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Cavityless powder lasers pumped by field-emission cathodes as a new class of monochromatic spatially incoherent radiation sources

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***Abstract*. A new class of monochromatic spatially incoherent radiation sources is proposed in which the cavityless lasing of field-emission electron-pumped nanocrystals is used.**

Keywords: *powder lasers, nanocrystals, emission cathodes.*

Cavityless lasing in a strongly scattering amplifying medium was predicted in 1967 [1, 2]. This phenomenon was experimentally demonstrated for the first time in the mid-1980s for powders of crystals doped with rare-earth ions [3]. Interest in this problem was recently rekindled. Lasing was demonstrated in dye solutions containing strongly scattering TiO_2 particles [4], in ZnO powders [5, 6], and dyes in various polymer matrices [7, 8]. New theoretical papers were also published in this field (see, for example, [9] and references therein).

Quite recently, lasing was demonstrated in powders of 20 – 40-nm nanoparticles doped with rare-earth ions of cerium, praseodymium, and neodymium and pumped by a weakly focused several kiloelectron-volt electron beam [10, 11]. Electron-beam pumping, along with obvious technological advantages, is also theoretically substantiated: photons used for optical pumping of strongly scattering media, only in which cavityless lasing is possible [1, 2], are strongly scattered from an active medium, resulting in a drastic decrease in the excitation efficiency. On the contrary, excitation of such media by 2 – 10-keV electrons is very efficient because the penetration depth of electrons with such energies is several tens or hundreds nanometres. As a result, the electrons propagate through the entire nanocrystal and their energy efficiently dissipates by pumping the active medium. Depending on the electron energy, ‘the active zone’, in which the population inversion is achieved, can be produced at a certain depth inside the sample.

It was shown in papers [10, 11] that lasing can be achieved by using 2 – 10-keV electron beams with currents 3 – 30 μA, which can provide upon focusing the current density of 0.1 – 3 mA cm^{-2}.

The aim of this paper is to attract attention to the fact that this current density can be now achieved with the help of multi-pointed field-emission cathodes.

The current density of 3.2 A cm^{-2} was achieved already in one of the first papers where multi-pointed field-emission cathodes were proposed and manufactured [12]. At present there exist dozens of various materials and technologies for manufacturing such cathodes. Among them are classical Shpindt diodes, arrays of silicon, diamond-like and other pointed emitters, emitters made of graphite nanotubes, etc. (see, for example, [13]).

Note that the current density required for lasing is close to that needed for the manufacturing of sufficiently bright flat emission displays, which is the main factor stimulating the development of field-emission cathodes (see, for example, [14]). A great increase in the current density is useless for exciting coherent radiation because a linear increase in the laser emission intensity observed above the lasing threshold of a ‘powder laser’ quite rapidly changes to saturation. For example, the lasing threshold in δ-Al_2O_3 nanocrystal powders of 27-nm nanoparticles containing approximately 240 Nd^{3+} ions per nanocrystal was achieved at a current of 3.5 μA for 8-keV electrons, while the saturation was observed at a current of 12 μA [11]. It is worthwhile to increase the size of a region being pumped by retaining the current density, and it is this problem that is being solved in the development of field-emission displays.

In our opinion, the use of a well-developed (and low-cost in large-scale production) technology for manufacturing field-emission arrays for pumping strongly scattering cavityless active media (‘powder lasers’) is capable of lending entirely new meaning to this scientific field. In fact, because we deal with a *cavityless* radiation source, the problem is to combine a standard field-emission diode with an active medium layer (Fig. 1).

As an active medium, nanocrystals doped with rare-earth metal ions can be used. The original piroelectrolytic technology of their synthesis was developed in [15], although ∼100-nm nanocrystals can be simply produced by the mechanical grinding of macroscopic crystals followed by its sorting (see, for example, [16]). A variety of polymer matrices doped with dyes as well as diamond nanoparticles with colour centres can also be employed as active media (diamond nanocrystals of size down to several nanometres are now commercially available, and the technology of their colouring is well developed [17]), etc.

A typical field-emission diode should provide the operating emission current at the voltage of several tens or hundreds volts. It should be equipped with an additional electrode, across which an accelerating voltage of several kilovolts, required for pumping the powder laser, is applied (Fig. 1). Therefore, the device is similar to a Shpindt diode with a control electrode and an anode. In our case, however,

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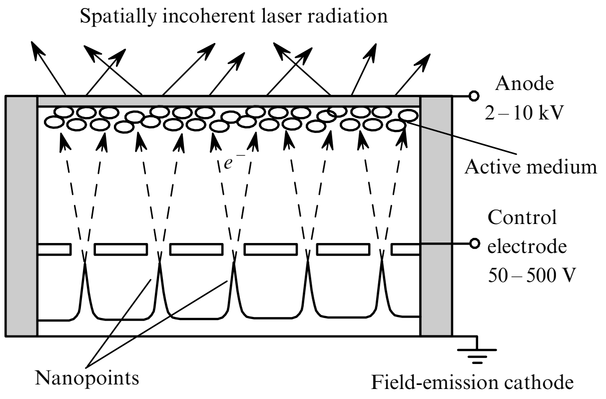

Figure 1. Scheme of a powder laser pumped by the current from a field-emission multi-pointed cathode (scale is distorted). Spatially incoherent laser radiation is outcoupled through a semitransparent anode; a control electrode can be omitted, which alleviates requirements to the emission cathode.

because it is necessary to use a voltage of several kilovolts, we can omit a control electrode. Great current densities should be produced by applying a voltage of several kilovolts across an array of field emitters, which allows us to alleviate drastically the requirements to the sharpness of emitting points and, hence, to increase the cathode durability.

The size of the device can be several millimetres. The manufacturing of sealed off vacuum units containing such a device presents no problems.

Such a cavityless laser pumped by field-emission diodes can find numerous applications. First of all, this are, of course, the same applications as for compact diode lasers (with additional possibilities provided by a narrow emission line and lasing in a broad spectral range; UV lasing at 362 nm was already demonstrated in δ-Al_2O_3 – Ce powders [10]). In addition, the spatial pattern of laser radiation without speckles can be useful for imaging without ‘ripples’, for communication devices, and even for new illumination systems.

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