 3, the value of α decreased by an order of magnitude as a result of cooling from 300 to 77 K.

It is well known that contradictions of this type are very often due to surface processes. In fact, investigations of the role of the surface in the formation of the 1/f noise also give ambiguous results.[2,5-7] For example, it is concluded in Ref. 4 that the surface plays the dominant role in the flicker noise. The results of Refs. 2 and 6 lead to the conclusion that the level of the 1/f noise is not affected in any way by the surface. Finally, the bulk and surface 1/f noise is reported in Ref. 7.

It is usual to assume that the 1/f noise is of bulk origin if a surface treatment method reduces strongly the level of the noise and if the result of such a treatment gives $\alpha \lesssim 10^{-3}$.

We shall show that in the case of silicon even when $\alpha \sim 2 \cdot 10^{-4}$ the 1/f noise may be of surface origin and light of photon energy ε_{ph}, exceeding the band gap ε_g of Si, reduces strongly the level of the 1/f noise.

We investigated bulk n-type Si samples prepared by the floating zone method characterized by a resistivity of $\rho \sim 300\ \Omega \cdot$cm ($n_0 \approx 1.6 \cdot 10^{13}$ cm^{-3}) and a dislocation density of $\sim 3 \cdot 10^4$ cm^{-2}. The shape and the dimensions of the samples were as shown as an inset in Fig. 1. Before deposition of the contact a surface n^+-type layer of thickness 0.5-1 μm was formed on both sides of the original plate and the phosphorus donor concentration in this layer was $\sim 10^{19}$ cm^{-3}. Contacts were formed by deposition and subsequent alloying with Ni in vacuum at 550°C. A plate was cut into samples by a laser.

A typical low-frequency noise spectrum of a sample immediately before laser cutting and before any treatment is represented by curve 1 in Fig. 1. Clearly, the spectrum had the form typical of the 1/f noise with the Hooge parameter $\alpha \approx 10^{-3}$. This value of α was less than α reported in Refs. 3, 8, and 9.

Illumination with light from a conventional incandescent lamp reduced considerably the noise level (curve 2). The spectrum was still typical of the 1/f noise; the Hooge parameter α for curve 2 was $\sim 2 \cdot 10^{-4}$.

Curve 3 shows the frequency dependence of the spectral density of the noise after etching of a sample in a boiling alkali, washing, and drying. A comparison of curves 2 and 3 demonstrates that the observed reduction in the noise level due to illumination was due to optical suppression of the surface component of the 1/f noise.

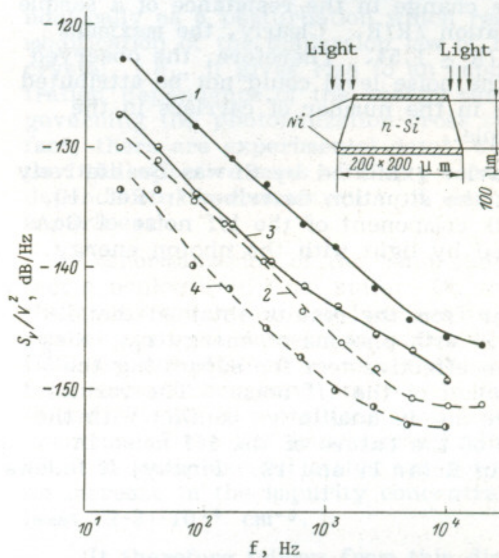

FIG. 1. Frequency dependence of the relative spectral density of the noise in a silicon sample: 1) after laser cutting; 2) during illumination; 3) after surface treatment in the boiling alkali; 4) illumination after this treatment. The inset shows the shape and dimensions of the samples.

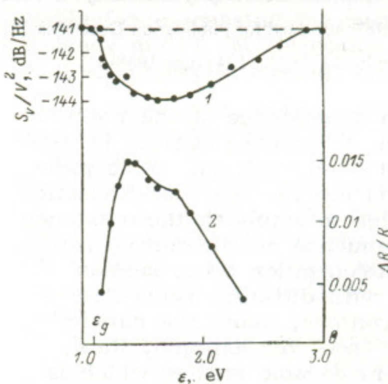

FIG. 2. Dependence of the relative spectral density of the holes S_V/V^2 (1) and of the change in the resistance (2) on the energy of the incident photons. Curve 1 was obtained at a frequency of 640 Hz. The dashed line represents the noise level in a sample kept in darkness.

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Curve 4 represents the dependence $S_V/V^2(f)$ obtained on illumination of an etched sample. Clearly, once again illumination suppresses the 1/f noise and the noise level during illumination after etching corresponds to $\alpha \sim 6\cdot10^{-5}$.

In the case of some of the samples after etching the Hooge parameter fell to $\sim 2\cdot10^{-5}$.

A comparison of curves 1, 2, and 3, 4 demonstrates that the nature of the influence of light on the noise was not affected by etching. This cirumstance made it possible to postulate that the observed 1/f noise was of surface origin even after etching. This was confirmed indirectly by the dependence of S_V/V^2 on the photon energy (curve 1 in Fig. 2). Curve 1 was obtained on illumination of a sample with light transmitted by a monochromator of the MDR-6 type. Clearly, the greatest contribution to the noise suppression came from photons of energy $\varepsilon_{ph} \approx 1.6$ eV, which penetrated the samples to a depth of ~ 5 μm.

Curve 2 in Fig. 2 is the spectral dependence of the relative change in the resistance of a sample due to illumination $\Delta R/R$. Clearly, the maximum value was $\Delta R/R \lesssim 1.5\%$. Therefore, the observed reduction in the noise level could not be attributed to an increase in the number of carriers in the bulk of a sample.

The behavior exhibited by Si was qualitatively different from the situation described in Ref. 10, where the bulk component of the 1/f noise of GaAs was suppressed by light with the photon energy $\varepsilon_{ph} \approx \varepsilon_g$.

It is clear from the results obtained that illumination of Si with photons of energy $\varepsilon_{ph} > \varepsilon_g$ can provide an effective test for separating the surface component of the 1/f noise. The results reported above are in qualitative conflict with the interpretation of the nature of the 1/f noise in Si developed in Refs. 11 and 12. Finally, it follows from these results that the Hooge parameter for the bulk component of the 1/f noise in ordinary silicon containing dislocations is less than $\alpha \sim 2\cdot10^{-6}$ if structure defects are not generated in the process of preparation of the samples.[6]

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Influence of the concentration of an impurity on its photoionization cross section (Zn^- ions in germanium)

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The concentration dependence of the photoionization cross section of impurity centers in semiconductors has not yet been analyzed. The published experimental data are few and unsystematic, so that it is not possible to establish the existence or absence of the dependence on the concentration. The values of the photoionization cross section calculated for samples with different concentrations of the impurity centers, using the data reported in some papers (see, for example, Refs. 1 and 2), exhibit a considerable scatter which is clearly greater than the errors in optical measurements.

The present paper reports the results of a determination of the photoionization cross section of the Zn^- ions in germanium in the continuous part of the absorption spectrum ($\hbar\omega \geq E_I$, where $E_{IZn^-} = 86.5$ meV — see Ref. 3) of samples with the zinc concentration from $2\cdot10^{15}$ to 10^{17} cm^{-3}.

The reliability of the optical measurements was improved by an additional detemination of the absorption at the fixed wavelength of a CO_2 laser and an accurate determination of the impurity concentrations was made by an analysis of the results of the Hall effect measurements corrected for the influence of a random field.[4]

The absorption spectra of the samples were determined at liquid nitrogen temperatures using a grating spectrophotometer. Samples had an area of 16 × 6 mm and a thickness from 0.3 to 1 mm, depending on the impurity concentration. The

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