HIGH-TEMPERATURE ELECTRON-HOLE LIQUID IN DIAMOND FILMS*

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The condensation of excitons into an electron-hole liquid (EHL) has been actively investigated since the late 1960s. The properties of three-dimensional EHLs in various semiconductors are rather well studied. EHL has been observed in Si, Ge, CdS, C, SiC, and many other materials. Note that the EHL critical temperature in most semiconductors is several tens of Kelvin.

The properties of EHLs in low-dimensional semiconductor structures are less studied. The formation of a quasi-two-dimensional EHL in $SiO_2/Si/SiO_2$ quantum wells (QWs), Si/SiGe/Si heterostructures, and GaAs/AlAs superlattices was demonstrated fairly recently. In diamond films, the formation of EHL is also possible. We apply density functional theory to calculate the EHL energy and equilibrium density in diamond films with thicknesses of a few nanometers. The exchange and correlation energy is taken into account in the local density approximation.

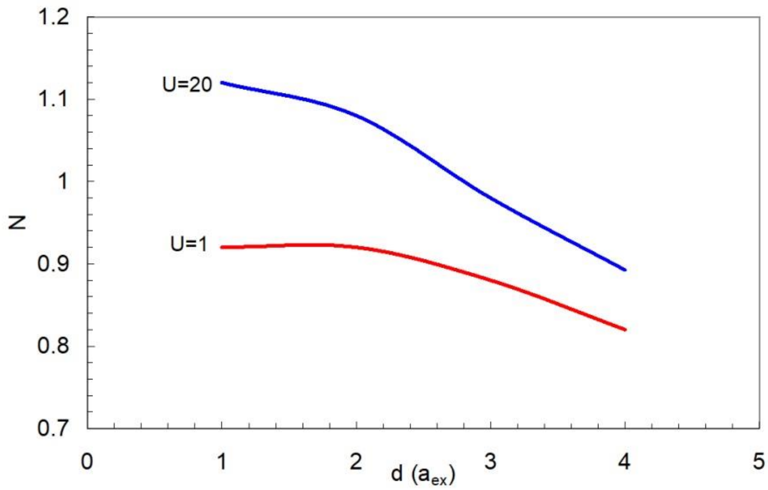

Fig.1. Electron-hole pair density versus the QW width for (111) diamond films.

It is shown that EHL is multicomponent and consists of electrons and heavy, light, and spin-orbit split holes. Figure 1 shows the dependences of the electron-hole pair density on the QW width d for well depths of $U = 1$ and 20 (excitonic units are used). The equilibrium density decreases with increasing d or decreasing U. This behavior is caused by a decrease in the contribution from the exchange-correlation interaction for large d and small U. The EHL is four-component; for example the hole densities for $d = 1$ and $U = 20$ are $N_{hh} \approx 0.73$, $N_{hl} \approx 0.27$, and $N_{so} \approx 0.12$. For a diamond film with a thickness of $d = 1$ and $U = 20$, we obtain a three-dimensional electron-hole pair density of $n \approx N/d = 1.1$ ($4.2 \cdot 10^{20}$ cm^{-3}). This is more than a factor of 4 higher than the density of a three-dimensional EHL. Therefore, following [1], we find that the critical temperature of the EHL in such a film is $T_c = 270$ K. It is noteworthy that the estimate for T_c in [1] is obtained for the three-dimensional case, while the critical temperature of a quasi-two-dimensional EHL can be higher than that of a three-dimensional EHL.

REFERENCES

[1] F.E. Leys, N.H. March, G.G.N. Angilella, M.L. Zhang, "Similarity and contrasts between thermodynamic properties at the critical point of liquid alkali metals and of electron-hole droplets," Phys. Rev. B, vol. 66, Article Number 073314, 2002.

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