Recent advances in laser technology have created new opportunities for the application of lasers in materials processing. High power fiber and disk lasers are being integrated into highly automated manufacturing systems that drill, cut, and weld at unprecedented accuracy and speed. Direct and fiber-delivered diode lasers provide high speed, high-deposition-rate cladding and repair work. Ultrafast lasers fabricate products ranging from solar cells to bone implants. They now enable commercial applications requiring superior processing speeds for small, precise features.

**Fiber and Disk Lasers**

Dramatic advances in hole drilling, cutting, and welding have resulted from the development of high-power fiber-delivered lasers. Fiber-optic delivery greatly simplifies the integration of these lasers into work cells, and significantly improves the stability of the beam during transmission.

Fiber-delivered lasers include ytterbium fiber lasers (1070 nm wavelength) and diode-pumped Nd:YAG disk lasers (1060 nm wavelength). Ytterbium fiber lasers are available with output powers up to 30 kW. The current cost of these lasers is approximately $60 K per kW. Remote switching or multiplexing of the fiber delivery system enables operation of several work cells. Combined with high wall plug efficiency (defined as the ratio of beam output power to electrical input power), this arrangement provides attractive business-case justification in many installations.

The disk laser has similar attributes to the ytterbium fiber laser, but is somewhat larger. The current output of the disk laser is 12 kW, but this is likely to increase in the near future.

The ytterbium fiber laser and the disk laser are applicable to a variety of processes. In hole drilling and cutting applications, high material removal rates, ease of automation, and the possibility of switching a single laser source between multiple work cells are attractive features that will drive their adoption in manufacturing.

**Hybrid Laser Arc Welding**

A noteworthy development, pioneered in Europe, combines the laser beam with gas metal arc welding to produce a hybrid process. The advantages of hybrid laser arc welding with ytterbium fiber and slab lasers include high processing speeds and penetration associated with laser beam welding, while allowing the accommodation of joint gaps and efficient filler addition through the gas metal arc welding process.

The photo shows a robotic welding system utilizing a 7 kW ytterbium fiber laser for hybrid laser arc welding of carbon steel pipe having wall thickness up to 12.7 mm (0.5 in) and diameters up to 76 mm (3 in). This system, funded by the Center for Naval Shipbuilding Technology (CNST) and developed through a collaboration of ARL-Penn State University, National Steel and Shipbuilding Company (NASSCO), and...
Recent advances in laser technology enable wide ranging applications in materials processing.

Wolf Robotics, was the first application of hybrid laser arc welding in a U.S. shipyard.

Direct and Fiber-Delivered Lasers

Exciting advances in heat treating and cladding have resulted from the development of high power direct and fiber-delivered diode lasers. These lasers are efficient to operate and are roughly comparable in dollars per kW cost to the ytterbium fiber and Nd:YAG disk lasers. They operate in the 800 – 900 nm wavelength range.

Heat treating applications include bearing surfaces, drive train components, valve seats, and seal surfaces. Advantages include high processing speed (three times faster than induction hardening), low or negligible distortion, and adaptability to a variety of geometries.

In cladding, they have a high material capture efficiency, resulting in less wasted material and hence lower cost. Direct diode lasers focus to a line heat source, providing large area cladding with minimal scanning. Optics are available to convert to line sources all fiber delivered lasers, direct diode, ytterbium fiber, and Nd:YAG disk lasers.

Ultrafast Lasers

Ultrafast lasers are capable of generating light pulses in the picosecond or femtosecond ranges. In such lasers, all the energy in a pulse is contained within an extremely short period, causing high electrical field intensities and very high peak powers.

Ultrafast lasers in micromachining have been expanding exponentially due to their flexibility, speed, and precision. Picosecond and femtosecond lasers are now widely used for applications where conventional solid-state lasers cannot be appropriately applied, such as micro scale surface texturing, cladding, and selective material removal.

These novel processing methods are being utilized to manufacture everything from energy-production devices to state-of-the-art electronics.

Solar Cells

As interest in photovoltaics has matured, many ultrafast laser techniques have been developed to overcome the obstacles inherent in higher solar cell production. Challenges such as improved efficiency and high throughput have been met by realizing the potential of ultrafast lasers for surface modification and high-speed manufacturing. It has been shown that solar cell efficiency can be improved via optimal surface structuring and doping mechanisms. However, the nontraditional materials in these cells require that novel processing methods be developed. Ultrafast lasers provide a fast, precise, noncontact method that can properly texture silicon or foil surfaces for improved light trapping.

Thin film solar cells provide monetary savings over their rigid counterparts due to the lower cost substrates and production equipment, as well as the higher throughput. However, a major bottleneck in high-volume thin film solar cell production has been the monolithic series interconnection. Although no standard procedure has been developed for this process, laser scribing has been preferred due to its fast, local, noncontact, and precise removal of material. Currently a large number of research efforts are underway to further improve the process by developing a depth-selective, debris-free, high-rate method for thin film removal.

Biomedical Applications

Ultrafast lasers have also been exploited by the biomaterials community for microstructuring, nanoparticle formation, and other applications. The goal of many of these techniques is to influence the interaction between biological cells and artificial surfaces. This is a major hurdle that needs to be addressed to increase the lifetime of implants and enable more biosensors and artificial tissues. The ability to adapt lasers to vastly different materials is highly beneficial for biomedical research, where dissimilar materials such as titanium and polyethylene are often combined.

Surface modification is necessary in a large number of biomedical applications, and is highly successful when microtexturing is done with ultrafast lasers. For example, microtexturing of metallic or ceramic substrates for bone implants significantly improves biocompatibility. Now methods are emerging to expand these techniques to polymer and composite surfaces for artificial tissues.

Another emerging technology is microcladding (by computer-controlled powder deposition techniques) for calcium phosphate implants. Because of their osseo-integration properties, these implants can replace diseased or damaged bone, and repair bone defects. Fabrication of patient-tailored bioactive implants has remained difficult because of the delicate nature of the material, but microcladding may remove this barrier to production.

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