

Line spectra of infrared luminescence of cubic silicon carbide crystals

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(Submitted February 3, 1975)

ZhETF Pis. Red. 21, No. 5, 263-266 (March 5, 1975)

Observation of several types of spectra of infrared (IR) photoluminescence (PL) of the α modification of silicon carbide was reported earlier.^[1-4] Here we present data on a new IR spectrum of SiC, observed for the first time in the cubic modification.

PACS numbers: 78.60.D

Cubic silicon carbide has the simplest lattice among all other polytypes, with nonequivalent atom positions that complicate the luminescence spectra.

The n -type β -SiC samples used by us were plates of yellow color, quite homogeneous and transparent (measuring $3 \times 3 \times 0.4$ mm). At $T = 4.2^\circ\text{K}$ we observed in them strong green photoluminescence of the excitons localized on neutral nitrogen donors.^[1] The procedure for the measurement of infrared photoluminescence was described in^[1].

Typical IR photoluminescence spectra of β -SiC are

shown in the figure. Their characteristic feature is that all are sharply bounded on the long-wave side by a strong line at 1.2827 eV, and this line is present in all the spectra. Nor were lines with shorter wavelengths than that of 1.361 registered. The line half-width is $\Delta h\nu \approx 0.4$ meV at $T = 4.2^\circ\text{K}$. It appears that all the lines are connected with nonphonon transitions. The line positions in the energy spectrum are given in the table.

An analysis of the spectra of several dozen samples has shown that it is possible to separate from the entire

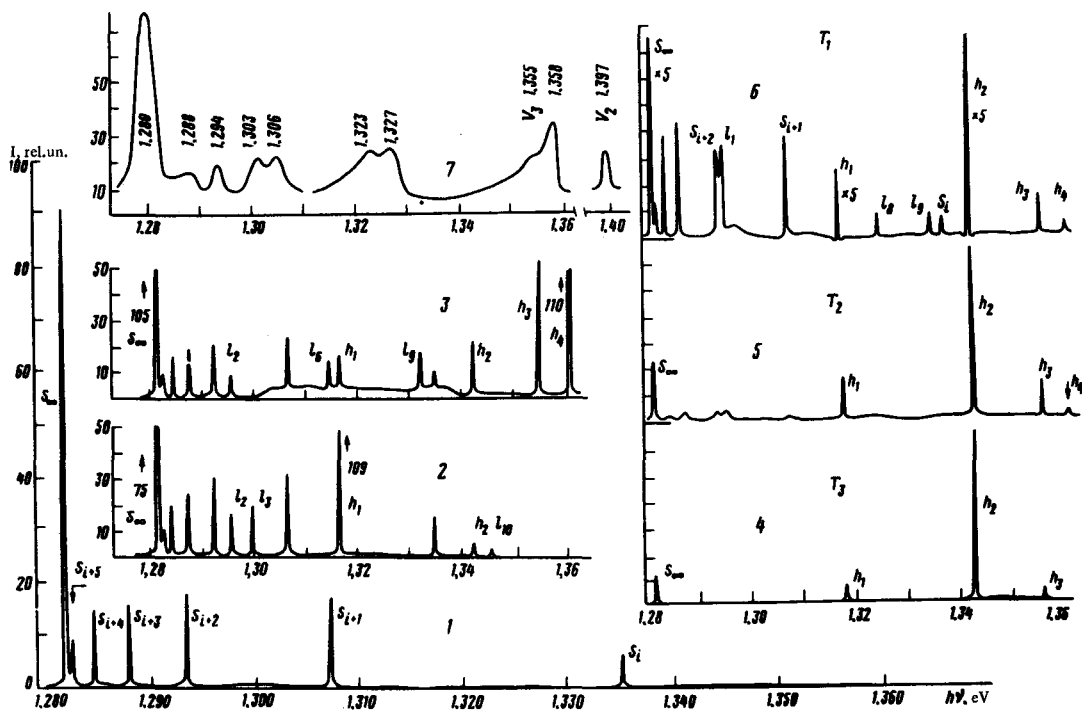


FIG. 1. Infrared photoluminescence spectra of silicon carbide: 1, 2, and 3—spectra of β -SiC at $T = 4.2^\circ\text{K}$ (the lines of the s series are not marked in spectra 2 and 3); 4, 5, 6—spectra of β -SiC at different temperatures, $T_1 = 4.2^\circ\text{K} < T_2 < T_3 = 77^\circ\text{K}$; 7—spectrum of 6H-SiC at $T = 77^\circ\text{K}$ (the numbers indicate the photon energies in the maxima of the bands, while the letters V_2 and V_3 designate the lines of the spectrum described in^[3]).

Line	$h\nu$, eV	Line	$h\nu$, eV	Line	$h\nu$, eV
s_∞	1.2827	l_1	1.295	l_7	1.318
s_{i+5}	1.2834	l_2	1.296	l_8	1.325
s_{i+4}	1.2848	l_3	1.300	l_9	1.333
s_{i+3}	1.2874	l_4	1.3045	h_2	1.3425
s_{i+2}	1.2937	l_5	1.310	l_{10}	1.346
s_{i+1}	1.3075	l_6	1.315	h_3	1.356
s_i	1.335	h_1	1.3173	h_4	1.361

manifold of line a series that converges towards the long-wave side. The lines of this series are always observed simultaneously, and their intensity ratios remain practically the same in all samples (the deviations do not exceed 20%). The line s_∞ , which is the long-wave limit of the series, always predominates in intensity. The other lines of this series are designated s_{i+k} , with $k=0$ for the line with the shortest wavelength.¹⁾ When the temperature is raised from 4.2 to 77°K the intensities of all the lines belonging to a series decrease simultaneously.

In addition to the s -series lines, which are present in all the crystals, it is also possible to observe lines whose intensity varies both relative to the lines of the series and relative to one another, depending on the sample. Four of them (h_1, h_2, h_3, h_4) have in some crystals an intensity of the same order as the s_∞ line (at 4.2°K). This intensity decreases with increasing temperature more slowly than the s -series intensity and at different rates for the different lines. A temperature rise has the least effect on the line h_2 . The remaining lines, designated l , never exceed the s -series lines in intensity. No regularities could be established for the lines not belonging to the s series.

The presence of individual narrow s -series lines that converge towards the long-wave limit can be attributed to the discrete character of the distances between the components of the radiating complex, with larger distances corresponding to higher electron-hole binding energies. The line s_∞ , which is the limit of the series, corresponds in this case to "infinite" distances. The energy of the emission quanta for these pairs can be represented in the form

$$h\nu = E_g - (E_1 + E_2) + f(r),$$

where E_1 and E_2 are the energy distances between the levels of the individual components of the center and the nearest bands, and E_g is the width of the forbidden band. The number of lines and their rapid convergence in comparison with the spectrum of donor-acceptor

pairs (e.g., in^[6]) may be due to the fact that the interaction energy takes the form $f(r) \sim 1/r^n$, with $n > 1$. This situation can arise, for example, in the case of interaction of a Coulomb center with a neutral center polarized by it, or else with an electric dipole having a short-range potential.

The possible explanation of the lines l and h is that they result from recombination of excitons localized not on simple paired centers of the s series, but on more complicated associations made up of the same defects. One cannot exclude, however, the participation of other impurities. Certain lines may turn out to be analogs of the spectra previously observed in other polytypes. Thus, for example, the line h_2 , which predominates at $T = 77^\circ\text{K}$, may be the nonphonon line of a spectrum of the abc type,^[1] corresponding to the only possible position of the luminescence center in the lattice.

We note in conclusion that we have succeeded in observing spectra of the type discussed in a number of 6H-SiC samples (Fig. 1, curve 7). The line s_∞ (6H) is shifted by only 2 meV in the long-wave direction in comparison with the line $s_\infty(\beta)$ (the widths of the forbidden bands are 2.390 and 3.023 eV for β -SiC and 6H-SiC, respectively). The lines of the 6H-SiC spectra are broader than those in the cubic crystals, so that a comparison of the spectral positions of the other lines is difficult. This broadening may be due to the presence of nonequivalent positions of the defects that take part in the luminescence.

¹⁾The lines of the series satisfy approximately the relation

$$h\nu_{i+k+1} = h\nu_{i+k} - \frac{1}{2}(h\nu_{i+k-1} - h\nu_{i+k}),$$

which leads to the formula

$$h\nu_{i+k} = h\nu_i - \left(1 - \frac{1}{2^k}\right)(h\nu_{i-1} - h\nu_i)$$

which is accurate enough for the short-wave lines but underestimates somewhat the results at large k .

¹I. S. Gorban' and A. V. Slobodyanyuk, Fiz. Tverd. Tela 15, 789 (1973) [Sov. Phys.-Solid State 15, 548 (1973)].

²I. S. Gorban' and A. V. Slobodyanyuk, Fiz. Tverd. Tela 15, 2877 (1973) [Sov. Phys.-Solid State 15, 1925 (1974)].

³I. S. Gorban' and A. V. Slobodyanyuk, Fiz. Tverd. Tela 16, 263 (1974) [Sov. Phys.-Solid State 16, 173 (1974)].

⁴I. S. Gorban' and A. V. Slobodyanyuk, Fiz. Tverd. Tela 16, 1789 (1974) [Sov. Phys.-Solid State 16, 1163 (1974)].

⁵W. J. Choyke, D. R. Hamilton, and L. Patrick, Phys. Rev. 133, A1163 (1964).

⁶W. J. Choyke and L. Patrick, Phys. Rev. B2, 4959 (1970).

Erratum: Line spectra of infrared luminescence of cubic silicon carbide crystals

[JETP Lett. 21, No. 5, 120–121 (March 5, 1975)]

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ZhETF Pis. Red. 21, No. 11, 692 (June 5, 1975)

PACS numbers: 01.85., 78.60.D

On p. 121, the lower formula in the footnote should read

$$h\nu_{i+k} = h\nu_i - \left(1 - \frac{1}{2^k}\right)(h\nu_{i-1} - h\nu_i).$$