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Modeling the Effect of Beam Shaping at Selective Laser Melting

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The drawback of selective laser melting (SLM) is the non-uniform thermal conditions in the zone of laser treatment. In the center of the laser spot the material can be overheated, which follows possible chemical decomposition and evaporation with useless losses of mass and energy, while at the periphery of the spot the material may not attain the melting point, so that the energy is essentially lost by heat diffusion. Currently laser beams of commercial SLM machines have bell-like radial profile, which approximately corresponds to TEM_{00} mode (see Fig. 1) of the optical resonator. Such a profile is not optimal because the energy flux attains its maximum in the center of the laser spot, which is favorable for the highly non-uniform temperature distribution over the spot. Nowadays optical tools for laser beam shaping are available. They were tested for SLM [1] and some differences in the obtained microstructure of materials were reported. The objective of this study is to model thermal fields and to estimate the optimal laser profile.

The simplest mathematical formulation is a circular heat source of radius r_0 with a given energy flux distribution q over the radius r, which moves over the surface of a conductive half-space with constant velocity u (see Fig. 2). The know result of the field theory is that at $u = 0$ and

$$q = \frac{P}{2\pi r_0^2}\frac{1}{\sqrt{1-r^2/r_0^2}},, \qquad (1)$$

where P is the power of the heat source, the steady temperature over this circle is uniform and equals

$$T = \frac{P}{4\lambda r_0}, \tag{2}$$

where λ is the thermal conductivity. Distribution (1) is shown in Fig. 2 and is referred to as TFT (energy flux profile assuring a flat-top temperature distribution). Generally, if the Peclet number

$$Pe = \frac{2r_0 u}{\alpha}, \tag{3}$$

with thermal diffusivity α is much lower that unity, a laser beam with the TFT radial profile forms a nearly uniform temperature distribution over the surface of the laser spot. High-productivity SLM machines often operate at high scanning velocities u corresponding to Pe > 1. In these case the TFT profile cannot guarantee the best result. Moreover, the profile TFT is difficult to obtain because of a discontinuity at the beam boundary $r = r_0$. The donut-like distribution of the first overtone TEM_{01*} could be a reasonable compromise (see Fig. 1). The three radial profiles of TEM_{00}, TFT, and TEM_{01*} are compared below at 0 < Pe < 3.

Figure 3 presents the numerical results for the linear conductive medium at initial temperature T_a. Indeed, in the case of TFT the flat-top temperature distribution considerably deforms with increasing Pe (see the central column in Fig. 3). It is supposed that the laser processing necessitates a specified

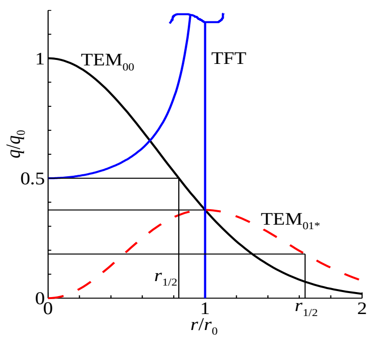

Figure 1: The testing profiles of the

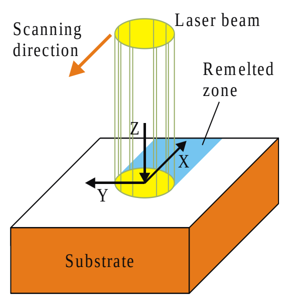

Figure 2: Interaction between the

laser beam and estimation of their radii at half-width $r_{1/2}$.

laser beam and the target and the coordinate system.

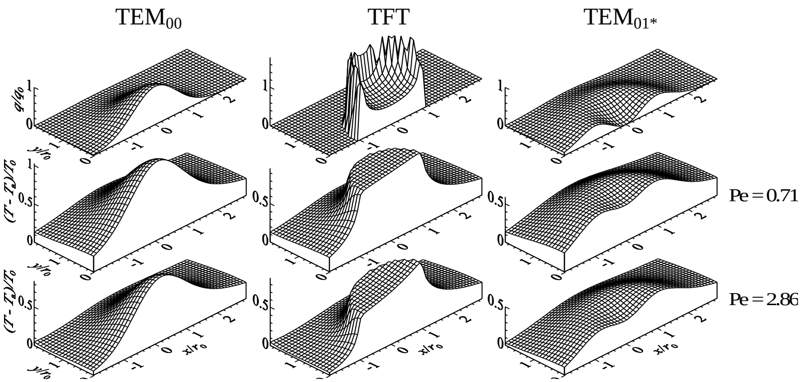

Figure 3: Normalized distributions: flux density of the absorbed laser energy q over the target surface z = 0 (top row); temperature T over the target surface (second and third rows from the top); The laser profile is marked on the top. Peclet's number Pe is marked on the right.

temperature interval [T_m, T_b], where T_m is the melting point and T_b the boiling or decomposition point. The laser-treated band is defined as the band on the surface where the temperature attains T_m at scanning. The width of this band B_γ depends on parameter

$$\gamma = \frac{T_m - T_a}{T_b - T_a}, \quad (4)$$

characterizing the relative temperature range of the treatment. Band $B_{1/2}$ approximately corresponds to SLM of such metals as Fe or Ti. Band $B_{0.9}$ corresponds to SLM of quartz glass, which requires a narrower temperature interval of treatment [2]. Figure 4 shows the band width normalized by the diameter of the laser beam at half maximum $d_{1/2} = 2r_{1/2}$ (see Fig. 1). In the considered range of the Peclet number from 0 to approximately 3, the conventional Gaussian profile of TEM_{00} is the best for the wide temperature range of treatment with γ = 1/2. Profile TFT can be significantly more advantageous for the narrow temperature range of treatment with γ =

0.9. In the latter case, profile TEM_{00} is the worst one and TEM_{01*} is intermediate.

The above results for the linear conductive medium are confirmed by numerical calculations for more realistic nonlinear media with strong evaporation from the surface according to model [2].

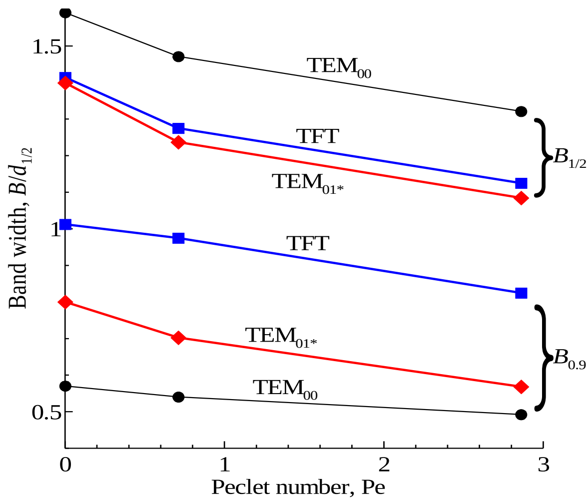

Figure 4: Widths of the treated bands $B_{1/2}$ and $B_{0.9}$ versus the Peclet number for various laser profiles.

References

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