PACS numbers: 42.55.Px; 78.60.Fi
DOI: 10.1070/QE2008v038n03ABEH013709

Lasing in zinc selenide single crystals pumped by high-voltage subnanosecond pulses

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***Abstract*. The action of subnanosecond high-voltage pulses ($U = 50 - 200$ kV, $t_p = 100 - 500$ ps) on 1 – 2-mm-thick plane – parallel ZnSe plates is studied. A sample was placed between a cathode and a circular anode. A discharge propagated along the lines of force of the electric field. Lasing at 480 nm appeared at the discharge front and opposite to the cathode. The average propagation velocity of the discharge achieved 5×10^8 cm s^{-1}, the pulse power was 600 W, and the radiation divergence did not exceed 2 – 3°. No streamer discharges oriented along crystallographic directions were observed.**

Keywords: *streamer lasers, zinc selenide single crystals, electroluminescence, subnanosecond high-voltage pulses.*

1. Introduction

When high-voltage pulses are applied to single-crystal semiconductor plates placed in a dielectric medium, luminous filament discharges (steamers) oriented along certain crystallographic directions are observed in them [1]. The diameter of streamers does not exceed a few micrometres. In the 'head' of a streamer moving at a velocity of $10^8 - 10^9$ cm s^{-1}, the conditions for amplification and generation of laser radiation appear. The density of nonequilibrium carriers in the head achieves $10^{19} - 10^{20}$ cm^{-3} and the laser radiation intensity achieves 10^9 W cm^{-2} [2]. Such a high density of nonequilibrium carriers can be provided by the collision ionisation or tunnelling effect in a strong electric field.

The features of streamer discharges in various semiconductors were studied in papers [1 – 6]. The advantages of streamer lasers are the simplicity of their design, the high radiation intensity, and the possibility of generating picosecond pulses of variable duration in a broad optical range from the UV to IR spectral region [3]. Despite these advantages, streamer lasers have not found wide applications so far because they also have important disadvantages such as the necessity of using a dielectric liquid or vacuum to which semiconductor crystals should be placed and the development of a discharge in the form of thin filaments, resulting in a high divergence of radiation and the difficulty of obtaining volume lasing.

It is known that the breakdown strength of media considerably increases when subnanosecond voltage pulses are used [7]. This makes it possible to perform experiments in air, to decrease the distance between electrodes, and to provide conditions under which the discharge propagates along the lines of forces of the electric field on the semiconductor surface. In this case, there is no need to place a crystal and an electrode in a liquid dielectric medium and, therefore, additional possibilities appear for ionisation of a semiconductor by the discharge radiation and an electron beam produced in the discharge gap by high-voltage subnanosecond pulses [8].

2. Experimental method and results

We used a high-voltage picosecond pulse generator with variable parameters, which was developed at the Institute of Electrophysics, Ural Branch, RAS [7, 8], and a coaxial attachment specially fabricated for our experiments. The basic element of the setup was a RADAN-303B nanosecond pulse generator [9] with an auxiliary picosecond energy compression unit equipped with a device for sharpening the pulse front and reducing the pulse duration with the help of high-pressure gas-filled gaps [10]. The picosecond generator provided the variation in the amplitude of a voltage wave travelling in the output coaxial to the cathode (travelling wave) in the interval from 20 to 250 kV; the wave duration could be changed from 100 ps to 4 ns. The scheme of applying subnanosecond pulses to a single-crystal ZnSe plate is shown in Fig. 1a.

Experiments were performed in the following way. Single-crystal 1-mm-thick plane – parallel ZnSe plates of size 6×5 mm were placed in a coaxial chamber opposite to the cathode which was closely pressed against the plate with the help of a spring-controlled unit. A movable circular anode electrode (AE) was placed at a distance of 0 – 1.5 mm from the plane of the semiconductor plate on its opposite side. Lasing was observed and the emission spectrum, power, and divergence were measured through an axial hole of diameter 3 mm in the AE. The pulsed radiation power was measured with a FEK-22 coaxial photocell. The emission spectrum was recorded with an MS-120 spectrometer equipped with a CCD array and an optical probe. The spectral resolution of the spectrometer did not allow us to study the mode composition of laser pulses. The voltage and

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Received 12 July 2007; revision received 11 September 2007
Kvantovaya Elektronika **38** (3) 213 – 214 (2008)
Translated by M.N. Sapozhnikov

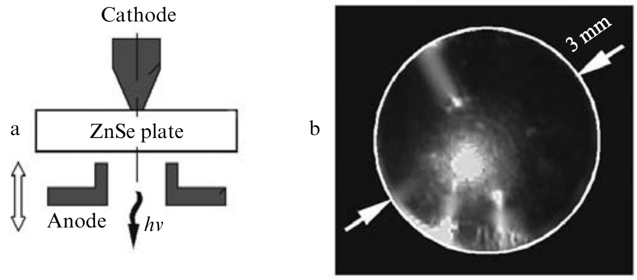

Figure 1. Scheme of excitation of a ZnSe single-crystal plate by high-voltage subnanosecond pulses (a) and the photograph of the near-field lasing region (b). The area of the contact spot of the AE with the ZnSe plate is $\sim 1 \times 1$ mm, the gap between the AE and plate is ~ 1.5 mm. The voltage in the travelling wave is $U_0 = 50$ kV, $t_p = 1.5 \times 10^{-10}$ s.

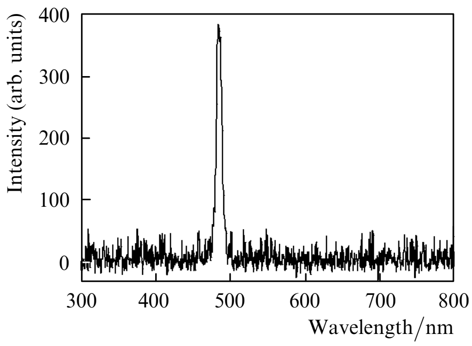

Figure 3. Emission spectrum of a ZnSe plate.

light pulses were recorded with a 6-GHz, 20-Gs s^{-1} broadband Tektronix TDS 6604 oscilloscope. The lasing threshold was determined by a drastic increase in the power and directivity of radiation and by the narrowing of the emission spectrum. Various stages of the emission development were recorded with a digital camera.

Beginning from the amplitudes 30 – 40 kV of the travelling wave (the FWHM of the pulse was $\sim 120 - 140$ ps), discharges were developed along the lines of force from the cathode edge to the anode. The blue emission first appeared opposite to the cathode and then – at the discharge front propagating toward the circular AE. As the high-voltage amplitude was increased, lasing appeared. Figure 1b presents the photograph of the ZnSe plate generating laser radiation under the action of a high-voltage subnanosecond pulse. Lasing usually appeared opposite to the cathode in spots of diameter 300 – 500 μm. The mean propagation velocity of discharges, calculated from the track length and the voltage action time, was 5×10^8 cm s^{-1}.

Figure 2 presents a photograph of the far-field laser radiation of a ZnSe plate placed at a distance of 40 mm from the recording plane. The divergence angle did not exceed 2 – 3°. The emission spectrum of the ZnSe plate ($d = 1$ mm, $U_0 = 109$ kV, $t_p = 1.5 \times 10^{-10}$ s, $T = 300$ K) is shown in Fig. 3. The maximum pulsed lasing power measured with a FEK-22 power meter achieved 600 W.

3. Conclusions

The experimental study of the action of high-voltage subnanosecond pulses on ZnSe single crystals have demonstrated the new possibilities of exciting stimulated emission in semiconductors and dielectrics. In this case, the conditions can be produced when an unfinished discharge propagates along the surface, producing a strong ionisation of the surface layer. The sample is subjected to the action of the electric field, optical radiation, and an electron beam appearing in the discharge produced in the gas by a high-voltage subnanosecond pulse. The influence of all these factors on the sample was not studied earlier in detail and is of scientific and applied interest. The authors plan to investigate in the future the dynamics of this process and the influence of each of these factors on the emission efficiency.

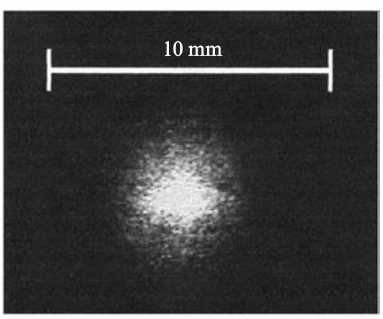

Figure 2. Photograph of the laser radiation of a ZnSe plate placed at a distance of 40 mm from the recording plane.

Acknowledgements. The authors thank A.V. Rasuleva and V.I. Solomonov, researchers at the Institute of Electrophysics, Ural Branch, RAS, for their help in spectral measurements and P.V. Shapkin, a researcher at the P.N. Lebedev Physics Institute, RAS, for the preparation of ZbSe samples. This work was supported by the Russian Foundation for Basic Research (Grant No. 07-02-12026-ofi).

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