Khristianovich Institute of Theoretical
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SB RAS

<Lab

Lab. 9. Physics of Plasma Arc and Laser Processes

The laboratory was founded in 2006 as a youth laboratory for process modeling in mechanics and laser physics. In 2008, it was transformed into the Laboratory of Physics of Plasma-Arc and Laser Processes. The main activity of the laboratory is related to the study of physical and chemical processes of the impact of highly concentrated energy flows on solid, liquid and gaseous matter in applications to laser and plasma-arc technologies. Currently, the laboratory has 17 employees, including:
2 Doctors of Science,
5 Candidates of Science.
Kovalev Oleg Borisovich
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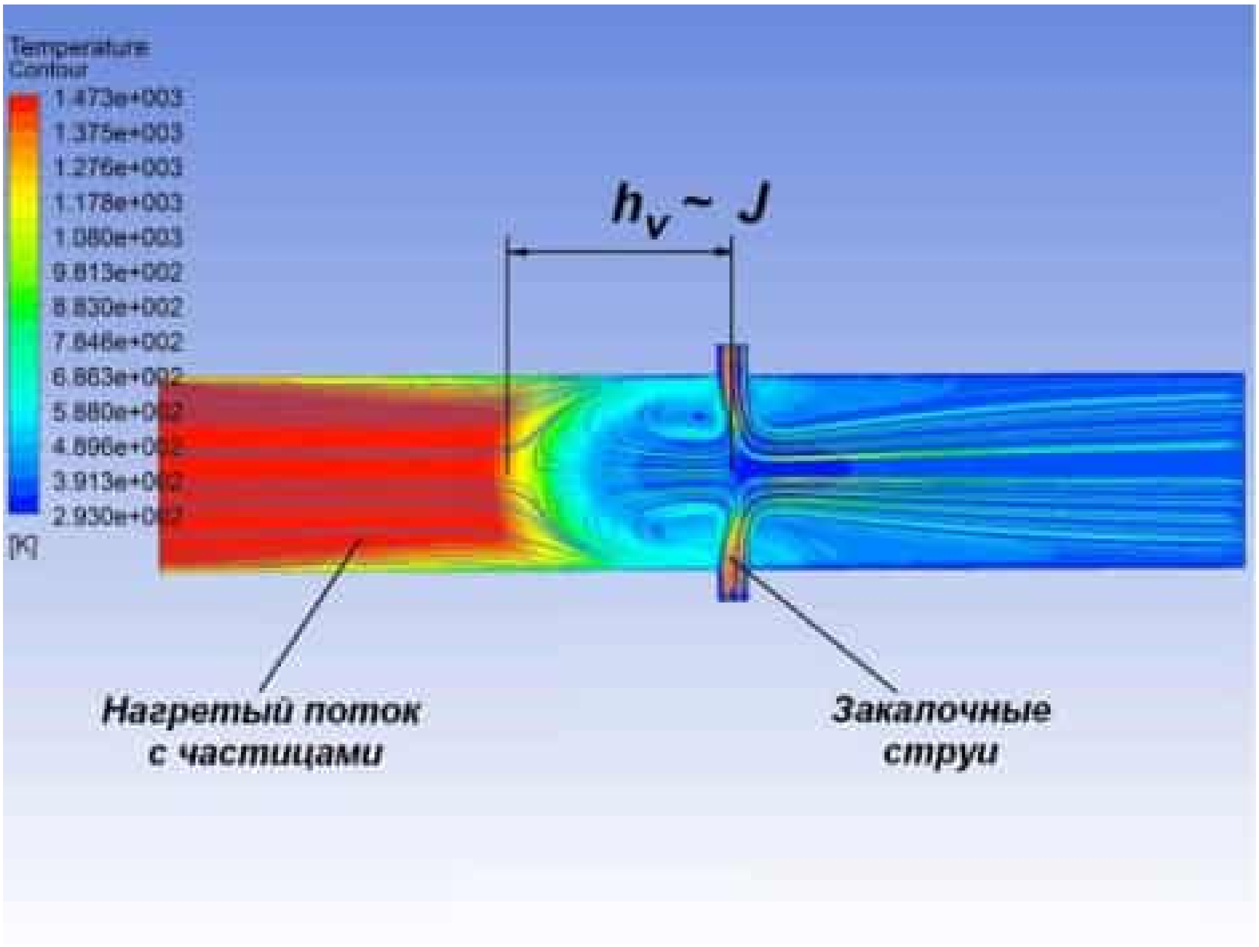
Areas of scientific research

1. Development of low-temperature plasma generators for the processing of mineral and man-made raw materials, testing of aerospace materials and the manufacture of wear-resistant, corrosion-resistant and heat-barrier coatings and products using plasma additive technologies.
2. Studies of Processes in Electric Arc Plasma-Chemical Technologies.
3. Creation of mathematical models for process optimization in laser material processing technologies:
   • Selective laser melting
   •laser cutting;
   • Laser cladding.

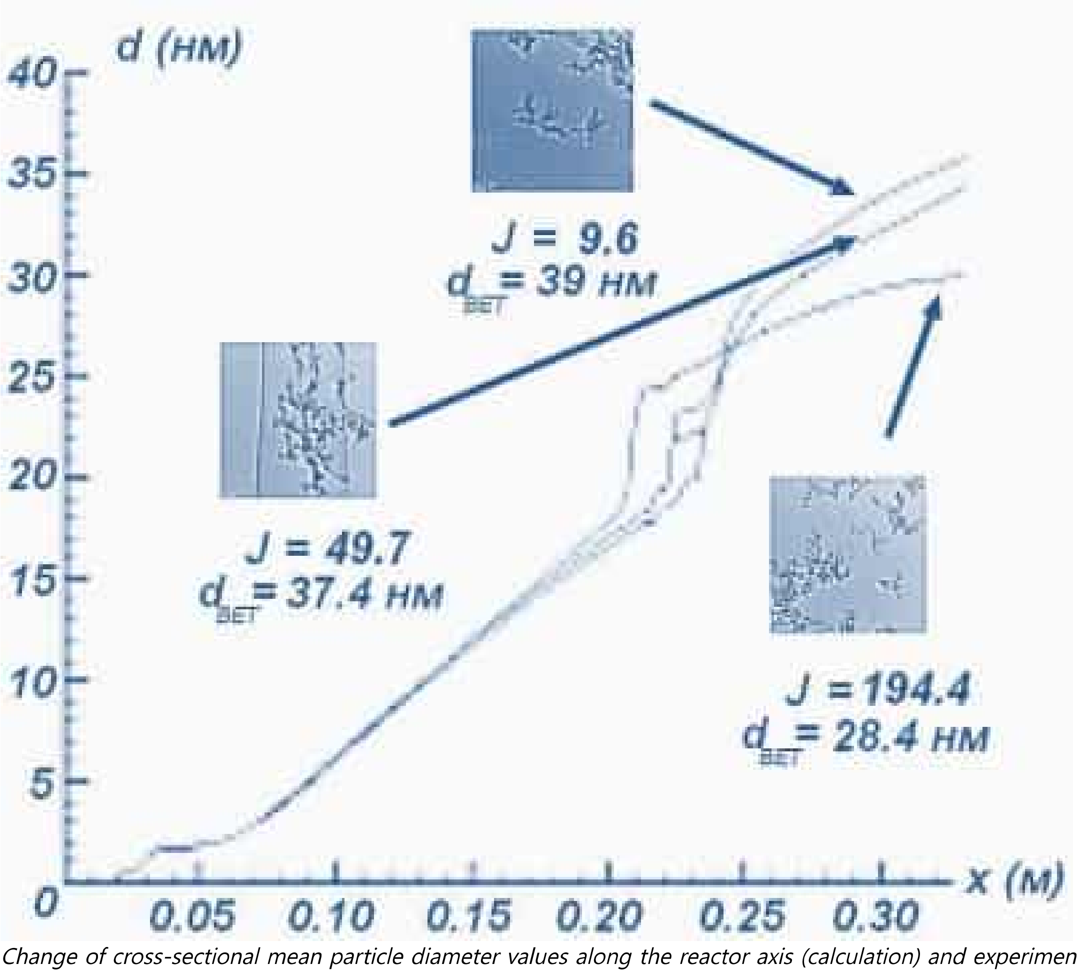
Key results

1. A method for controlling the size of nanoparticles, as well as the proportion of contaminants during the one-stage synthesis of silicon dioxide nanopowder in a plasma-chemical reactor has been developed. Variation of the depth of counter hardening, determined by the ratio of hydrodynamic heads J of the quenching jets and the heated flow with particles, makes it possible to solve this problem in many respects. With an increase in J, the characteristic particle size of silicon dioxide decreases (from 39 nm to 28 nm under experimental conditions) and the proportion of chlorine contaminating the powder decreases by a factor of three.



Temperature field in the working part of the reactor in the counter quenching mode.

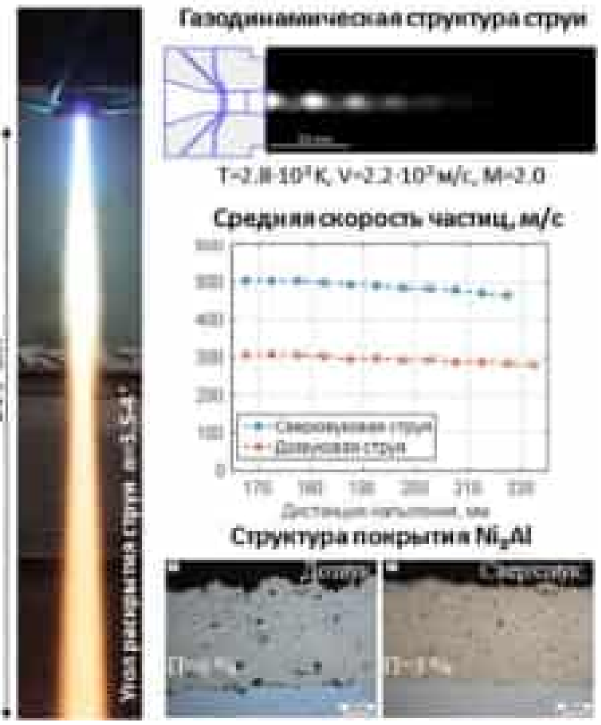
Using the obtained experimental data, the parameters of the mathematical model of synthesis were clarified when solving the inverse problem, which makes it possible to predict the size of the synthesized nanoparticles with sufficient accuracy. The figure shows the calculated change in the weighted average diameter of silicon dioxide powder nanoparticles along the reactor axis and experimental data. The obtained errors in the approximation of experimental data and the type of curves reflecting the influence of the flow rate of quenching jets allow us to conclude that the model identification level is satisfactory.



Change of cross-sectional mean particle diameter values along the reactor axis (calculation) and experimental data (particle diameter and *their appearance obtained on the basis of scanning electron microscopy).*

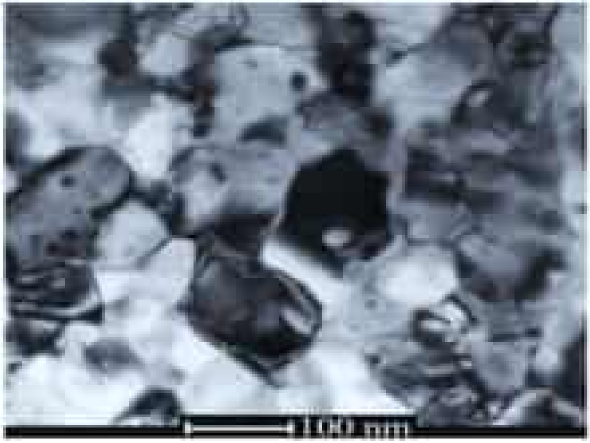
2. A supersonic plasma torch for coating deposition with new properties has been created. In comparison with subsonic spraying, the following parameters have been improved:

- increasing the velocity of particles from 200-250 to 550-600 m/s; reduction of the spray spot diameter from 18 to 10 mm;
- Improved particle velocity and temperature uniformity reduction of porosity (from 6 to 3 %, PN85Yu15);
- hardness increase (from 560 to 680 HV, H77X15C3R2-3);
- a finely dispersed microstructure of coatings was obtained;
- the possibility of implementing advanced SPS and LPPS sputtering technologies (suspensions and solutions) using a dispersed phase of 0.1–3 μm.



Supersonic plasma torch for air-plasma spraying of powder materials.

4. The structure and tribological properties of heat-resistant intermetallic nickel alloy coatings obtained by air-plasma spraying have been investigated. A submicrocrystalline structure of coatings with an average grain size of 80 nm was obtained. Wear resistance is up to 70% higher than that of 20 steel specimens after carburizing.



Submicron Structure of Nickel Alloy Coatings Obtained by Air-Plasma Spraying.

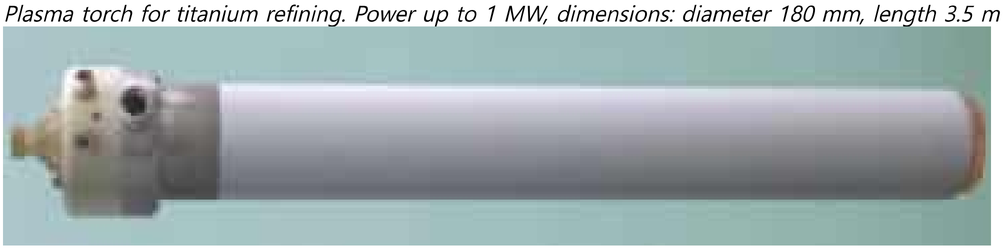
5. A pilot industrial unit for air-plasma spraying of powders "Thermoplasma 50-01" was developed. Main technological characteristics of the Thermoplasma 50-01 unit:

- • work with air at atmospheric pressure;
- high temperature of plasma streams (3000 – 12000 K), which makes it possible to apply functional coatings made of the most refractory materials;
- Wide range of sprayed particle velocities (40 – 650 m/s), which allows you to control the structure and porosity of coatings;
- coating thickness from tens of micrometers to several millimeters;
- high spraying capacity (up to 30 kg/h); A wide range of different materials: metals, alloys, ceramics.

Thermoplasma 50-01 pilot plant for air-plasma spraying of powders.

6. A series of technological plasma torches operating with remote arc and jet mode with a service life of more than 1000 hours in neutral, oxidizing and chemically active gases have been developed.

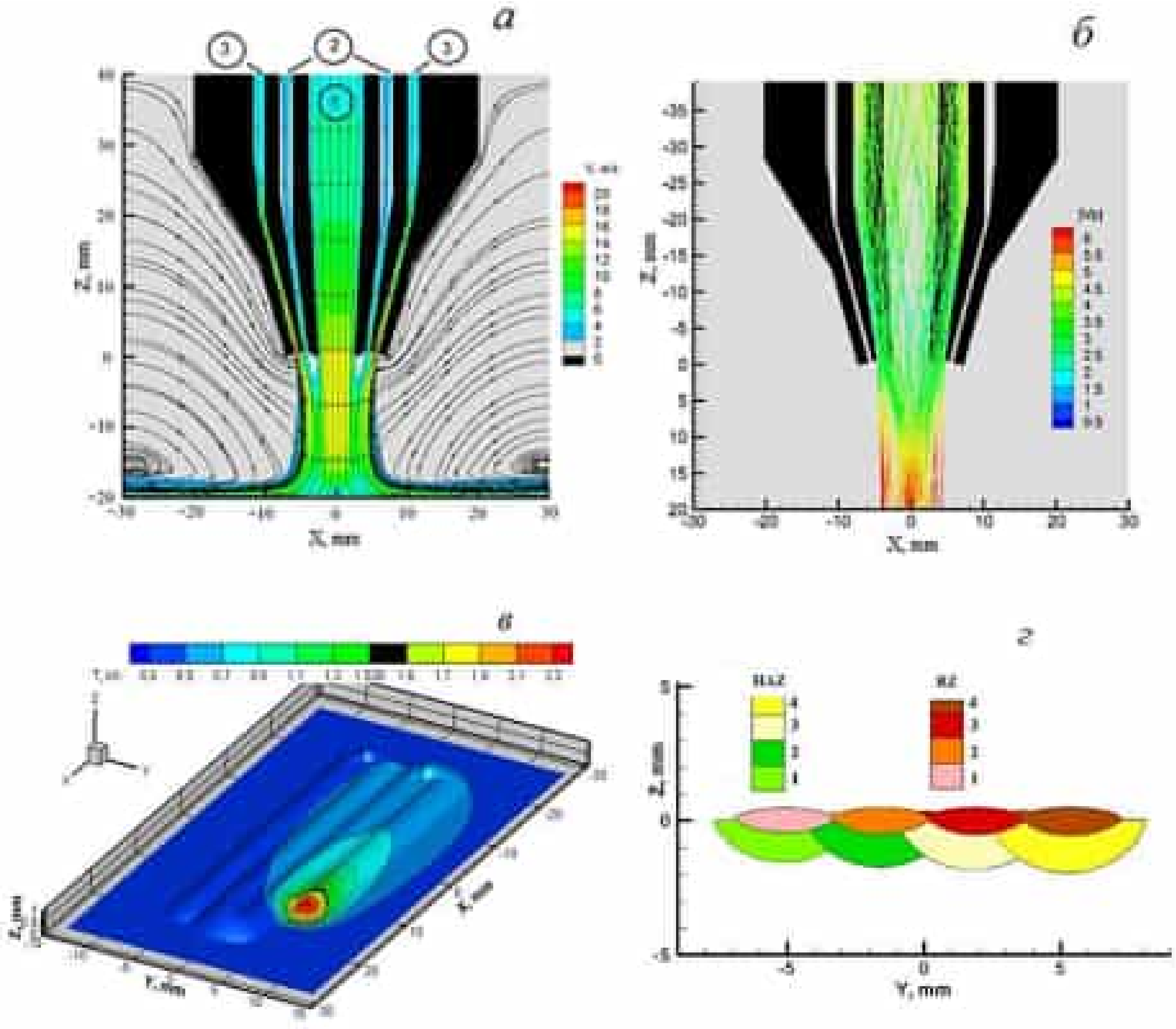
Plasma torch for titanium refining. Power up to 1 MW, dimensions: diameter 180 mm, length 3.5 m



A series of melting plasma torches with a capacity of 100 to 1000 kW for a number of industrial technologies, the plasma-forming gas is air. Diameter 108–170 mm, length 0.7–1.5 m.

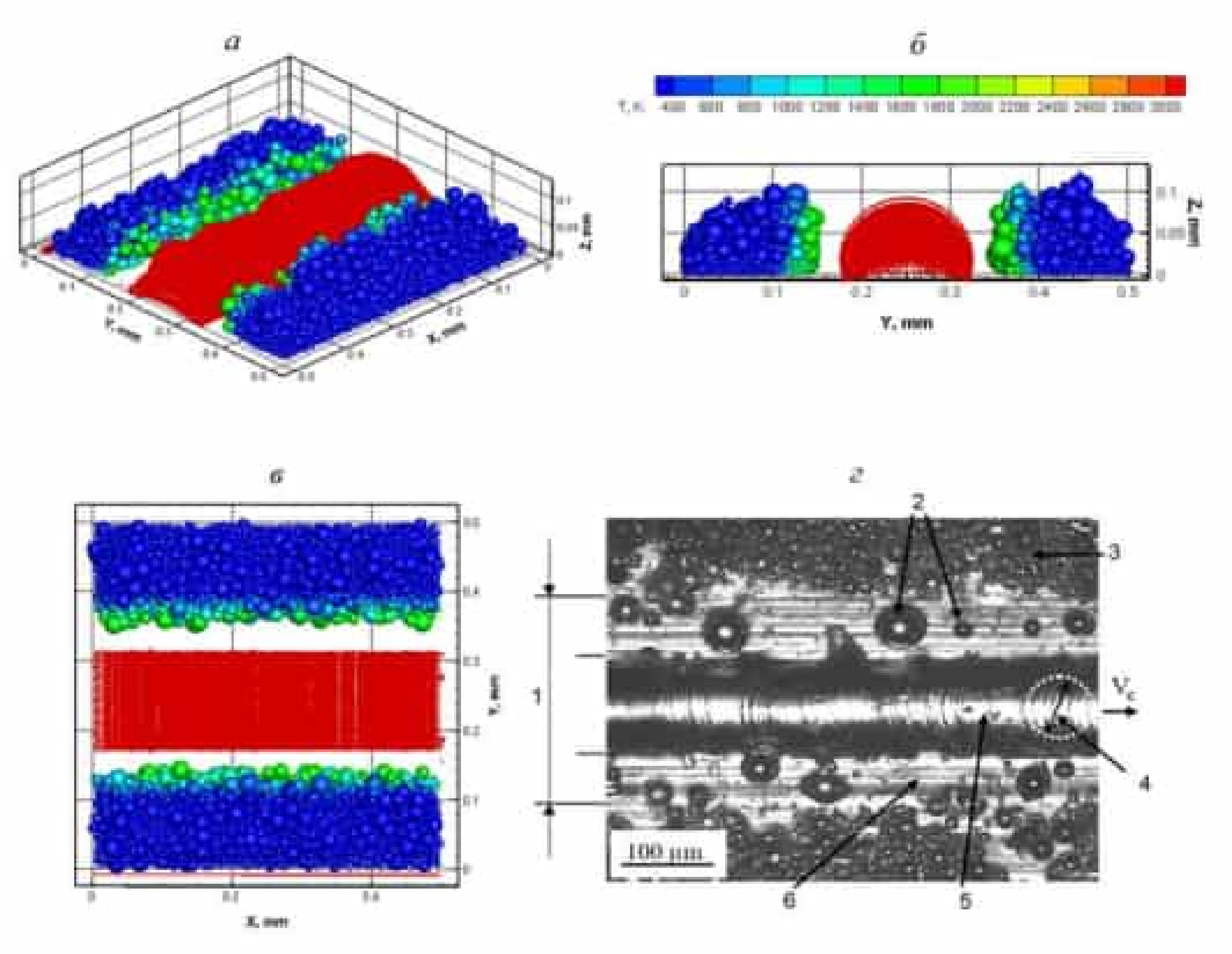
Two-jet plasma torch for heating O_2, N_2, air. Power 100 kW.

7. A methodology and software for self-consistent numerical simulation of laser cladding have been created. Optimal strategies for coating a given area have been obtained. The figure shows the results of 3D simulation of the gas dynamics of jet streams in the Trumpf DMD505 triple coaxial nozzle: the velocity field and gas flow lines, XZ projections of particle tracks and changes in their velocity along trajectories in the transport channel and external flow. The figures refer to the channels for the supply of radiation, working gases and powder: 1 – shielding gas and radiation; 2 – carrier gas and powder; 3 — compression gas. The temperature distribution on the surface during sequential laser cladding of four adjacent rollers is presented. Surfacing parameters: power W = 4 kW, powder consumption Fp = 30 g/min, scanning speed Vc = 1.0 m/min, calculation given at a time of 10 s. Heat-affected zones (HAZ, T ≥ 900 K) and remelted zones (RZ, T ≥ 1538 K) of the material are separately distinguished.



Results of numerical simulation of laser cladding.

8. Создана компьютерная методика расчета свободно насыпанных упаковок порошка. Алгоритм основан на моделировании последовательности актов случайного бросания на подложку одиночных частиц. Начальные координаты и радиусы частиц вычисляются с помощью датчика случайных чисел с учетом функции распределения по размерам и адгезии, обусловленной силами Ван-дер-Ваальса при контакте частиц. На основе полученной насыпной упаковки предложен дискретный метод трассировки лучей для описания взаимодействия лазерного излучения с зернистым слоем. Алгоритм позволяет рассчитывать процессы тепло- и массообмена в слое порошка при лазерном на него воздействии. Равномерность поглощения обеспечивается за счет эффектов многократного поглощения и отражения излучения внутри слоя. На рисунке представлен пример расчета селективного лазерного плавления и консолидации частиц в слое конечной толщины. При движении источника формируется валик. Лазерный след в слое порошка конечной толщины образует поверхность по форме близкую к полуцилиндру. Результаты моделирования согласуются с данными экспериментов И. Ядройцева (Selective Laser Melting / Ed. I. Yadroitsev. LAP Lambert Academic Publishing, 2010).



Образование валика при селективном лазерном плавлении. а, б, в – распределение температуры по частицам и профиль валика в трех проекциях; г – микрофотография, вид сверху (Selective Laser Melting / Ed. I. Yadroitsev. LAP Lambert Academic Publishing, 2010); 1 – зона агломерации и слияния частиц; 2 – слившиеся и не попавшие в валик затвердевшие капли расплава; 3 – слой порошка, не подвергнутый агломерации; 4 – диаметр лазерного пятна; 5 – лазерный след (валик); 6 – обнаженная поверхность подложки после консолидации частиц.

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