ERIF Final Report

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Project: Laser-Assisted Nanomachining (LAN) and Laser Tip Sharpening (LTS) for AFM-Based Mechanical Nanofabrication
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1. Accomplishment Summary

The following is a brief summary of the accomplishment relevant to the project:

(1) On the modeling side, by solving Maxwell's wave equation, the laser interaction with AFM tips/workpiece has been simulated, and the results support the feasibility of LAN.

(2) A nanosecond laser processing system has been setup, and the experimental work has shown the system can deliver the light accurately and rapidly, and can realize material heating and machining. This shows we have built up the necessary equipment for LAN.

By combining (1) and (2), it seems to us that the generated preliminary results are sufficient to write proposals to get external funding. Opportunities from NSF, DARPA, ARO, and AFOSR, etc., will be checked.

2. Mathematical Modeling

A model has been developed to provide a tool for the study of laser-assisted nanomachining (LAN) and laser tip sharpening (LTS) for AFM-based mechanical nanofabrication. This model is based on the numerical solution of Maxwell's wave equation and heat transfer equation to describe laser-tip-target interaction, in terms of both the laser energy deposition and the resulted temperature increase.

The Maxwell's wave equation, governing the propagation of laser beam is given by:

$$\nabla \times (\nabla \times E) + \frac{1}{c^2}\frac{\partial^2 E}{\partial t^2} = -\mu_0 \frac{\partial^2 P}{\partial t^2} - \mu_0 \frac{\partial J}{\partial t} \quad (1)$$

where ***E*** is the electric field associated with the laser beam, ***P*** is the polarization of the medium, ***J*** is the electric current density, c is the speed of light in vacuum, t is time, and μ_0 is the permeability of the vacuum. Laser radiation flux can be calculated based on the electric field.

This equation provides a general description of laser propagation in nonmagnetic media. The two terms on the right side of Eq. (1) are generally called source terms, which determine how a medium affects the electromagnetic wave that propagates in it. Different media mainly differ in that the equations that relate ***P*** with ***E*** and ***J*** with ***E***, and the relevant material property variables are different. For non-conducting materials, the electric current density ***J*** is typically negligible.

Generally, for isotropic media the direction of ***P*** coincides with that of ***E***, and their magnitudes are related by the following equation:

$$P = \varepsilon_0(\chi E + \chi^{(2)}E^2 + \chi^{(3)}E^3 + ...) \quad (2)$$

where E and P are the magnitudes of electric field and polarization, ε_0 is the permittivity of the vacuum, χ is the linear susceptibility, and $\chi^{(2)}$, $\chi^{(3)}$ and so forth are nonlinear coefficients. The linear susceptibility is generally much larger than the nonlinear coefficients, and the latter are important only when the laser intensity is extremely high.

Figures 1 and 2 have shown some results of the model calculation. Figure 1 shows the model-predicted electric field distribution associated with the laser beam, and Figure 2 shows the temperature increase due to the laser energy deposition. The modeling results support the feasibility of LAN: the small region of the workpiece under the AFM tip can be heated for lower hardness and lower resistance for machining, while the tip itself is not significantly heated and hence not damaged.

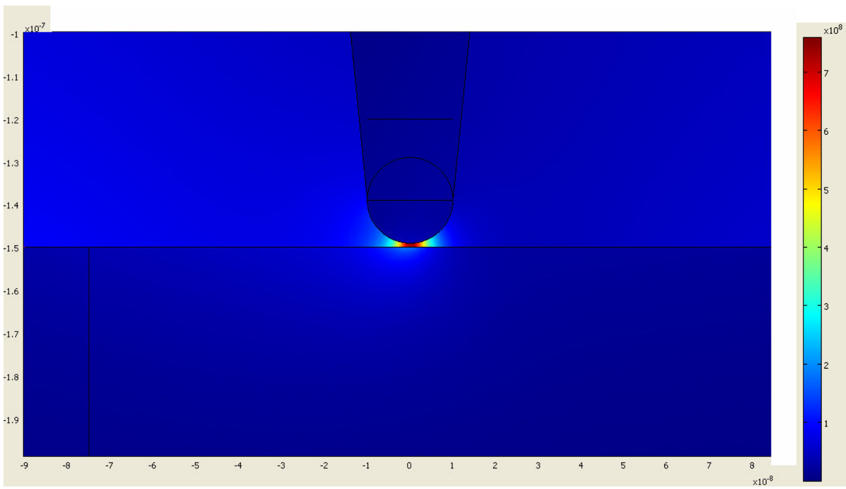


Figure 1. Model-predicted electric field (V/m) distribution for AFM tip and workpiece target under laser beam irradiation (length is in the unit of meter).

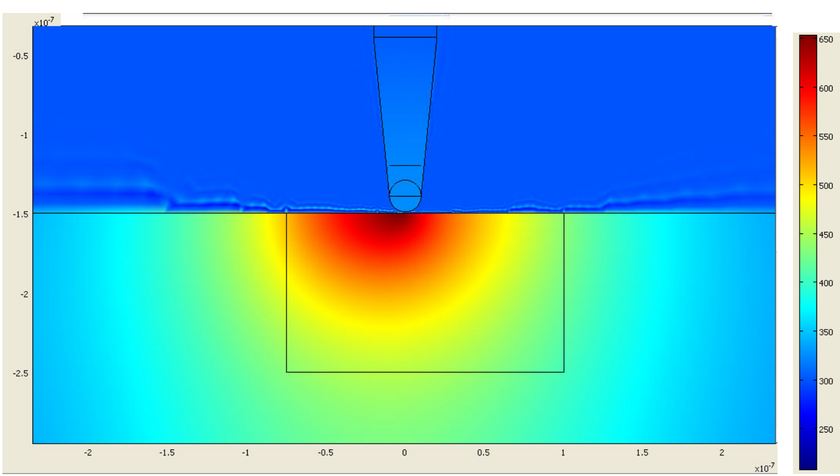


Figure 2. Model-predicted temperature field (K) for AFM tip and workpiece target under laser beam irradiation (length is in the unit of meter).

3. Experimental Work

Figure 3 shows the schematic of the nanosecond laser processing system, and the experimental work has shown the system can deliver the light accurately and rapidly, and can realize material heating and machining. Figure 4 shows some sample processing results from the system. This shows we have built up the necessary equipment for LAN.

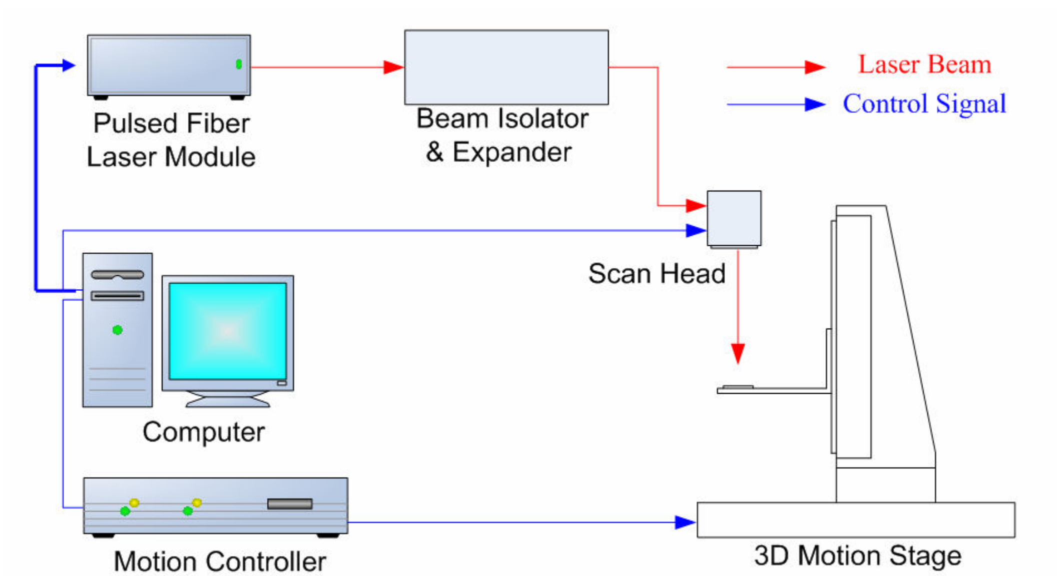
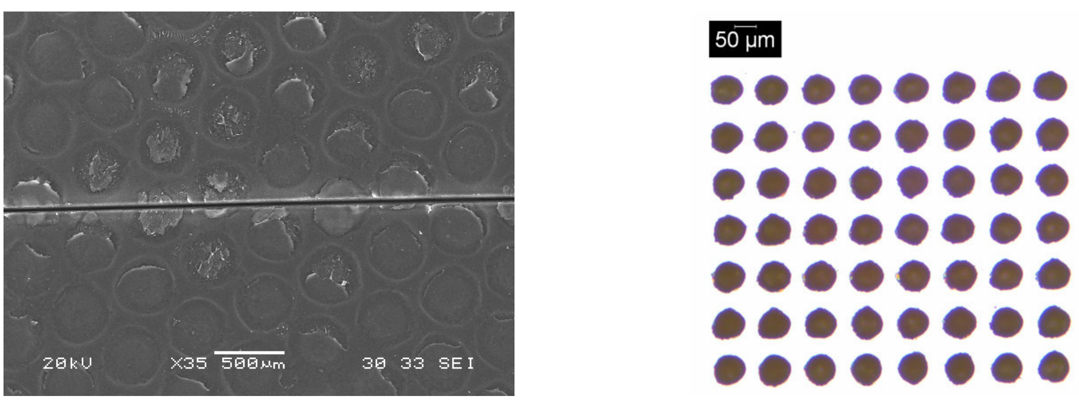


Figure 3. The schematic of laser processing system.



(a) (b)

Figure 4. Some processing results from the system: (a) laser cutting of nanotube paper; (2) laser drilled hole arrays on silicon.

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