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A highly ordered radiative state in a 2D electron system

Parakhonsky A, Lebedev M, Dremin A and
Kukushkin I

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Abstract

A two-dimensional (2D) electron system in a perpendicular magnetic field acts like a macroscopic strongly correlated source of radiation with inherent temporal and spatial correlations. The formation of the correlated macroscopic state of 2D electrons passes through uniform and nonuniform states of the electron subsystem. These are reflected in two types of noise of photoresponse in the 2D system. The strange attractor characterized by small-sized dynamics in the phase space of a photoluminescence of 2D electrons is revealed.

Keywords: giant optical fluctuations, highly ordered correlated state of electrons, nonlinear dynamics, quantum Hall effect, strange attractor

1. Introduction

The formation of a highly ordered correlated state in low-dimensional electron systems is well known to produce fluctuations of their physical parameters (a potential fluctuation, spin and charge fluctuations, phase fluctuations of wave functions, etc.) [1]. The fluctuation character of various kinds of phenomena can be implicitly indicative of their fundamental nature. In particular, the studies of quantum shot noise made it possible to reveal the fractional electron effective charge [2,3]. The strong correlation effects may occur in a quasi-two-dimensional (2D) electron system in a transverse magnetic field, such as the fractional quantum Hall effect (FQHE) [4] and the pinned Wigner solid [5]. However, to date, quantum-sized electron systems have not been investigated in terms of the fluctuations in their optical response. In that context, the optical methods could provide information that is beyond the reach of the magnetoresistance

studies. These are the single-particle density of states immediately below the Fermi level, single-particle energy gaps, some information on a random potential (the amplitude and characteristic length scales), interference-enhanced effects, polarization correlations, coherence time, and so on. It is also important to emphasize here that quantum localization effects are not the strong restriction for the optical technique in the QHE regime [6].

In a series of articles [7–17], we reported that the giant optical fluctuations (GOFs) occur in a photoexcited 2D electron system (GaAs/AlGaAs quantum wells) in the QHE regime. Initially, it was revealed that the rated value of a variance of an intensity of radiative recombination of 2D electrons with photoexcited holes increases by several orders of magnitude for certain values of the Landau-level filling factor v [the ratio of a 2D electron concentration n_s to the multiplicity of the Landau-level degeneracy $(2\pi L^2_B)^{-1}$; $L_B=(\hbar/eB)^{1/2}$ is the magnetic length, $\hbar$ is the Plank constant, B is a magnetic field, and e is the elementary charge] [7]. The fluctuations are of a low-frequency character with characteristic times on the order of tens, hundreds, and even thousands of seconds. The follow-up study revealed that these fluctuations occur due to the strong interaction between elements of the photoexcited 2D system and have large-scale spatial and temporal correlations [8,9]. Moreover, we revealed that the signal intensity of intersubband inelastic light scattering in the QHE regime [the spin-density excitation (SDE) mode] exhibits giant fluctuations similar to the luminescence intensity fluctuations [10].

Fluctuations of optical signals are considered traditionally in the theory of optical coherence [18]. It is thus considered that the source of radiation is in a stationary state close to thermodynamic equilibrium and only field fluctuations are taken into account. However, besides optical coherence, intrinsic times of quantum dynamics of an electron subsystem can be perceptible in an optical signal. It seems that the consideration of source fluctuations under thermodynamically nonequilibrium conditions is a reasonable generalization of the existing theory. In particular, the source can be in a deterministic chaos regime, as it must occur at critical points and phase transitions. QHE is the macroscopic quantum effect that is manifested in the quantization of the Hall resistance ρ_{xy} and disappearance of the diagonal resistance ρ_{xx}. In that context, ρ_{xx} valleys can be considered as the system states in the vicinity of a critical point. It is reasonable to expect in the circumstances that the radiation of a source will be not chaotic. Indeed, we found that the radiation of the GOF source has correlations [8,12–14]. This radiation is not chaotic *a priori* and has nonlinear dynamics of photon counts as revealed from the time series analysis [11,15]. At that, there are conditions in a vicinity of the filling factor v=2, where the system behaves as the macroscopic correlated ("coherent") source of radiation [16,17].

2. GOF detection under QHE conditions: sample structure and initial experimental conditions

High-quality samples containing a 250-Å-wide GaAs/Al$_{0.3}$Ga$_{0.7}$As quantum well were used as a standard object where the effect of GOF is observed [7]. **Figure 1** shows the sample structure in which the radiative recombination of 2D electrons with photoexcited holes was studied.
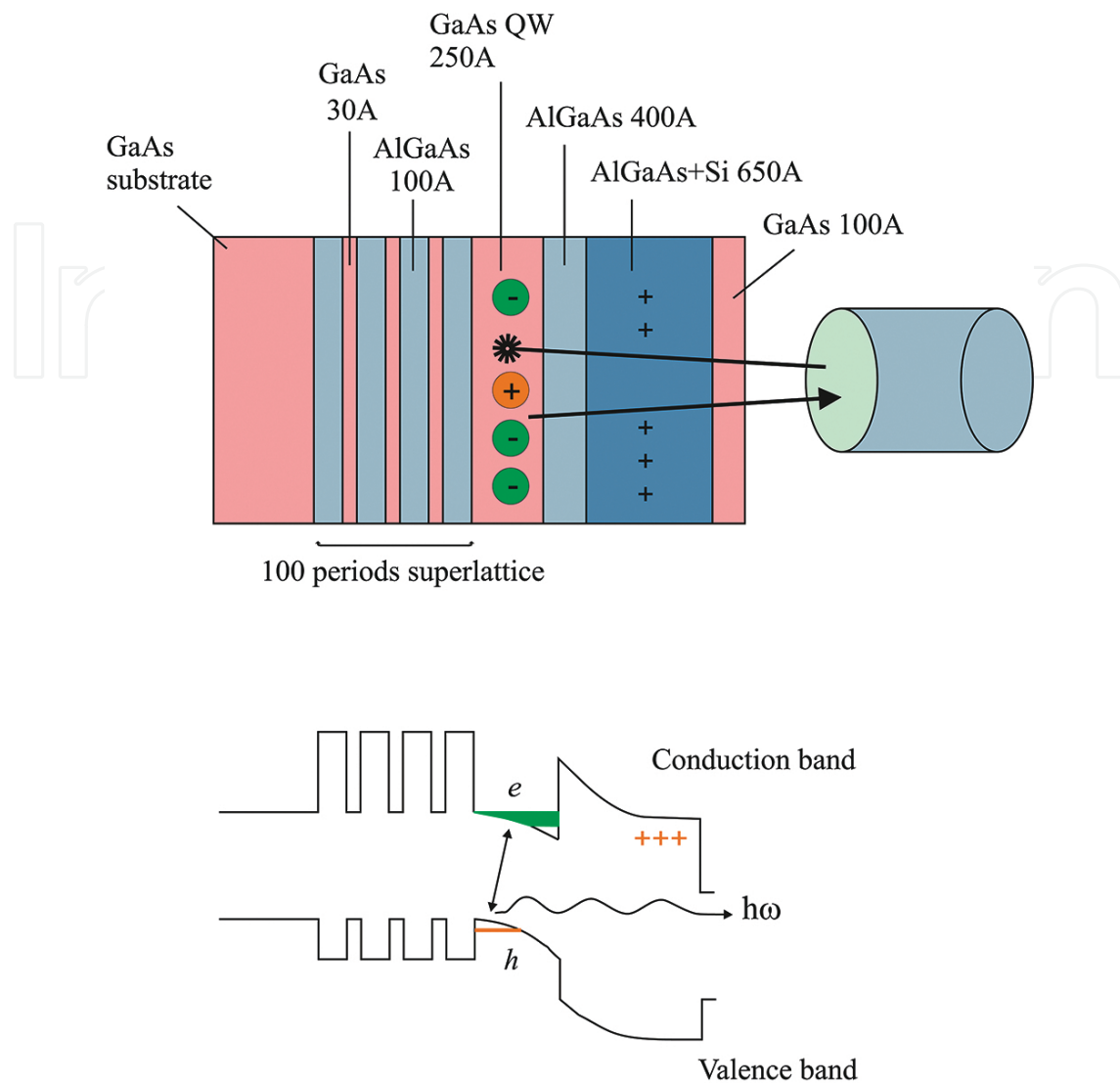
Figure 1. Layer-by-layer structure of the sample studied and the corresponding schematic energy band structure.

The samples were grown by molecular beam epitaxy on a GaAs substrate by the following scheme: GaAs buffer layer 3000 Å thick, undoped GaAs/AlGaAs (30/100 Å) superlattice 13,000 Å in total thickness, GaAs quantum well 250 Å thick, AlGaAs spacer 400 Å thick, doped AlGaAs:Si layer (doping level, 10^{18} cm^{-3}) 650 Å thick, and GaAs cap layer 100 Å thick. The characteristic mobility of 2D electrons and the concentration in these structures were $\mu=1.3\times10^6$ cm^2/(V s) and $n_s=3.8\times10^{11}$ cm^{-2}, respectively. The sample under study was immersed into a liquid helium cryostat with the superconducting solenoid provided magnetic field B from 0 to 12 T. The temperature of the sample T was varied from 1.5 to 4.2 K. In early experiments, the system was optically excited by a laser diode with photon energy E_L=1.653 eV and output power time instability of less than 10^{-4}. The photoexcitation was delivered and the photoluminescence (PL) signals were collected using optical fibers. Here, it is appropriate to mention another advantage of the magneto-optics over magnetotransport measurements. The fact is that, under the conditions of nonequilibrium electron-hole pair injection, along with the

reduction of the concentration of 2D electrons, their mobility considerably increases. This is because the concentration of charged centers decreases near a heteroboundary under illumination [19]. In early experiments in GOF, we used an optical scheme with a small photoexcitation spot ($d_{PE} \leq 3$ mm). Herein, the excitation of PL signals and their collection was accomplished using one of the registering fibers. The GOF effect is characterized as follows under these conditions. These are telegraph noise of the spectral position of a 2D PL line and a giant noise of the PL intensity. **Figure 2a** represents a set of 2D PL intensity spectra in a color scale measured at T=1.65 K in the range of magnetic field B=0–10 T at small steps of 0.1 T: the higher intensity corresponds to white and the black color corresponds to a weak intensity.

Figure 2a illustrates a simple method to find out the location of the required filling factor v and to get the GOF conditions. Each PL spectrum was detected using a semiconductor charge-coupled detector (CCD; Princeton Instruments) with 1340×100 imaging array and the high quantum efficiency (QE=70%) available in the near-infrared regions of the spectrum. A "Monospec" spectrometer was used as a spectral instrument providing a spectral resolution of 0.03 meV. This allowed the entire luminescence spectrum to be measured simultaneously in the wavelength region of our interest. The CCD matrix response speed (1 spectrum per second) was quite sufficient for studying 2D PL fluctuations. The positions of filling factors
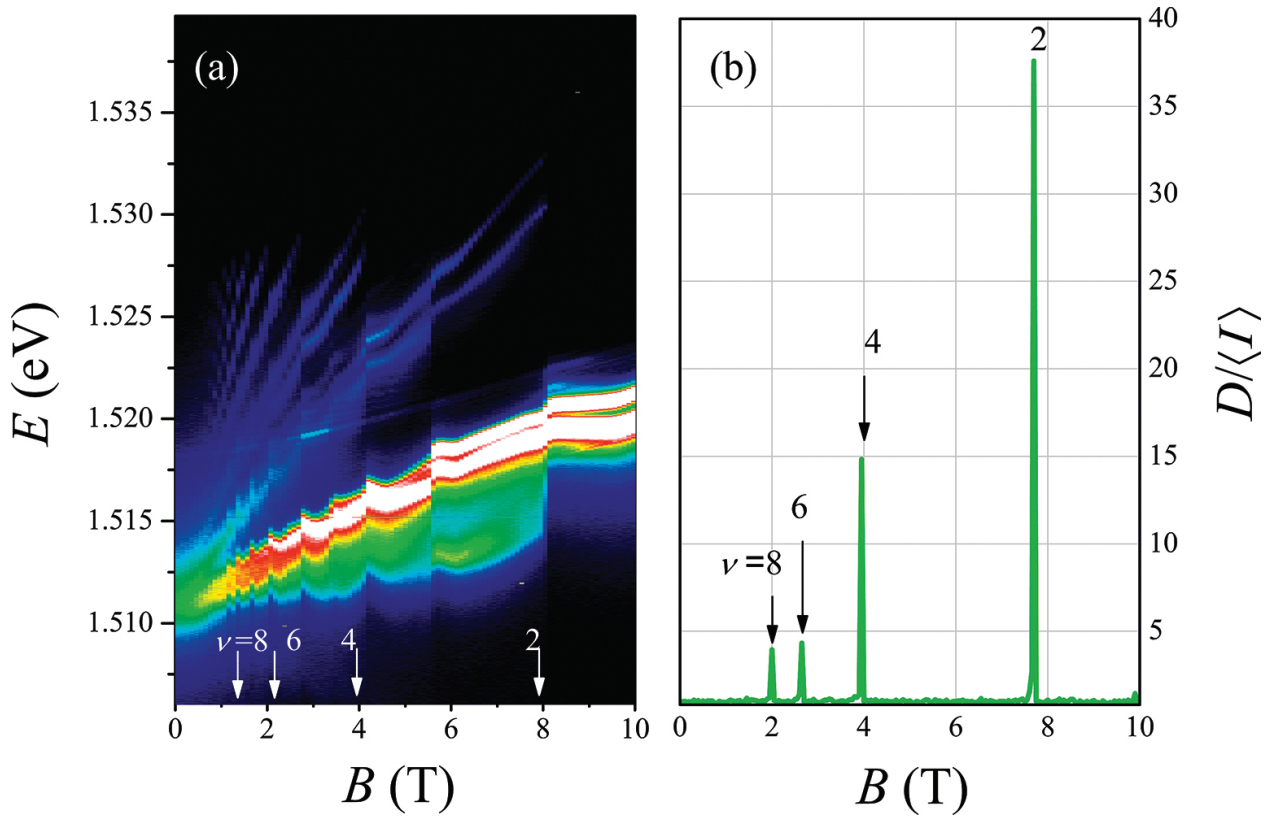

Figure 2. (a) 2D PL spectra measured in the range of magnetic field B=0–10 T (the color scale) and (b) ratio of the variance to the mean intensity $D / \langle I \rangle$. One can see that the PL statistic acts deviate significantly from the Poisson distribution and $D / \langle I \rangle >> 1$ at integer even filling factors v=8, 6, 4, and 2 (T=1.65 K).

v=8, 6, 4, and 2 correspond to very sharp jumps in the spectral positions of 2D PL lines. The transport characteristics of the samples were measured in parallel with the optical studies (under continuous laser illumination) to control the magnetoresistance at the Shubnikov-de Haas oscillation minima corresponding to the QHE (see [7]). **Figure 2b** illustrates the magnetic field dependence of the ratio of the variance $D = \langle I^2 \rangle - \langle I \rangle^2$ to the mean intensity $\langle I \rangle$ (the mean number of photon counts) of a PL signal from the lowest Landau level in the sample studying. The spectra were processed mathematically simultaneously with their recording. It is seen that this parameter increases by an order of magnitude at these values of v:

$$\frac{D}{\langle I \rangle} \gg 1. \tag{1}$$

Thus, this distribution of photon counts differs substantially from the Poisson distribution and the magnitude of fluctuations has a maximum in the vicinity of the filling factor v=2.
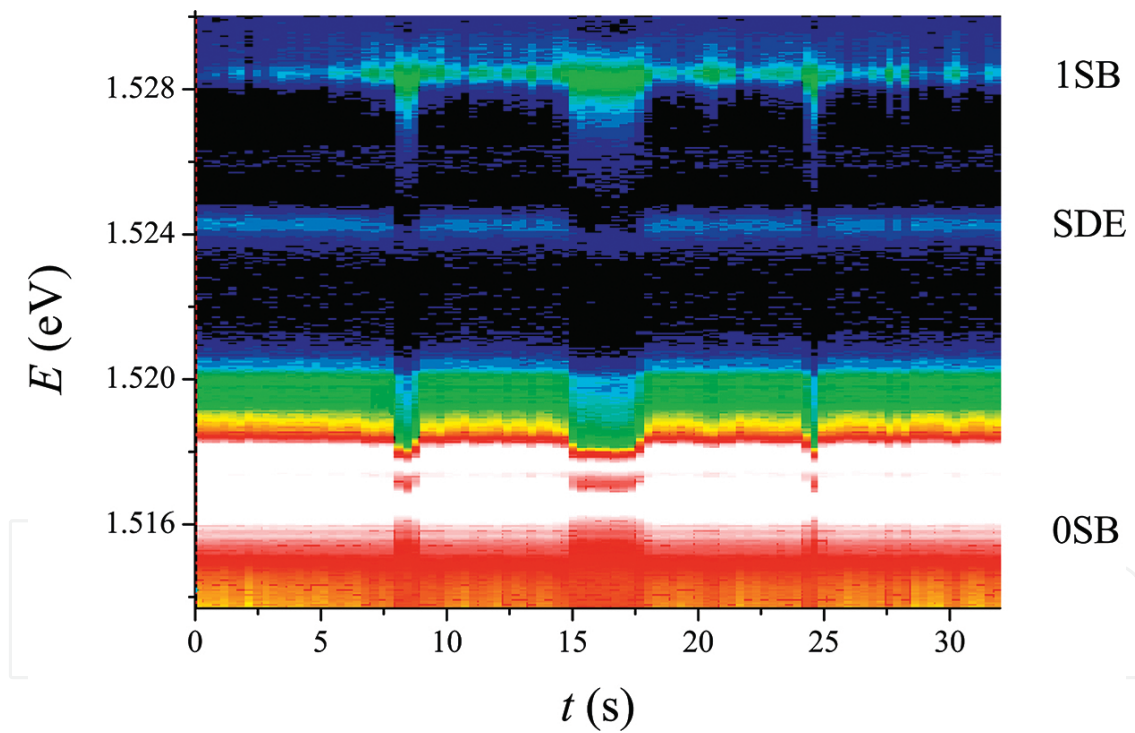
Figure 3. Time dependences of the spectral positions of the SDE line and the PL lines of the ground (0SB) and the first excited (1SB) size-quantized subbands.

It should be noted here that such a regime occurs also for v=1 and for fractional factors v as well at lower temperatures [11]. By studying the inelastic light scattering spectra under the QHE conditions, we revealed that the intensity of intersubband Raman scattering (SDE mode) undergoes giant fluctuations analogous to the PL intensity fluctuations [10]. In addition to the fluctuations in the inelastic light scattering intensity, we also revealed the telegraph noise of

the SDE spectral line analogue to the PL spectral lines of the ground (0SB) and the first excited (1SB) size-quantized subbands in the vicinity of v=2 (**Figure 3**). Fluctuations of the SDE mode intensity are observed simultaneously and in phase with fluctuations of the 2D PL intensity, and the recombination and inelastic light scattering processes proceed consistently over a long period of time. This fact indicates that, under the QHE conditions, the electronic system is in a macroscopic correlated state.

3. Macroscopic character of giant fluctuations of 2D electrons: a multifiber scheme technique

We applied the correlation analysis to the study of formation and characteristic aspects of the revealed macroscopic state in a 2D electron system. Correlation functions are quite often used in the analysis of noise due to the ease of interpretation. Correlation spectroscopy was for the first time applied to study of intensity fluctuations by Hanbury Brown and Tviss [20]. Subsequently, it was gradually resulting in a situation where the correlation spectroscopy became the traditional tool of quantum optics. However, as mentioned above, this method had rarely been used for studying fluctuations near critical points or phase transitions. Meanwhile, the correlation spectroscopy could be used successfully for spatial and tempo-ral analysis of optical fluctuations of complex systems. In a critical point, a characteristic range of correlations (correlation radius) significantly exceeds the interparticle distance and a system is becoming susceptible to changes of local concentrations [21]. If the photoexcited 2D electron system is in the quasi-equilibrium under IQHE conditions, then the intensity of recombination radiation consists of a convolution of 2D electron and photoexcited hole distribution functions [6]:

$$I(\hbar\omega) \propto \int\limits_0^\infty f_e(E) D_e(E) f_h(\hbar\omega - E) D_h(\hbar\omega - E) dE. \tag{2}$$

The width of the experimentally measured hole distribution function f_h turns out to be small; therefore, the 2D line spectrum reflects the energy distribution of the single-particle 2D electron density of states $D_e(E) \propto dn_s/dE$ [6]. Thus, if we consider fluctuations of 2D PL intensity under the existing conditions, they will depend on the fluctuations of a local concentration of 2D electrons n_s. The connection between $D_e(E)$ и n_s will remain in the case of interparticle interaction as well, but the energy spectrum will be significantly complicated and it is necessary to apply for the Green function approach. This means that a random potential screening will play a significant role in nonequilibrium processes and the 2D electron redistribution. In this context, high electron concentrations in doped quantum wells (as in the case of our samples) are sensitive to optical excitation [22] and deviations from the single-particle scenario of the integer QHE can occur resulting in that fluctuations and correlation effects are enhanced. The exciton effects are of little importance in this case because of the screening of exciton states by a system of 2D electrons in the doped systems. It was observed in both luminescence and reflectance spectra [23].
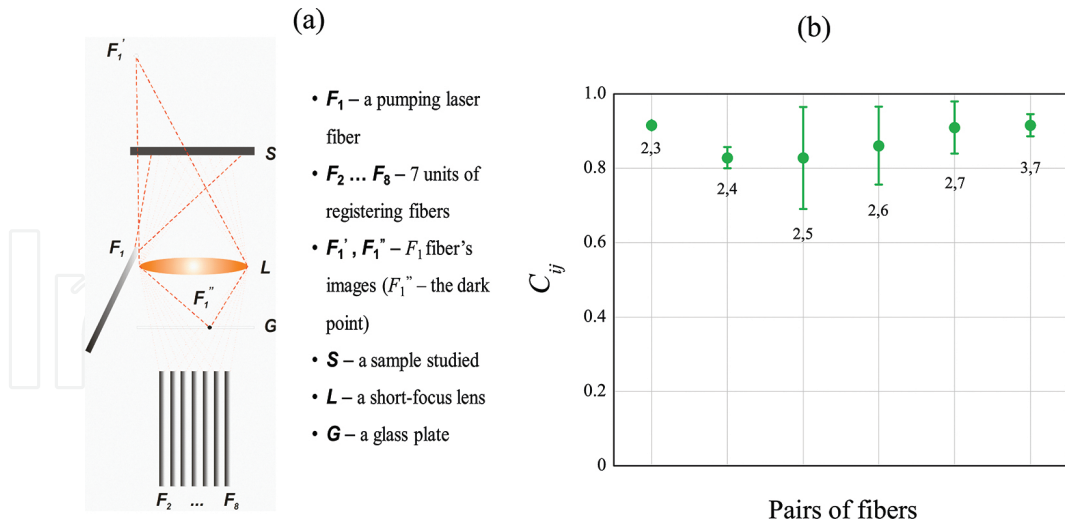
Figure 4. (a) An optical multifiber scheme used to record PL signals from seven sections of the surface; the transparent glass plate G was placed between the multifiber set and the lens to eliminate the laser light reflectance (a dark spot on the glass plate at the point-focused image). (b) C_{ij} for different pairs of fibers at the magnetic field $B=7.78$ ($T=1.65$ K).

In steady-state conditions, time dependence of the radiation intensity represents a realization of a stationary random process. The intensity correlation functions depend only on the time difference. The information on the concentration redistribution is contained in correlation functions of intensity fluctuations. In analyzing the autocorrelation function, it is possible to study periodic processes to find the characteristic time of a relaxation and dynamics of attractors. Cross-correlation function can provide information on spatial correlations in the system of interacting carriers.

We used special multifiber optical scheme to record and analyze the spatial correlation between the radiation intensities of PL signals from different points of a large sample ($S \propto 1$ cm²) in the lateral direction (**Figure 4**) [14]. Pumping a fiber F_1 with a core of 0.4 mm in diameter gave a light spot of approximately 1 cm in diameter on the sample surface (the spot appeared larger than the sample size). Short-focus ($f=15$ mm) lens L formed an image of the sample with a magnification close to unity in the plane where the edges of the registering fibers (F_2-F_8) were arranged. These fibers with the same core in diameter were arranged right up to each other with distances between their centers of approximately 1.2 mm, which did not overlap with each other. Sufficiently long sequences of the photo count time dependences were recorded at a step of 1 s. These sequences were simultaneously measured from two different fibers F_i and F_j. The subscript indexes i and j mean any pair of a number of F_2-F_8. The 2D system was optically excited by a continuous wave (CW) semiconductor laser Uptronic with photon energy of 1.536 eV and an output power of 75 mW. The correlation coefficients C_{ij} were calculated between the radiation intensities (I_i and I_j):

$$C_{ij} = \frac{\langle \Delta I_i \cdot \Delta I_j \rangle}{\sqrt{D_i \cdot D_j}},$$

(3)

where $\varDelta I_{i(j)}=I_{i(j)}-\langle I_{i(j)}\rangle$, D_i and D_j are variances of I_i and I_j respectively. The values of C_{ij} ranged from 0.80 to 0.97 for different sets of indexes i,j at $v=2$ (**Figure 4b**). This result is quite surprising, indicating that local electron concentrations at different points in the entire area of the 2D system are essentially equal. That is, all areas of the 2D electron system spaced at approximately 1 cm can emit light in a strongly correlated way. This is the point of uniformity of the electronic density ($B=7.78$ T, $v=2$). Both types of noise (intensity fluctuations and noise of the spectral position) are simultaneously observed in this point. The existence of a common optical excitation spot is essential for the correlations observed [8]. The resonant photoexcitation (it was carried out by means of a tunable diode laser DL pro 780 with an output power of 15 mW) in the first excited subband (E_{1SB}) of a quantum well has shown that this state formation occurs due to the exchange of electrons between the neighboring regions of a 2D layer [16]. **Figure 5** shows spectra measured in two different points of a sample separated by a distance of 6 mm ($i=2$, $j=7$). It is easily seen that PL lines, originally not coinciding by spectral positions, converge to the same value of energy $E_J=1.517$ eV (a point of uniformity). In the work [16], a 2D electron system near $v=2$ is considered as being in one of the radiant states: uniform electron density in 2D layer and a nonuniform one. The switching between these two states represents a telegraph noise where the autocorrelation function is given by:

$$A(\tau)=\langle I(t)\cdot I(t+\tau)\rangle=I_0^2 e^{-\frac{2|\tau|}{\tau_s}},$$

(4)

where $|I_0|$ is a fixed value of intensity, and τ_s is the average switching time. This value can reach hundreds of seconds at $T<1.7$ K.
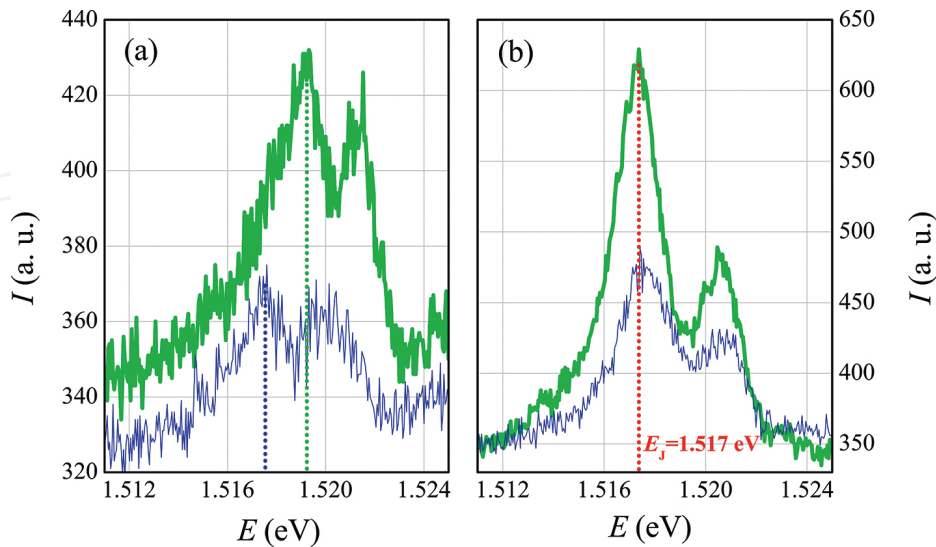
Figure 5. 2D electron PL spectra measured in two different points of a sample separated by a distance of 6 mm [fiber 2 (green curves) and fiber 7 (blue curves)] at $B=7.55$ T (a) and $B=7.78$ T (b) ($v=2$; $T=1.65$ K). PL spectra (in color scale; bottom) have identical spectral positions at $v=2$ for all points of a sample.

With further increase in magnetic field ($B > 7.78$ T, $\nu \le 2$), the telegraph noise disappears and the intensity noise amplitude decreases by more than one order of magnitude.

The range of an intensity noise covers a much wider range of a magnetic field (~2 T; see **Figure 6**) than it occurs in the case of a small spot of photoexcitation (0.005–0.01 T). We decided to analyze the noise region in terms of possible regularities in its dynamics and turned to the analysis of autocorrelation and cross-correlation functions of 2D PL signals in this region.

It was revealed that time dependences of the PL autocorrelation $A_S(\tau)$ and cross-correlation $C_S(\tau)$ functions have a periodic component and they practically coincide at B=7.78 T [16]:

$$A_S(\tau) \approx C_S(\tau) \propto \left(1 + e^{-2|\tau|/\tau_s}\right) \cos\left(\frac{2\pi\tau}{P}\right) e^{-|\tau|/\tau_d}. \tag{5}$$

Here, P is a period of oscillations and τ_d is a damping time. A term referred to as the damping time τ_d was introduced in formula (5), where the experimental dependences need to be adequately described [16].
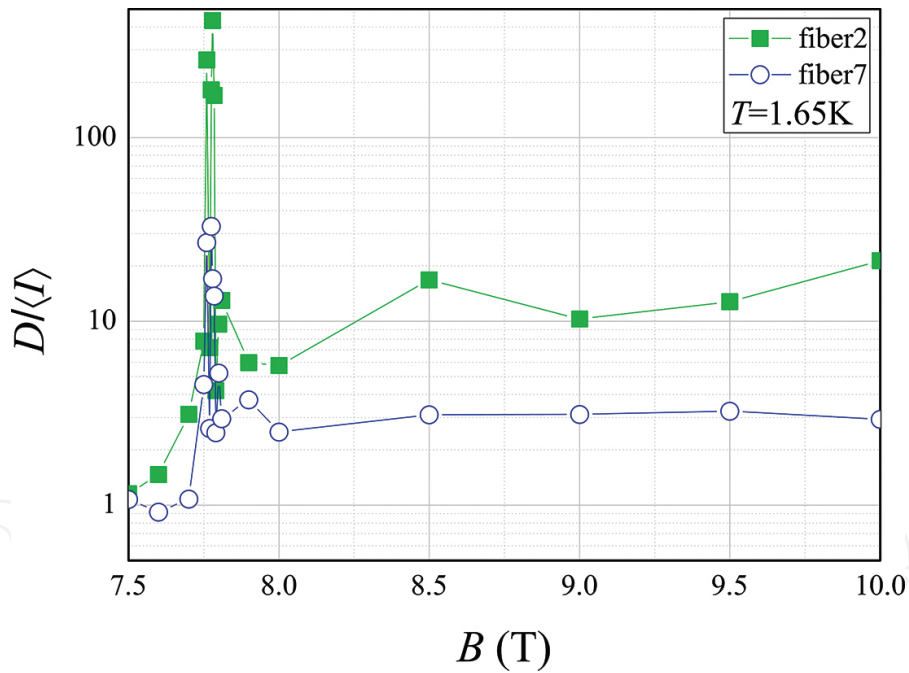

Figure 6. Ratio $D \,/\langle I\rangle$ calculated for a 2D PL intensity measured in two different points of the 2D plane (fibers 2 and 7) simultaneously in the range of magnetic fields of B=7.5–10 T at T=1.65 K.

Here, it must be taken into consideration that damped autocorrelation function is one of the criteria for the strange attractor of a dynamical system (see the next section). **Figure 7a** shows these correlations. Practically complete coincidence of the functions $A_S(\tau)$ and $C_S(\tau)$ means that the processes in two spatially spaced points of a sample proceed consistently. This confirms the fact that we have some kind of a macroscopic correlated radiative source. With the increase

in magnetic field ($B > 7.78$ T), the first exponential term in (5) disappears, and cross-correlation functions have only oscillating terms and a damped component:

$$C_S(\tau) \propto \cos\left(\frac{2\pi\tau}{P} + \Delta\Phi\right) e^{-|\tau|/\tau_d}, \tag{6}$$

where $\Delta\Phi = \Phi_j - \Phi_i$ is a difference in phase of stationary waves in corresponding points of the sample.
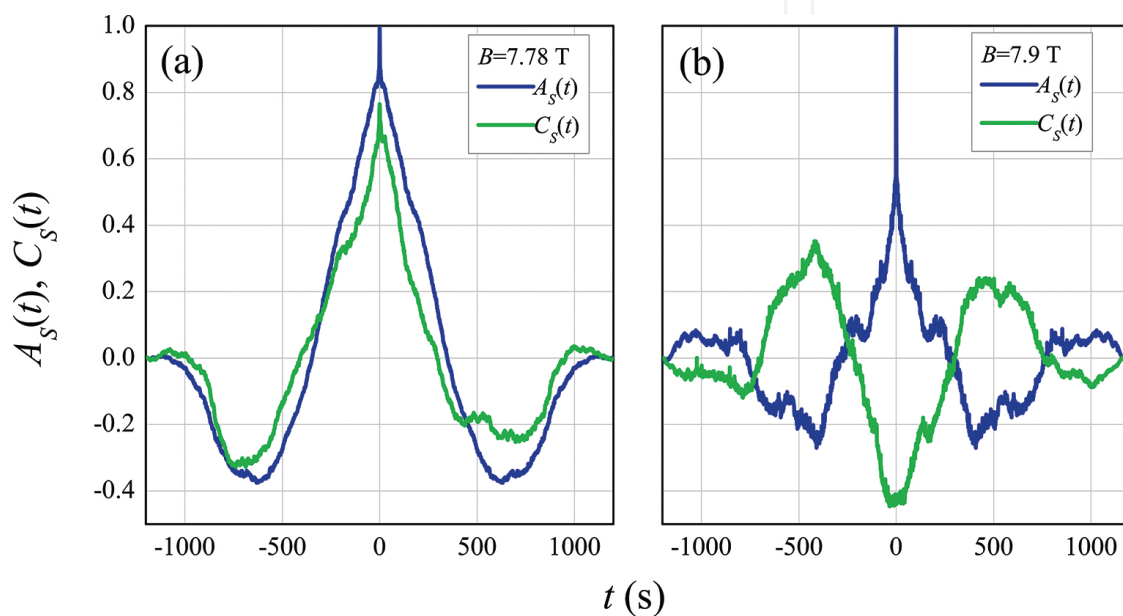
Figure 7. Autocorrelation functions of 2D PL signals from the fifth fiber and cross-correlation functions for the pair of fibers (2 and 5) at the magnetic fields of $B=7.78$ T (a) and $B=7.9$ T (b).

Thus, cross-correlation functions are sensitive to this difference in phase of stationary waves in corresponding points of the sample (**Figure 7b**). A phase difference indicates that the phase is not a random variable, but it has a fixed value, unalterable by the switching. It appears that a 2D PL intensity is modulated by "a standing wave", whose phase is defined by experimental conditions. An example of 2D electron systems in which a standing wave can be generated is plasmon excitation in the microwave (MW) field [[24]

4. Phase space portrait of the GOFs: beginning of the instability in the 2D system in a vicinity of $v = 2$; overview of the GOF effect and its possible mechanisms

It is well known that the comprehensive analysis of the time-series data of fluctuating signals may give useful information on the evolution of many kinds of dynamical systems. The study

of GOF time dependences, using this idea, showed that there are complex regimes of a motion in our 2D electron system in the vicinity of ν=2 [14].

In particular, it was natural to expect a specific dynamics of PL intensity fluctuations with the presence of a modulating standing wave in a point of uniformity of the electron density. The phase portrait of a possible strange attractor of dissipative dynamical systems can be received using the methods described in the works [25–27].

It was shown in [26] that a time series of measurements of a single observable $x(t)$ of the dynamic system trajectory can be used to reconstruct qualitative features of the strange attractor in phase space. In our case, such a component is the time dependence of 2D electron PL intensity $I(t)$.

Sufficiently long (1–3 h) time sequences $I(t)$ with the steps of Δt=1 s at different values of magnetic field in the vicinity of $\nu = 2$ were recorded and analyzed. The sequence of the m-phase space vectors of one component $x(t)$ is given by:

$$x(t) = \left\{ I(t), I(t+\tau), I(t+2\tau), ..., I(t+(m-1)\tau) \right\}. \tag{7}$$

Here, m is the embedding dimension and τ is the time shift. The parameter τ is taken to be the temporal correlation radius, whereby the autocorrelation function $A(t)$ of a time sequence goes to zero or has the first minimum. We used system (7) for the reconstruction of a pseudo-attractor of the fluctuating 2D system at various values of magnetic field. We revealed that, at the value m=3, there is such mode of noise in the point of uniformity of the electronic density (B=7.78 T) where the value of vectors (7) are eventually grouped in the vicinity of each of three axes of phase space (**Figure 8**, green curve). Moreover, it was found that the pronounced multiplying effect occurs in the phase space volume in this regime, that is, this phase portrait has distinctive features of a strange attractor [for the time sequences measured at the other magnetic, a strange attractor was not observed (**Figure 8**, red curve)]. The central 3D graph (the blue curve) demonstrates the result of a similar reconstruction when re-recording the noise under the close conditions; however, it has no such a characteristic phase portrait as shown in the top figure. A set of trajectories in phase space forms a structureless sphere in this case. A noise character differs for these two cases (**Figure 8**, left). In the first instance, fluctuations have discrete regions where the noise amplitude is insignificant. In the latter, the GOFs occur in a continuous mode, practically throughout all time series $I(t)$. It is necessary to notice that a noise character is essential to the understanding of this regime of a motion: fluctuations have discrete regions where the noise amplitude is insignificant. A strange attractor is absent in the system when the fluctuations occur in a continuous mode. An evaluation of correlation dimension requires some adjustment in the presence of data, taking into account transient states in the dynamics of attractors. We have provided a qualitative picture of the attractors here. An extensive statistical analysis including a consideration of these transient processes and the correlation entropy will be the subject of subsequent works. Nevertheless, we note that there is the process stage with nonlinear small-sized dynamics in a point of uniformity. The process of GOFs is not random in this regime but is governed by the limited number of control

parameters. Such nonlinear small-sized dynamics is defined by the coherence of elements of 2D electron system. The described analysis points to a certain determinism in the behavior of a 2D electron system under the GOF conditions. Such determinism takes place at the beginning of instability in the system [25].
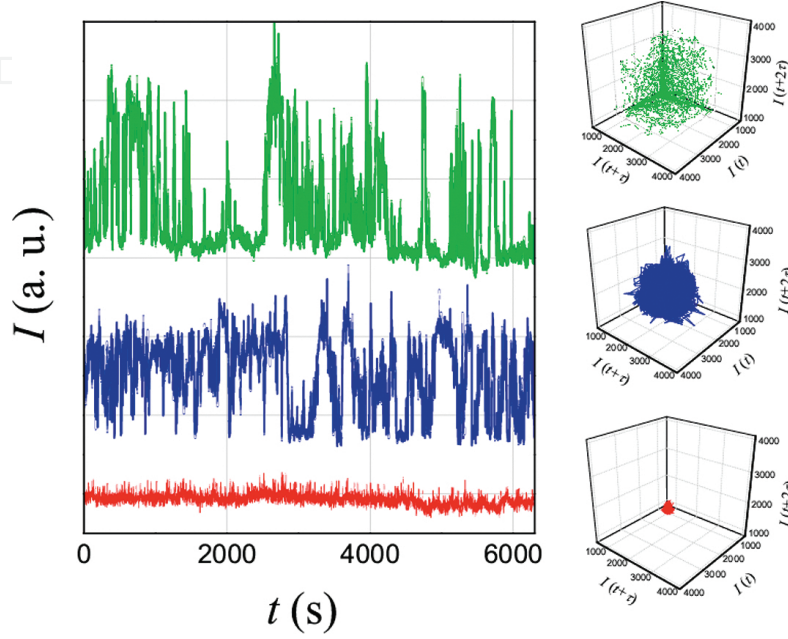
Figure 8. Time dependences of a 2D PL intensity measured at $v = 2$ (green and blue curves) and $v < 2$ (red curve; left). The measurements are carried out for the maximum of a PL line of the lowest Landau level; corresponding phase space portraits (right).

As an autocorrelation function of a periodic function is a function with the same period, the characteristic time t_{in} of the beginning of system instability can be derived. $A_S(t)$ data set at $v=2$ showed that t_{in} greatly varies from several seconds to dozens of minutes. The study of the 2D PL spectral power density (SPD) obtained through the fast Fourier transform of $A_S(t)$ functions in the vicinity of $v=2$ has revealed that this time can be as long as 20 min (**Figure 9**).

This time may be called an electronic "coherence" time. It should be noted that optical coherence time in the system studied is very short and it is defined by a spectral line width ($t \infty 1$ ps). **Figure 9** demonstrates the initiating step of the GOF process since before a point of uniformity. An SPD of noise is at a maximum value in the GOF regime. Following the factor $v=2$, SPD decreased by several times within a narrow magnetic field interval ($\Delta B=0.02$ T).

Thus, there is a mechanism that makes 2D electron concentration uniformly distributed across the all illuminated surface ($S \infty 1$ cm^2) under photoexcitation in the QHE regime. This attenuation of the electron density along a sample surface occurs due to the exchange of electrons between the neighboring regions of a 2D layer.

One possible scenario of this specific ordered 2D electron state formation under QHE conditions is the phase transition in the 2D electron system. A phenomenological model, describing the correlation functions of 2D PL signals, has been developed based on experimental data [17].
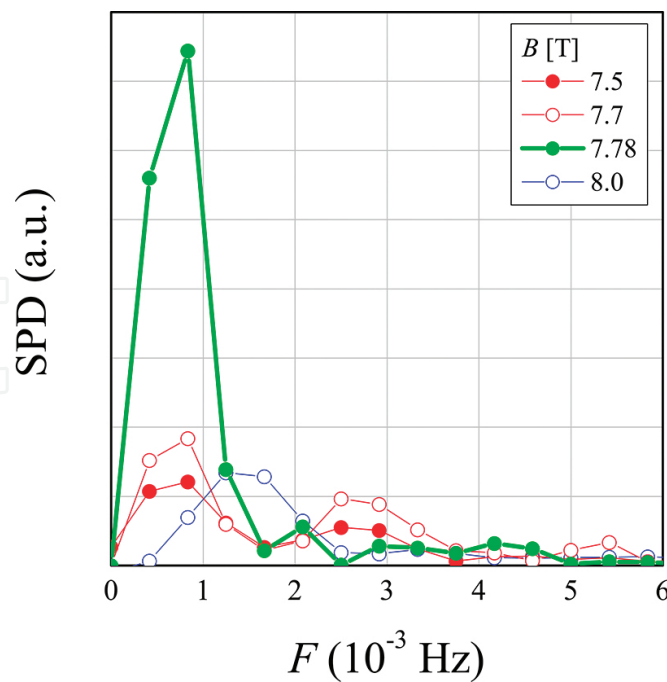
Figure 9. SPD for the second fiber at different magnetic fields ($v \geq 2$, $v=2$, and $v \leq 2$). The maximum time value of the beginning of system instability $t_{in}=1370$ s.

It gives the explanation for various phase conditions of a 2D electron system in a vicinity of the filling factor $v=2$ in terms of the formation of incompressible quantum liquid. In that case, once the electron concentration is attenuated along the entire surface, a random impurity potential is no longer to be screened. Therefore, a large electrostatic energy is attributing to that state. This uniform state is unstable and there are spontaneous transitions between the Hall insulator states and a conducting state in the system that results in the two types of a noise in 2D system. When a magnetic field is over the uniformity point ($v=2$), the system is divided into regions where there are drops of Hall liquid and an electron gas. Optical fluctuations go on, but the correlation between the regions decreases. With a further increase in a magnetic field, the drops gradually disappear. Vacuum fluctuations of the electromagnetic field can become an additional contribution to the system noise [10].

Under QHE conditions, small electron-density fluctuations can give rise to giant fluctuations of the conductivity of the 2D electron system and lead to fluctuation metal-insulator transitions. Another possibility involves the occurrence of a new coherent macroscopic state of the electron system described by a common wave function with a unified phase similar to superfluidity. Such coherent ordered electron states could occur due to the quantum leakage, such as the steady-state Josephson effect.

5. Summary

Thus, a system of 2D electrons in a perpendicular magnetic field in a vicinity of the filling factor $v=2$ exhibits GOFs. The photon count statistics deviates appreciably from the Poisson descrip-

tion and a 2D electron layer in this regime cannot be considered as a system consisting of a high number of independent systems. A technique for the study of spatial correlations of optical fluctuations in 2D layer by means of the multifiber set under conditions of a big photoexcitation spot ($S \infty 1$ cm^2) was developed. The study of the optical fluctuations, using this technique, showed that there are strong correlations between the radiation intensities from different points of the large sample. All areas of the 2D electron system emit light in a strongly correlated way under these circumstances, that is, the correlations are restricted by the dimensions of a sample. Hence, a 2D electron system acts like a macroscopic light source. Correlation analysis of the fluctuations showed that, in a 2D electron system, the uniform state with low PL intensity (v=2) or the nonuniform state with high intensity ($v < 2$) could exist. The autocorrelation and cross-correlation functions of the fluctuations are periodic and practically coincide at v=2 (a point of uniformity of the electron density). Cross-correlation functions are sensitive to the difference in the phase of stationary waves in corresponding points of the sample and the phase is strongly defined by the experimental conditions. When the filling factor v=2, the electron density equalizing along the sample surface, as a consequence, we observe correlations of the PL signals at macroscopic distances. The noise correlation time (electronic "coherence" time) varies from several seconds to dozens of minutes. A photoexcited 2D electron system can be considered as an open dissipative system being far from equilibrium because it continuously gains energy due to laser excitation and consumes energy through the recombination of 2D electrons with photoexcited holes. The use of a mathematical analysis tool of the theory of nonlinear dynamic systems showed that the GOFs are a manifestation of complex dynamics in the system of interacting 2D electrons. The behavior of a 2D electron system at v=2 corresponds to the regime of deterministic chaos: the strange attractor characterized by small-sized dynamics was revealed in the phase space of a 2D PL intensity in this regime. Thus, in this study, we deal with the radiation source in the 2D electron system in the vicinity of a critical point. This source is not chaotic and has a specific shape and intrinsic time of correlations. In the following studies, the question to be answered is whether these correlations resulted from the phase transition in a 2D electron system or the formation of a strongly correlated superfluidity-like quantum state.

Acknowledgements

Author details

Parakhonsky A*, Lebedev M, Dremin A and Kukushkin I

*Address all correspondence to: alpar@issp.ac.ru

Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, Moscow Region, Russia

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