About the lattice formation in the structure of islands of electron-hole liquid in some single-layer dichalcogenides

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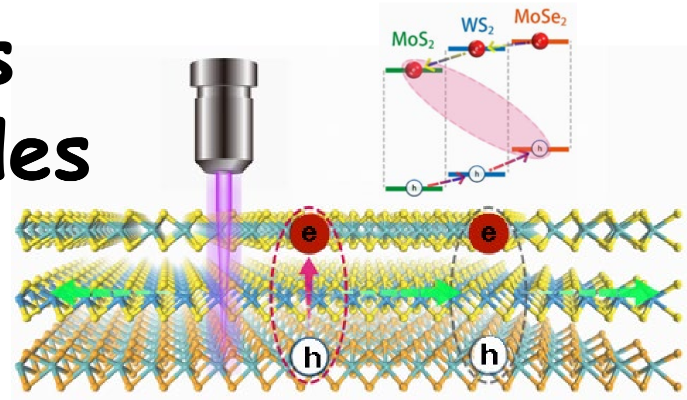
Thematic area: ***Nanocomposites and nanomaterials***



I. Introduction

Recently, electron-hole liquid (EHL) in dichalcogenides of transition metals (DTM) has been under intense research [1]. In 2D systems, EHL should be formed in the shape of individual islands. As a result of carrier recombination processes, the island has a finite radius, the size of which depends on the recombination speed and radiation intensity. Currently, there is almost no investigation of EHL droplets in DTM, and the interaction between islands has not been considered until now. The formation of EHL islands is an example of phase separation. We study these processes theoretically.

The investigation of EHL in low-dimensional structures remains relevant, in particular for applied purposes [2].

II. Model of the system

The stochastic theory of the formation of spatial structure of EHL under light irradiation was composed in [3] for 2D semiconductor systems using the kinetic approach applied to excitonic liquid [4].

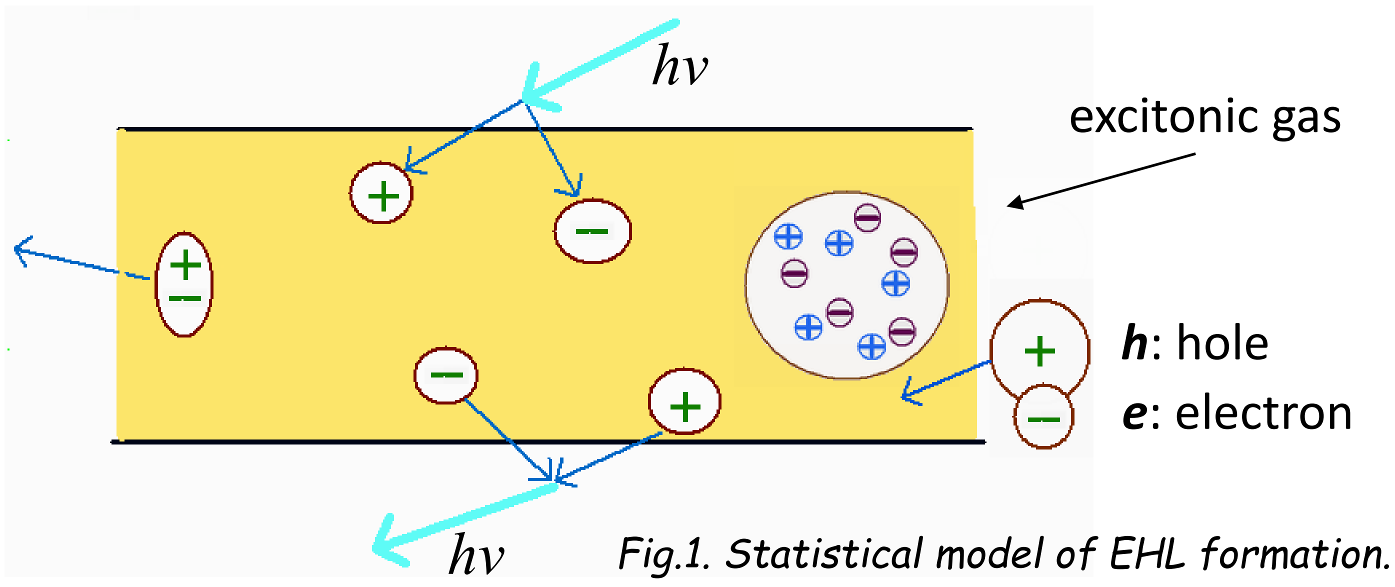
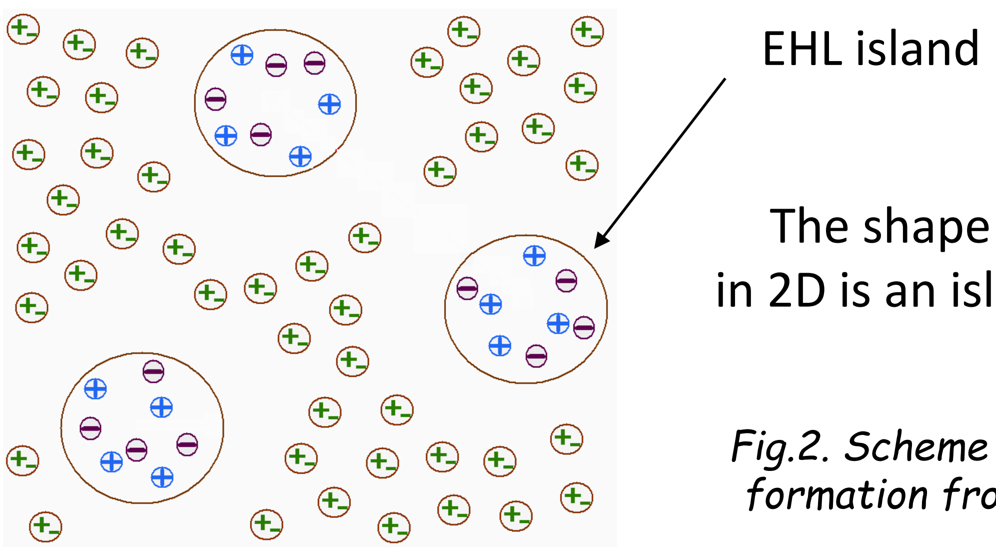


Fig.1. Statistical model of EHL formation.



The shape of an droplets in 2D is an island in the plane.

Fig.2. Scheme of EHL islands formation from exciton gas

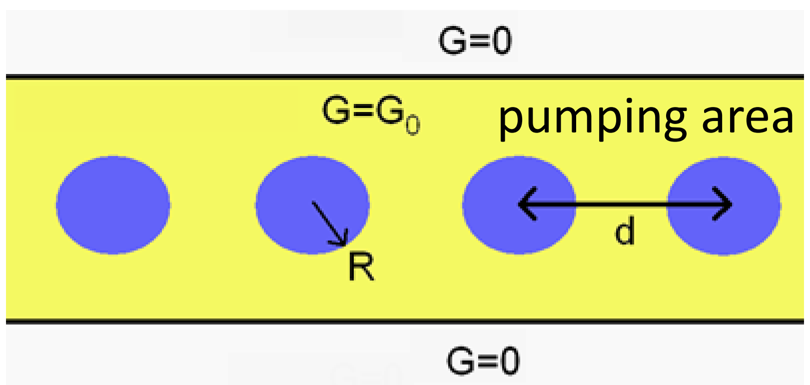
The kinetic equation for the number of e-h droplets in an island was solved together with the equation for the diffusion of excitons outside the island.

$$\frac{df}{dt} = P$$

f is the probability of realizing the distribution of islands by the number of e-h pairs, the radius and the distance between them. P is the probability of all transitions associated with the capture, emission and creation of e-h pairs.

$$D_X \Delta c - \frac{c}{\tau_X} = -G$$

D is the diffusion coefficient of excitons, which concentration is c. τ is the exciton lifetime.



The interaction between islands, which leads to the formation of spatial structures, occurs through diffusion fields of free excitons, which are created by an external source and form islands.

Fig. 3. Scheme of the system in the case of uniform irradiation of DPM in the form of a thin strip: the formation of EHL islands from exciton gas.

The paper considers cases of various spatial pumping G.

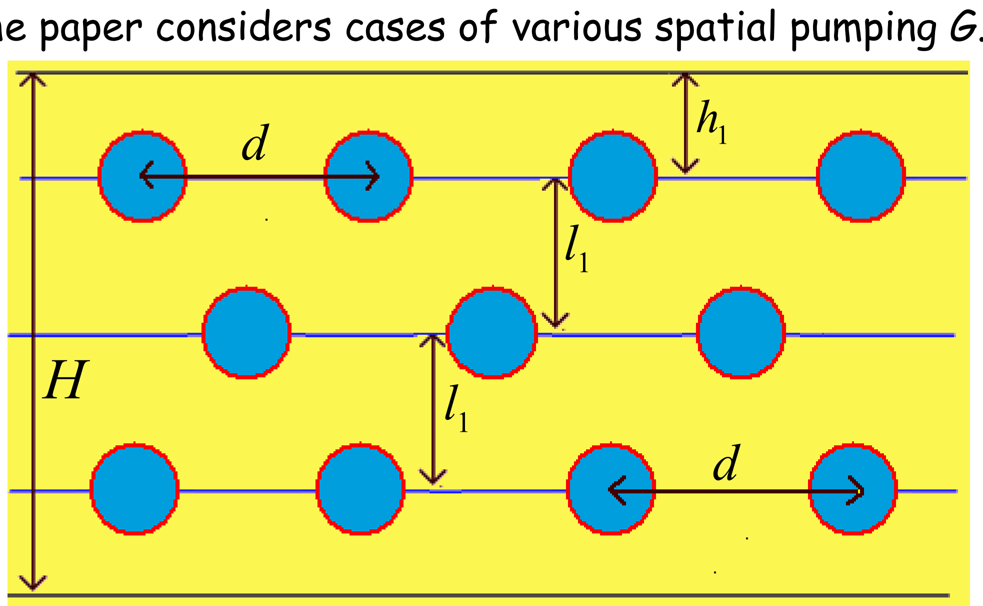
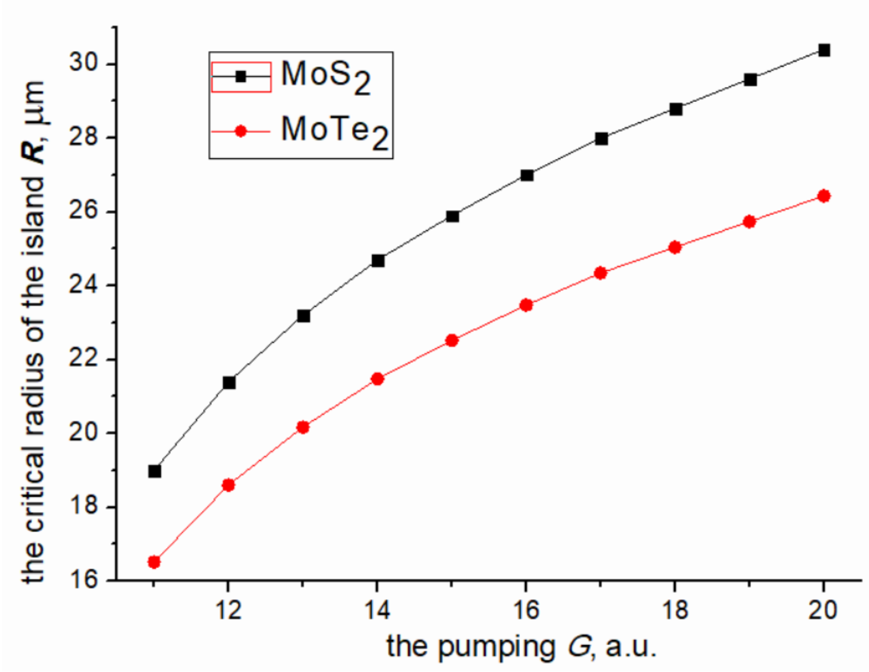


Fig. 4. Optimal arragement of EHL islands in the case of uniform irradiation of DTM in the form of a wide band.

III. Numeric calculations

We performed simulations in the case of homogeneous pumping of the DTM layer (namely, MoS_2 and $MoTe_2$). The pumping was assumed to be in the shape of a strip, the thickness of which varied from the value, at which the formation of islands was possible along the line of the strip only, to thicker strips, where the formation of several rows of EHL islands is possible.



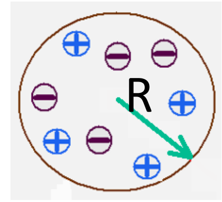
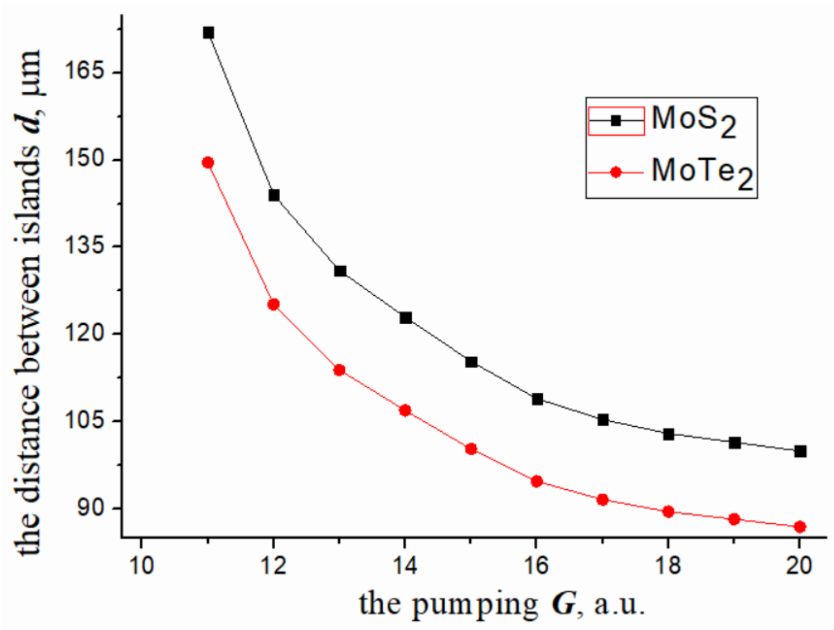


Fig.5. The size of the EHL island depending on the pumping.



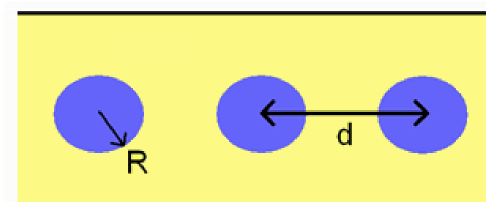


Fig.6. The most probable distance between EHL islands depending on the pumping.

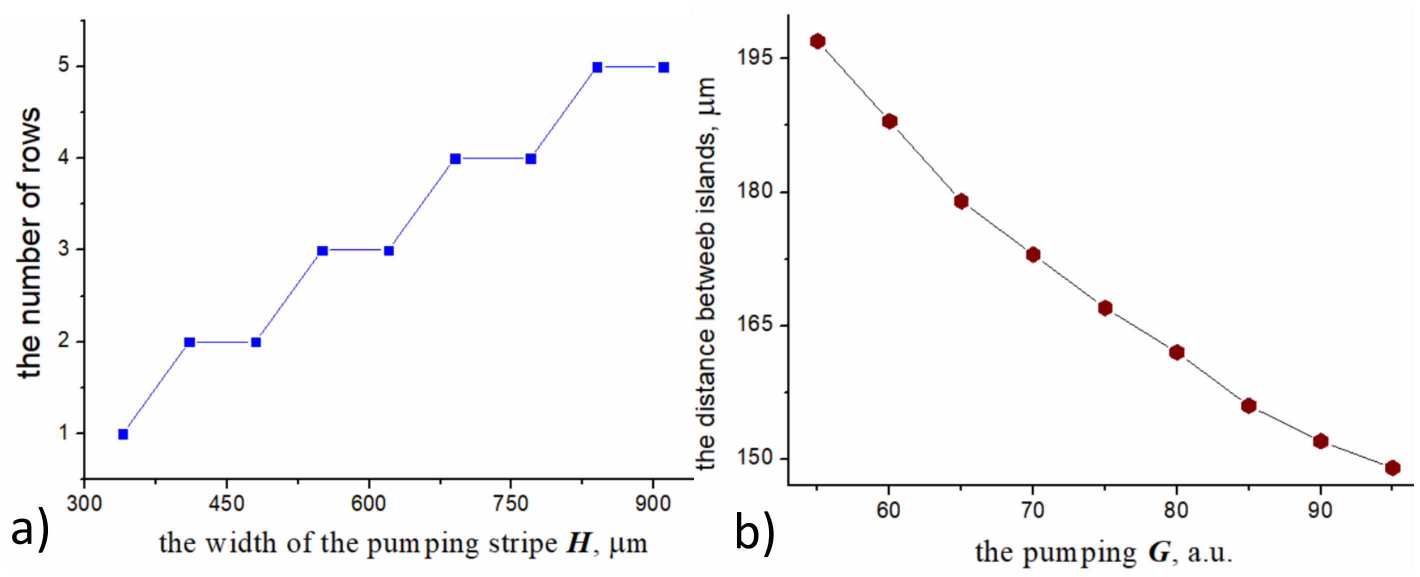


Fig.7. Placement of EHL islands in MoS_2 : a) the number of rows of EHL islands at fixed pumping G_0=80 depending on the width of the pumping stripe; b) the distance between EHL islands in the same row depending on the pumping at fixed width of the pumping stripe H=0,62 mm.

IV. Conclusions

With the help of the extremum of the EHL distribution function, the most probable size of the EHL island at a given pumping rate was estimated. It was established that the pumping threshold decreases with a reduction in the exciton lifetime or with a decrease in temperature.

In case of uniform irradiation of a dichalcogenide layer by pumping in the form of a strip, it was found that the periodic arrangement of round EHL islands and the estimated distance between them are the most likely. This distance decreases with increasing intensity of irradiation.

The parameters of the locations of the islands were estimated depending on the geometry of the system and the pumping intensity.

The calculations can be repeated for other dichalcogenides and for other pumping geometries.

The ordered arrangement of EHL islands in the layer of a dichalcogenide is an example of the new type of lattice in a 2D structure.

V. Literature

[1] *Arp T.B., Pleskot D., Aji V. et al.* Nature Photonics **13,** p.245 (2019).
[2] *Xiao Tang and Liangzhi Kou*. Phys. Status Solidi B **259**, p.2100562 (2022).
[3] *Chernyuk A.A., Sugakov V.I.* Physics Letters A **384**, p.126185 (2020).
[4] *Sugakov V.I.* Phys. Rev. B **76**, p.115303 (2007).