The Cavitation Process in Proximity to an Ultrasonic Waveguide

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Abstract. Ultrasonic cavitation may be accompanied by sonoluminescence – light emission from the cavitation area. The work discusses the connection between two-phase domains and light emission (sonoluminescence). Experimental evidences provide some proves to non-thermal theories of sonoluminescence.

1. Introduction
Ultrasonic cavitation (USC) has many advantages over other cavitation research methods: it is a clear way to obtain well-interpreted results. Besides other interests, USC gives us a chance to observe an interesting phenomenon: sonoluminescence, i.e. light emission from the cavitation area.

The nature of sonoluminescence remains undiscovered despite numerous theoretical attempts. Generally, it is possible to partially explain sonoluminescence with almost any theory. However, it is currently impossible to describe this phenomenon fully, i.e. to explain all the features of sonoluminescence (especially its spectrum). In this work, we present experimental results for ultrasonic cavitation and its connection with sonoluminescence.

2. Two-phase domains at an ultrasonic waveguide
One of the interesting issues of USC is that foam appears near the ultrasonic waveguide. This foam, consisting of small bubbles, can be easily observed [1], [2] and may take bizarre (regular) forms (see figure 1).

Figure 1. The regular foam on the ultrasonic waveguide
In this work, we present the results of the investigation of USC in glycerol. The experimental setup was described in our previous works [3], [4]. The most convenient liquid for investigation of sonoluminescence for our relatively weak ultrasonic generator is glycerol. The appearance of the foam and its behavior is shown in figure 2. The total time between the first frame and the last one is ~ 3 s.

![Figure 2. The foam formation and jet into the bulk of the liquid](image)

The snapshots presented in figures 1, 2 are taken with a simple video camera. To understand the real dynamics of the cavitation foam we used a high-speed camera; videos taken at frame rate of $\sim 10^5$ fps evidence that this foam (the microbubbles that make up a foam, indeed) oscillates at a frequency very close to that of the ultrasonic waveguide. The foam on the waveguide is much brighter than the waveguide itself (see figure 2), thus the color of the given point from a snapshot obtained with a video camera can be considered as the evidence of foam. The result (radiation intensity from the given point, i.e. the point color) at the ultrasonic generator frequency of 20 kHz (with 2 kW of power) taken with a camera at 390 000 fps is presented in figure 3. We see that the maximum frequency corresponds to 20 kHz, i.e. time period of 0.05 ms, while the strongest changes occur at half frequency at time periods ~ 0.1 ms.
3. Light emission from two-phase domains

Two-phase domains are the sources of luminescence. In figure 4 shows sonoluminescence on the ultrasonic waveguide; it is easy to compare this image with figure 1. As we see, the light emission area repeats the form of a regular two-phase domain, discussed in the previous section. We are not in a position to discuss the “fractality” of the light emission area; the crucial fact that the glow is produced in regions containing a vapor phase. Usually, one can make a direct inference from such a fact: light emission is produced by the vapor phase, but in [5] we suggested another hypothesis – luminescence is the result of the process at the liquid–vapor interface.

Figure 3. Oscillation of foam. Ultrasonic frequency 20 kHz; taken at $3.9 \times 10^5$ fps

Figure 4. Sonoluminescence on the ultrasonic waveguide

Figure 5. Light emission from a couple of bubbles below the ultrasonic waveguide; the waveguide can be easily recognized by the luminous rim (in the middle part of an image)
Bubbles inside the bulk of liquid also emit light, see figure 5. This image was obtained when the frequency of the ultrasonic generator was turned away from the resonance value; in this dangerous mode (for the equipment) individual shocks repel the cavitation zone away from the waveguide; to be exact, light is emitted by the cavitation area, not by the double layer on the waveguide.

Thus, as we see, two-phase regions are responsible for the luminescence. However, the most astonishing (and rare) mode of luminescence is presented in figure 6.

![Figure 6](image)

**Figure 6.** The “sonoluminescent” streamer under the ultrasonic waveguide

In figure 6, we see that the only emission area in a vessel is the luminescent streamer, which moves towards the bulk of liquid from the ultrasonic waveguide. We see no light emission from the neighboring areas in the liquid volume. Thereby, bubbles coming from the waveguide bear something that bubbles in the liquid volume don’t have.

4. Discussion

As we see in figure 6, the streamer from the waveguide emits light while the surrounding media doesn’t. Of course, this streamer has nothing in common with the gas discharge object: this streamer is a narrow jet of foam (a wide jet of foam, consisting of many narrow parts, can be recognized on the last frames of figure 2). It is obvious that the bulk of liquid contains microbubbles too, and, formally, two types of bubbles (coming from the waveguide and “sitting” in the liquid) are in the same external conditions, i.e. in the same ultrasonic field. However, as we see, some bubbles remember their origin, and can emit light even far away from the waveguide (also, note the absence of luminescence on the waveguide itself).
It is possible, of course, that the “waveguide bubbles” have special sizes: they might be larger (for example) than the bubbles in the bulk of liquid. This simple reason, however, doesn’t look very realistic since liquid contains bubbles of various sizes, and some of those bubbles must be of “suitable” size anyway. The real explanation looks more complicated.

A more serious hypothesis must involve a possible mechanism of sonoluminescence. As it was shown in [3], sonoluminescence is accompanied by electrical effects, which can be easily explained: the double-layer can produce additional electrons if its width is sufficiently large, as it was considered by Frenkel. Thus, the bubbles coming from the waveguide may carry an electrical charge, and this particular feature can be the key to understanding their luminescence.

In [5] we showed that the glow of liquid under various external conditions has similar spectra: glycerol running through a narrow channel provides the same glow as glycerol cavitating in an ultrasonic field.

Thus, we came to the same conclusion as in [5] but from the other side: sonoluminescence occurs in two-phase media under special conditions of the combination of mechanical impact and the presence of electrical charges at the interface.

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Conclusion
Ultrasonic cavitation accompanied by sonoluminescence must be explored from various points of view. Here we present results that show the direct connection between the two-phase domains and sonoluminescence: clearly visible areas of cavitation are the zones where sonoluminescence germinates. The character of glow in some modes shows that the source of luminescence is not just an ordinary cavitation bubble or a common-or-garden mechanically disturbed phase interface, but a two-phase medium with electrical charges inside.

Of course, the additional research of mechanically induced light is needed, but most of these investigations, as we understand, must be of a theoretical sense rather than the experimental one. Experimental research should be aimed to obtain the same glow as sonoluminescence but under slightly (or, maybe, even substantially) different conditions compared to the ultrasonic cavitation.

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