SFF Using Diode Lasers

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ABSTRACT

Rapid prototypings using direct selective laser sintering (SLS) of metal/ceramic powders have a great potential for design and fabrication of near net shape of metal/ceramic parts. At presents CO_2, Nd:YAG and Excimer are the only possible solutions for the heavy duty manufacturing applications. At the University of Connecticut, researchers advanced the concept of rapid prototyping and other desk top manufacturing tasks such as welding, sintering, drilling, marking, soldering of electronic components, face hardening of metal and other materials applications by the use of high power diode lasers.

Utilizing SLS techniques and approaches designed to harness the full potential of diode lasers, computer controlled sintering system was developed. The system is capable of producing complex three dimensional shapes of metal/ceramic parts from CAD/CAM solid model data files. In the paper direct sintered Fe-Bronze parts using high power laser diodes has been demonstrated. The system comprises of high power laser diodes (25 W cw, λ=980 nm and 60 W pulse or cw, λ=810 nm), beam scanning systems, atmospheric controlled chamber, and CAD/CAM software.

INTRODUCTION

Recent advance of diode laser technology makes possible of desk-top manufacturing of metal/ceramic parts directly from a computer model without part-specific tooling or intervention. These technologies have been termed Solid Freeform Fabrication[(1)] and differ dramatically from normal fabrication techniques due to their additive nature. Normal machining operations fabricate a part by removing a material until the remaining desired component specific material is left. Additive processes, however, build up the desired part by selectively sintering of powders' layer by layer. The benefit of this technology is greatly reduced fabrication time and cost and capability to achieve, in one operation, shapes that would otherwise require multiple operations or in some cases, be impossible to manufacture with current standard techniques.

For the last two years, we have been working on Solid Freeform Fabrication (SFF) desk-top manufacturing techniques. This technique is adopted from the Selective Laser Sintering (SLS) process. At the University of Connecticut desk-top manufacturing SLS test bed uses diode laser to selectively sinter metal/ceramic powders without any polymeric binder.

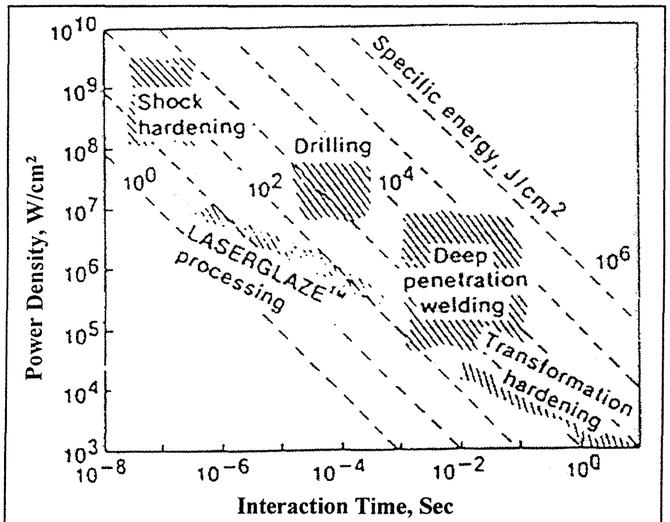

Fig. 1 Beam-material interaction spectrum[2]. A large number of commercial processes of surface material processing can be carried out at cw intensity levels from 1 kW/cm² to 1 MW/cm².

Many of the industrial desktop manufacturing applications require directed laser beam energy that has high total power and brightness. In many situations, it is also important to deliver an extremely small spot of concentrated laser energy to a tiny area. Figure 1 shows a variety of laser-processing tasks that can be performed with intensities in the range of 10^3 to 10^8 W/cm^2. Focused diode lasers, despite relatively low output power per stripe (~1W), emit 10^6 to 10^7 W/cm^2, a range suitable for many laser manufacturing jobs. The engineering difficulty is to collect 100 to 1000 watts from numerous diodes and deliver the power within a small spot with high brightness. Photonics Research center (PRC) at the University of Connecticut is in the process of acquiring high brightness laser diode systems that can deliver CW power exceeding 1 kW with power density reaching 100 kW/cm^2 in a spot not exceeding 600 micrometers [(3)].

Noted for their small size, greater than 40 percent electrical-to-optical plug in efficiency, ease of modulation and low power requirements (about 300 watts), diode lasers are an ideal source of direct thermal energy for a multitude of industrial tasks. Moreover, they are much less expensive than competing lasers and interface easily with computers and robotic arms. Since diode lasers have tremendous mass production capabilities their price per watt is expected to drop steadily as high-volume applications continue to open up. At moderate volumes, the current market price for non-fiber-coupled diodes has dropped to about $30 per delivered watt of raw diode energy as compared to $150 per watts CO_2 or Nd:YAG lasers.

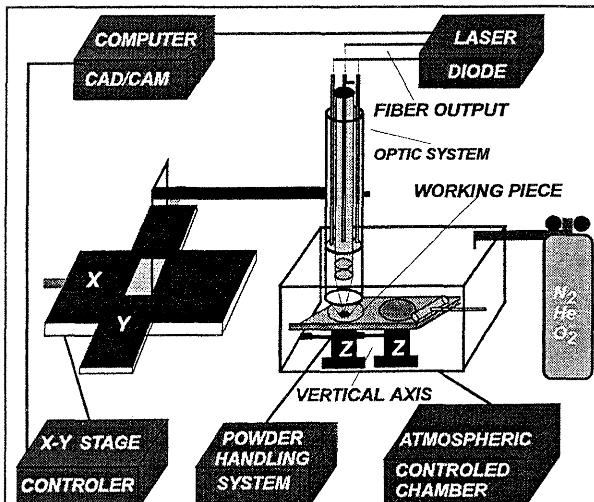

Fig.2 Schematic diagram of an experimental set-up of a sintering system and sketch of the powder feeding system.

EXPERIMENTAL SETUP

To demonstrate the use of diode lasers for sintering-based SFF, an experimental apparatus was constructed (Fig. 2). The system consists of a fiber-coupled diode laser array, optical delivery system, powder feeding system, oxidation prevention system and laser scan control system[4]. In this setup, the SFF device generates three-dimensional parts from CAD/CAM data files by selectively bonding multiple layers of powder using high-power diode lasers. PRC has three high power CW laser diode systems in use from three different companies: 1) 60 W @ 810 nm, 2) 25W @ 980 nm and 3) 50 W @ 808 nm. These systems can deliver intensity up to $10 kW/cm^2$.

MATERIALS

For sintering, the materials used in the present study were Fe-Bronze (Cu-Sn) premixed powder, grade 661($Fe_{34\sim36}Cu_{58\sim60}Sn_{6\sim7}$). Particle size was 100 to 200 μm. The alloy was supplied by Pyron Metal Powders Inc., from Maryville, Tennessee.

RESULTS

Some examples of elementary (SSF) sintered parts with multiple sintered layers made from Fe-Bronze premix powders are shown in Fig. 3. Other sintering examples include a sintered strain gauge also made from Fe-Bronze premix powder (Fig. 3d). To suit the requirements of researchers for these particular sintering experiments, the delivery end of the diode laser's

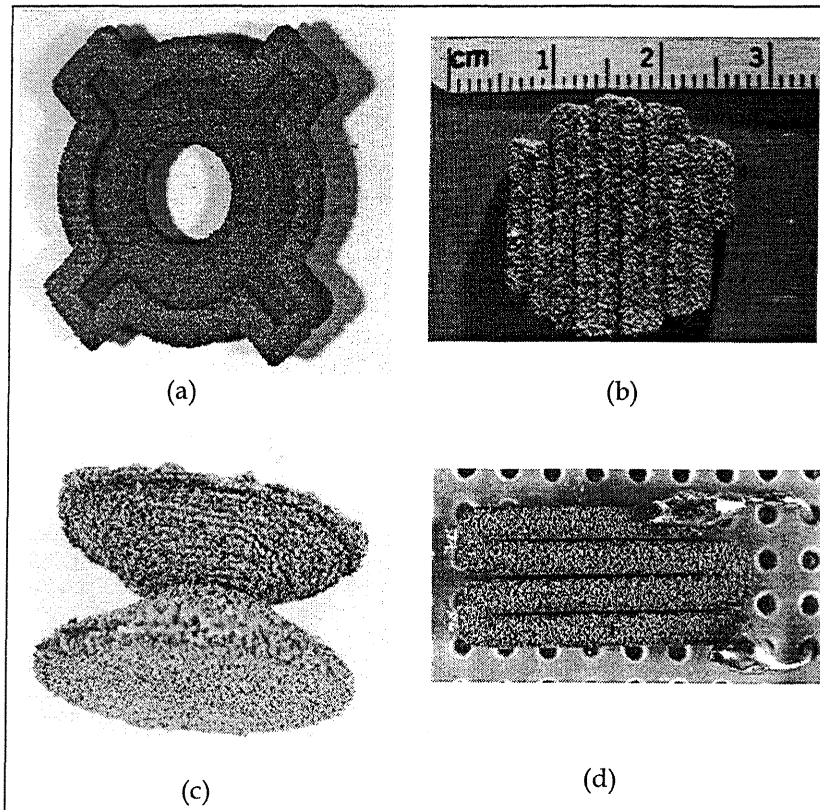

Fig. 3 (a-c)The sintered samples made from iron-bronze premix powder in an argon atmosphere.
Fig. 3 (a, b) The sintering laser spot size was 0.8 mm carrying, 15 W cw power at a 2mm/sec & 1 mm/sec scanning speed. The layered fan shape disk has 8 layers, each layer being 0.5 mm thick., (c) 14 W cw power at 1 mm/sec scanning speed. The layered conical shape has 36 layers, each layer being 0.5 mm thick.
Fig. 3 (d) Our first attempt to fabricate a strain-gauge by SFF techniques from iron-bronze premix powder. The sintering laser spot size was 0.8 mm carrying a power of 14 W cw, scanning at a speed of 0.8 mm/sec. The sintering was done in a flowing Ar-gas. The sample has 6 layers, each layer being 0.5 mm thick. Length and width of the sintered folded sample is 16 mm and 8.3 mm respectively. The grove size is around 100 μm.

optical fiber was attached to an OPC re-imaging unit from "Opto Power Inc.". This unit can produce a spot size of 0.8 mm (<0.37 N. A.) on the sintering bed from 2.16 mm (0.11 N. A.) fiber bundle. Using the re-imaging unit, researchers were able to achieve transmission efficiency in excess of 90 percent.

LASER PROCESSING PARAMETERS (Table 1):

Sample	Power	Scan-Speed	# of Layers	Energy density
Fig. 3.a	15 W	2 mm/sec	8	14.92 kJ/cm^3
Fig. 3. b	15 W	1 mm/sec	10	29.84 kJ/cm^3
Fig. 3 c	14 W	1 mm/sec	36	27.85 kJ/cm^3
Fig. 3. d	14 W	0.8 mm/sec	6	34.82 kJ/cm^3
Fig 4 c	12 W	2 mm/sec	4	11.94 kJ/cm^3
Fig. 4 d	14 W	1 mm/sec	4	27.85 kJ/cm^3
Fig 5, #1	12 W	2 mm/sec	4	11.94 kJ/cm^3
Fig 5, #2	16 W	2 mm/sec	4	15.92 kJ/cm^3
Fig.5, # 3	10 W	1 mm/sec	4	19.89 kJ/cm^3
Fig. 5, #4	12 W	1 mm/sec	4	23.87 kJ/cm^3
Fig. 5, #5	14 W	1 mm/sec	4	27.85 kJ/cm^3
Fig. 5, #6	16 W	1 mm/sec	4	31.83 kJ/cm^3

- Energy density = Power/(Spot size x Scan speed) = P_D/Scan speed
- P_D = Power density
- Laser wavelength: 980 nm
- Laser spot diameter: 0.8 mm
- Layer thickness: 0.5 mm
- Powder bed temperature varies between $80^O \sim 100^O C$

DENSITY of a SLS Parts:

The sintered SLS parts density is around 50% of the theoretical density with about 50% open porosity. Cu_{75}-Pb_{25} samples prepared by SLS techniques have higher density (70% of theoretical) compared to Fe-Bronze sample.

CURLING of a SLS Parts:

In this research we have also observed the curling and bending of the sintered parts. In our research we have observed that fast scanning speed and high power reduces the curling. To investigate it further we fabricate different samples on different substrates (Brass screen, Cu strip, iron strip and on powder). Our finding is that using powder bed substantially reduces the curling. Powder beds trapped the laser radiation and increase the temperature of the bed, which is essentially reducing curling.

Microstructure and Microhardness:

Mechanical properties of SLS process sintered parts depend mostly on the amount of energy that goes into the surface during SFF processeing. The amount of energy density during laser sintering for the powder depends on the absolute power at the spot and the scan speed of the laser beam. To study the effects of energy density of the sintered parts, different samples were prepared from Fe-bronze powder at varying power and scan speeds. Table 1 shows the lists of samples prepared at different processing parameters. Figure 5 shows that as the energy density increases the microhardness of the sample decreases. Increase of energy density on the powder bed increases temperature and decreases the cooling rate. This causes grain growth. Figure 4 (c, d) show the evidence of grain growth due to an increase of energy density. Due to the grain growth of the sintered Fe-Bronze samples the microhardness decreases (Fig. 5).

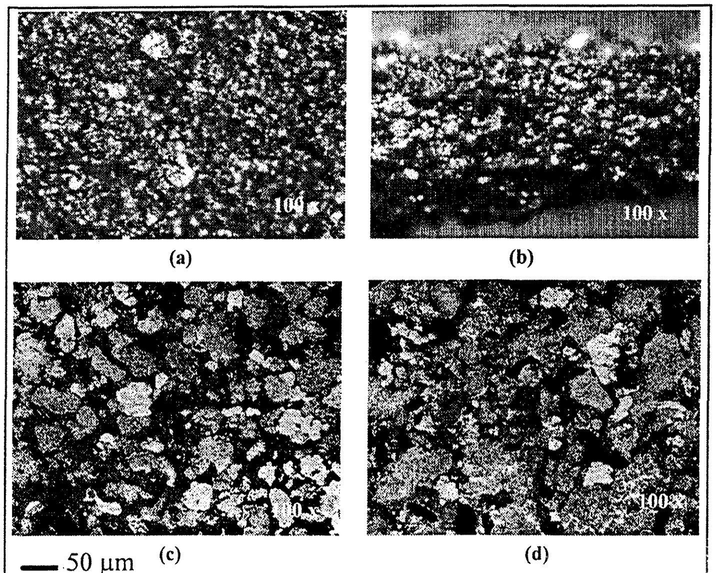

Fig. 4 (a) Top free surface of sintered Fe-bronze powder, (b) Is the cross-section of the sample. Fig. 4 (c, d) is the microstructure of the samples at two different powers and scanning speeds. (c) Energy density = 11.94 kJ/cm^3 and (d) energy density = 27.85 kJ/cm^3 has been used.

MARKING

Presently, ink-jet or bubble technologies are the leading methods for marking consumer products. However, due to the high consumable cost of the inks and solvents used in these processes along with the associated environmental concerns, laser techniques are making rapid inroads as viable alternatives. Semiconductor diode laser arrays operating in

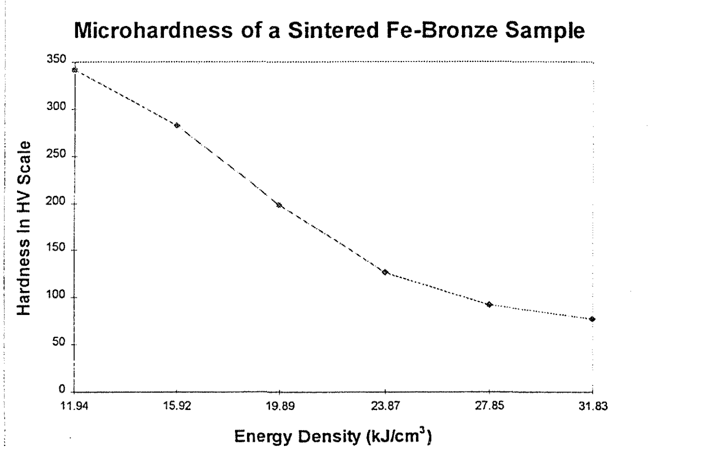

Fig. 5 As energy density increases the microhardness of the sintered Fe-Bronze sample decreases, making the sample softer.

the 10 to 200 watt output range have tremendous promise in this market. Utilizing Opto Power's OPC-B060-812-FC, laser diode, the University of Connecticut research team has shown that it can mark black plastic with a 2D-array of fiber bundles coupled to high power diodes (Fig. 6). This is now being pursued for the SFF diode laser proximity

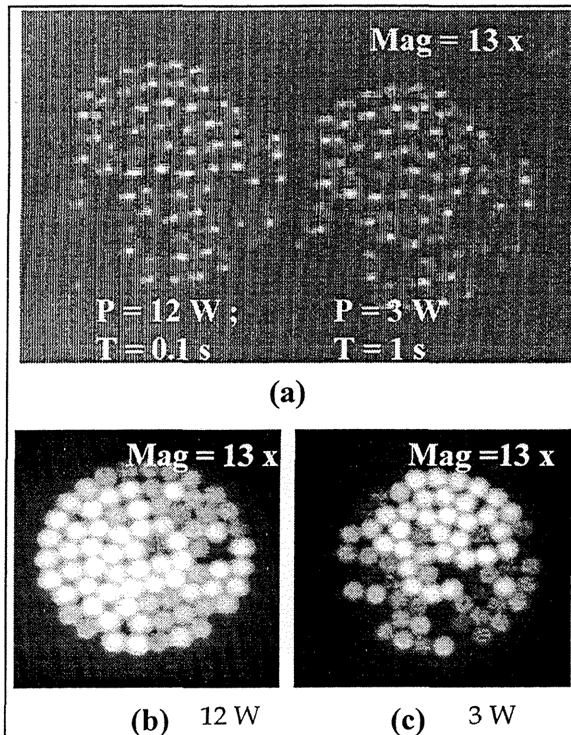

Fig.6 Experimental demonstration of 2D-array marking by a flexible 2D-array of fibers. The sample is a black plastic(Acrylonitrile-Butadiene-styrene Resins). The average power density at each spot was about 200 W/cm^2 and the exposure time was 100 ms. White dots are the engraving on the black plastic.

CONCLUSION

The sintering results are just a part of a continuing effort to determine the performance parameters of high-power semiconductor diode lasers and their effectiveness in desktop manufacturing of small objects. In addition to sintering, the scope of this work includes marking, engraving, cutting, drilling, soldering and wire stripping. Of these applications, individually addressable 2D of array sintering has been given the most attention to date. Specifically the UConn research team is exploring the feasibility of this new idea with initial implementation in the area of marking or engraving.

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