DESIGN NOTE

A compacted Ernst-electrodes profile for pulsed high-pressure lasers

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Abstract. A compacted form of the usual Ernst profile for high-pressure gas lasers is derived, without reduction in the field uniformity for a given aspect ratio.

Keywords: field uniformity, gas lasers, compactation

It is well known that an efficient pumping of gas-discharge lasers is achieved only if the excitation is made by homogeneously distributed diffuse discharges. An electrode geometry capable of producing very uniform field distributions is necessary in order to obtain pulsed diffuse discharges in high-pressure gases. However, before the discharge begins, a pre-ionization mechanism has to operate in order to produce a homogeneous sowing of seed ions. In transversely excited atmospheric pressure (TEA) lasers, this pre-ionization system consists of some kind of ultraviolet (UV) source, placed along the sides of the discharge, which is generated between the uniform field electrodes (UFE).

Since the pre-ionizing UV light is absorbed by the gas, it is very convenient for the UV sources to be placed as close as possible to the discharge volume. For this reason and for the sake of compactness of the laser structure, the lateral electrode dimensions should be narrowed as much as possible.

Several kinds of uniform-field electrode have been used and a critical discussion about the shortcomings and advantages of the most popular ones can be found in [1], in which the Chang profile and its compacted form were reported. Later, a new profile narrower than the compacted Chang one was developed by Ernst [2]. By following this direction, in this work we obtain an even more compact profile, based on the Ernst type.

The compactness of a pair of UFEs has to be compatible with the aspect ratio chosen as a design parameter for the homogeneous diffuse discharge. This aspect ratio is the relation between the two transverse dimensions of the discharge (figure 1):

$$r = x_m/y_0. \tag{1}$$

Here $2y_0$ is the electrode separation and $2x_m$ is the width of the interelectrode volume in which the relative variation of the electrical field $E(x)$, with respect to the central value

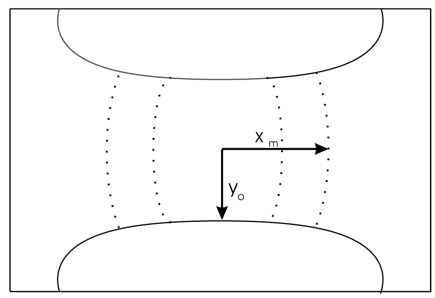

Figure 1. Parameters of the profile aspect ratio.

$E(0)$, is less than the maximum tolerated by the discharge uniformity, δ_m. That is

$$\delta_m = \frac{E(0) - E(x_m)}{E(0)}. \tag{2}$$

The usual kind of profiles mentioned above can be derived from the series expansion of a conformal transformation:

$$\xi = \omega + k_0 \sinh(\omega) + k_1 \sinh(2\omega) + \cdots \tag{3}$$

where

$$\xi = x + \mathrm{i}y \tag{4}$$

$$\omega = u + \mathrm{i}v \qquad |v| < \pi. \tag{5}$$

Here x and y are the spatial coordinates (figure 1) and u and v are the field flux and potential functions respectively [2].

When we keep only the three first terms in (3), we have a family of equipotential surfaces, which contains the maximum-uniformity Ernst profiles. In these, $k_1 \ll k_0 \ll 1$ and $v \simeq \pi/2$ [2]. So, let us now consider an equipotential surface in which $v = \pi/2$, whose parametric equations, obtained from (3)–(5), are

$$x = u - k_1 \sinh(2u) \tag{6}$$

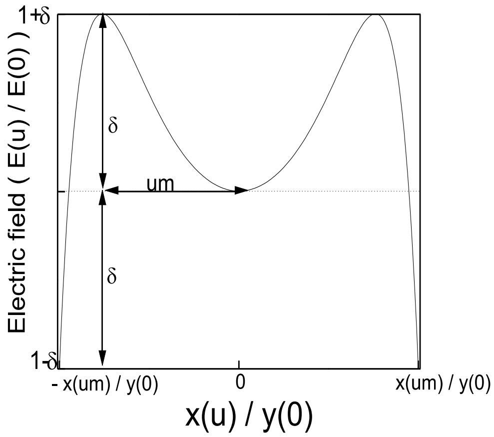

Figure 2. The general form of the normalized electrical field in the compacted Ernst-like profile.

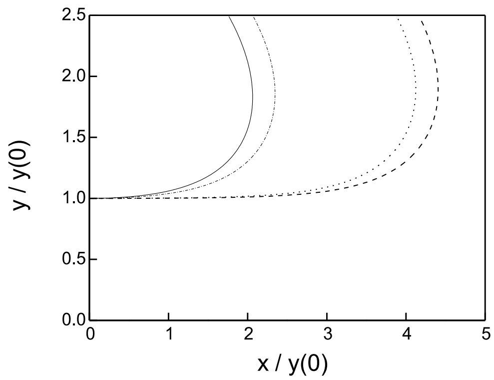

Figure 3. A comparison of the compacted and uncompacted normalized Ernst profiles in two different cases: (——), compacted profile, $r = 1$; (— · —), uncompacted profile, $r = 1$; (· · · · · ·), compacted profile, $r = 3$; and (– – –), uncompacted, $r = 3$.

$$y = \frac{\pi}{2} + k_0 \cosh(u). \tag{7}$$

On that surface the field is

$$E(u) = \{[1 - 2k_1 \cosh(2u)]^2 + k_0^2 \sinh(u)^2\}^{-\frac{1}{2}}. \tag{8}$$

In the general case this field has a central minimum ($x = u = 0$):

$$E(0) = (1 - 2k_1)^{-1} \tag{9}$$

and two lateral maxima at

$$u_d = \frac{1}{2} \cosh^{-1} \left(\frac{8k_1^2 - k_0^2}{16k_1^2} \right) \tag{10}$$

with

$$\frac{8k_1^2 - k_0^2}{16k_1^2} \leqslant 1 \tag{11}$$

in which the field is given by (figure 2)

$$E(u_d) = \frac{8k_1}{k_0} (16k_1 - 32k_1^2 - k_0^2)^{-\frac{1}{2}}. \tag{12}$$

The Ernst profile for $v = \pi/2$ is the equipotential surface in which [2]

$$\frac{8k_1^2 - k_0^2}{16k_1^2} = 1. \tag{13}$$

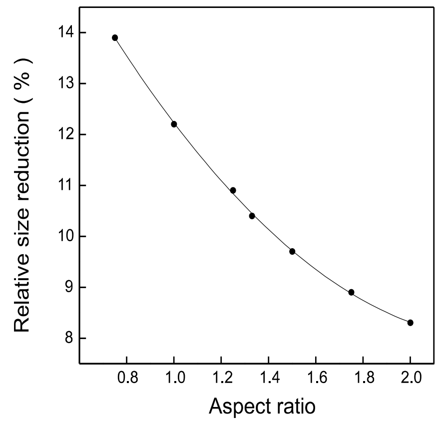

Figure 4. The percentage lateral reduction as a function of the aspect ratio, r.

In that case we only have a central maximum given by (9). For a given aspect ratio the Ernst profile is even more compact than the compacted Chang uniform-field electrode [2]. However, the Ernst profile (6) and (7) can also be compacted if we allow the relative variation of the field at these maxima to reach the tolerance value δ_m:

$$\delta_m = \frac{E(u_d) - E(0)}{E(0)} = \frac{8k_1}{k_0} \frac{1 - 2k_1}{(16k_1 - 32k_1^2 - k_0^2)^{\frac{1}{2}}} - 1 \tag{14}$$

and the profile can be laterally extended to the point $x(u_m)$ at which the field falls by δ_m with regard to $E(0)$:

$$\delta_m = \frac{E(0) - E(u_m)}{E(0)}$$
$$= 1 - \frac{1 - 2k_1}{\{[1 - 2\cosh(2u_m)]^2 + k_0^2 \sinh(u_m)^2\}^{\frac{1}{2}}}. \tag{15}$$

Insofar as the interelectrode distance $2y_0$ and the aspect ratio r are usually considered as given parameters in concrete practical applications, we have from (1), (6) and (7) that

$$u_m - k_1 \sinh(2u_m) = r \left(\frac{\pi}{2} + k_0 \right). \tag{16}$$

Equations (14)–(16) determine the values of u_m, k_0 and k_1. Those values in (6) and (7) give the compacted electrode profile. Figure 3 shows a comparison between the usual Ernst profile (with $v = \pi/2$) and our corresponding compacted profile. A considerable reduction in the transverse dimension of the profile has been produced by the compacting process. The relative reduction as a function of the aspect ratio can be seen in figure 4, in which it is shown how this relation fits an exponential decay well.

Acknowledgments

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References

[1] Chang T Y 1973 *Rev. Sci. Instrum.* **44** 405
[2] Ernst G J 1984 *Opt. Commun.* **49** 275