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ABLATIVE MATERIAL REMOVAL UTILIZING THE COPPER VAPOR LASER

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Since its invention in the late 1960s, the copper vapor laser has been developed predominantly for laser isotope separation.¹ In this application the laser is valued because of its visible wavelength, 50 ns pulses, multi-kilohertz repetition rate, and 1 - 2% electrical to optical efficiency. As this laser system has matured into an industrial tool, new material processing applications for the laser have developed. When applied to materials processing, the visible wavelength is found to couple well to most materials, the short pulse length causes ablative material removal, and the high repetition rate increases the material removal rate to a moderate level. A further advantage of the laser is near diffraction-limited operation at hundreds of watts average power, allowing precise spatial control.

Over the past couple of years LLNL has investigated both a one-dimensional model and experimental measurements of copper laser beam/material interactions. The model involves a one-dimensional description of heat transport below a surface, hydrodynamic expansion of the vapor and compressed air, and light propagation through the vapor to the vaporization surface.^{2,3} Laser light strikes the surface, causing a melt layer to develop and propagate inward into the solid material. When the vaporization temperature is reached, the vapor begins to blow off, preceded by a plug of compressed air. This is bounded by a shock front. When the temperature becomes sufficiently high, both the incident beam and the reflected beam (to the extent that it is appreciable) can be absorbed in the vapor by photoionization and inverse bremsstrahlung. Figure 1a displays modeled bulk temperatures versus time. Figure 1b displays a Schlieren image at $t = 50$ ns indicating a laser produced spherical vapor expansion with a laser detonation front.

Laser drilling has been widely used in industry because of its high production rate, ability to rapidly vary hole size, ability to drill holes at shallow angles, and ability to drill traditionally hard to work materials such as ceramics and composite materials. We have extended this utility to sub-millimeter dimensions by use of a near diffraction-limited copper laser and precision wave front tilting technology. In our investigation, laser trepanning is achieved by tilting the X-Y scanning mirror sinusoidally such that the laser spot generates a circular pattern on the work piece. Trepanned holes down to 50 microns in diameter have been drilled this way.

Figure 2a illustrates three CVL trepanned holes with 185 micron diameter in 1 mm stainless steel. Measurements indicate that both the entrance and exit hole have a roundness error of about 5 microns caused by various mechanisms. The nature of the laser/material interaction, discussed above, leads to ablative material removal from these deep holes with negligible heat affected zones, less than 1 micron in most cases. Copper laser trepanning represents a great potential in laser precision micro-drilling. Non-circular holes have been drilled by simply changing the laser scanning pattern. The hole quality drilled by this laser micro-machining system is found to be comparable or better than holes drilled by electric discharge machining (EDM). With the flexibility in hole geometry and size, and scalability to higher speed, this micro-machining system offers a superior technique to EDM machines which currently are widely used in industry.

The same virtues that make the copper laser a good drilling source also make it a good source for pulsed laser deposition (PLD). LLNL has utilized 100 — 200 W copper lasers to vaporize carbon from a graphite target, producing diamond-like-carbon (DLC) thin films. Since the pulse repetition rate of the laser is several kilohertz, we can deposit films at 10 — 50 times other reported PLD rates. Figure 2b displays the spatial distribution of the DLC after 10^5 laser shots (23 seconds). The properties of these films indicate high value for electronics, chemical resistance, and tribological applications. In addition to carbon, there are many high-value thin film materials that may provide a significant market for copper laser technology.

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Figures 1. (a) Temperature profiles of the stainless steel material. Note z is the dimension into the surface. (b) Shadow image of a copper laser produced vapor plume from an aluminum target at a laser intensity of 7.3×10^9 W/cm².

Figures 2. (a) Precision laser trepanned holes with hole diameter of ~ 200 microns. (b) DLC Spatial distribution after 10^5 shots.

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