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# Development of a Dynamic Transmission Electron Microscope (DTEM) for the Study of Self-Propagating Reactions in Multilayer Foils

J.S. Kang,*, **, A. Ziegler,* N.D. Browning,*, *** and G.H. Campbell**

* Dept. of Chemical Engineering and Materials Science, University of California, Davis, CA 95616
** Chemistry and Materials Science Division, Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
*** National Center for Electron Microscopy, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

The DTEM is an analytical instrument that provides great potential for original scientific discovery because it maintains the high resolution of conventional transmission electron microscopy (TEM) but also allows scientists to explore the realm of fast time dependence (nanoseconds and faster). Often phase changes and other dynamic material events occur on such short time scales that they appear nearly instantaneous, but these occurrences could be captured for analysis if they are induced and imaged within nanoseconds, picoseconds or even femtoseconds. On this ultrafast timescale, new concepts can be discovered that correlate structure with dynamics, even finding and exploiting transient materials properties [1].

The instrument that is currently being developed at Lawrence Livermore National Laboratory (LLNL) is modeled after the DTEM created by Bostanjoglo *et al.* at TU-Berlin [2]. It uses high-speed ultraviolet laser pulses to induce electron photoemission, creating a pulsed incident electron beam. As illustrated in figure 1a, a mirror deflects the incoming laser onto the electron source and a second mirror and laser setup simultaneously pumps the sample for a desired duration and wavelength to initiate a reaction in the specimen. This particular microscope (figure 1b) utilizes an 800 μm diameter tantalum disk mounted to a tungsten filament as the electron-emitting cathode for more straightforward laser to cathode alignment and the possibility of higher current densities and therefore greater spatial resolution. DTEM users are challenged with energy-resolution degradation due to Coulomb interaction causing electron-to-electron spreading within each incident electron pulse known as the Boersch Effect (the energy spread increases with the emission current and continues to increase when the beam is focused to a crossover [3]). This, in turn, will negatively affect image quality or spatial resolution, masking the amount of useful scientific information. The technical challenge is therefore to minimize this effect while still having sufficient current to image a dynamic process.

One area of research that will benefit immediately from the use of the DTEM is reactive multi-layer thin films of Ni/Ti, Al/Pt, or Co/Al, where fundamental scientific information on diffusion, phase transitions and the interplay between interface and bulk dynamics can be obtained. After an initiating energy deposition is applied via a laser, interfacial alloy formation will be highly exothermic inducing a chain reaction along the film. When this is captured at high time and spatial resolution at ~10nm and 1 nanosecond, the self propagating reaction fronts can be related to the foil parameters, improving current modeling [4] which is based upon diffusion and energy equations. Here, the first experiments using the LLNL DTEM to investigate the dynamics of reactive multi-layer films will be presented and the potential applications of the DTEM in the future will be discussed.

## References

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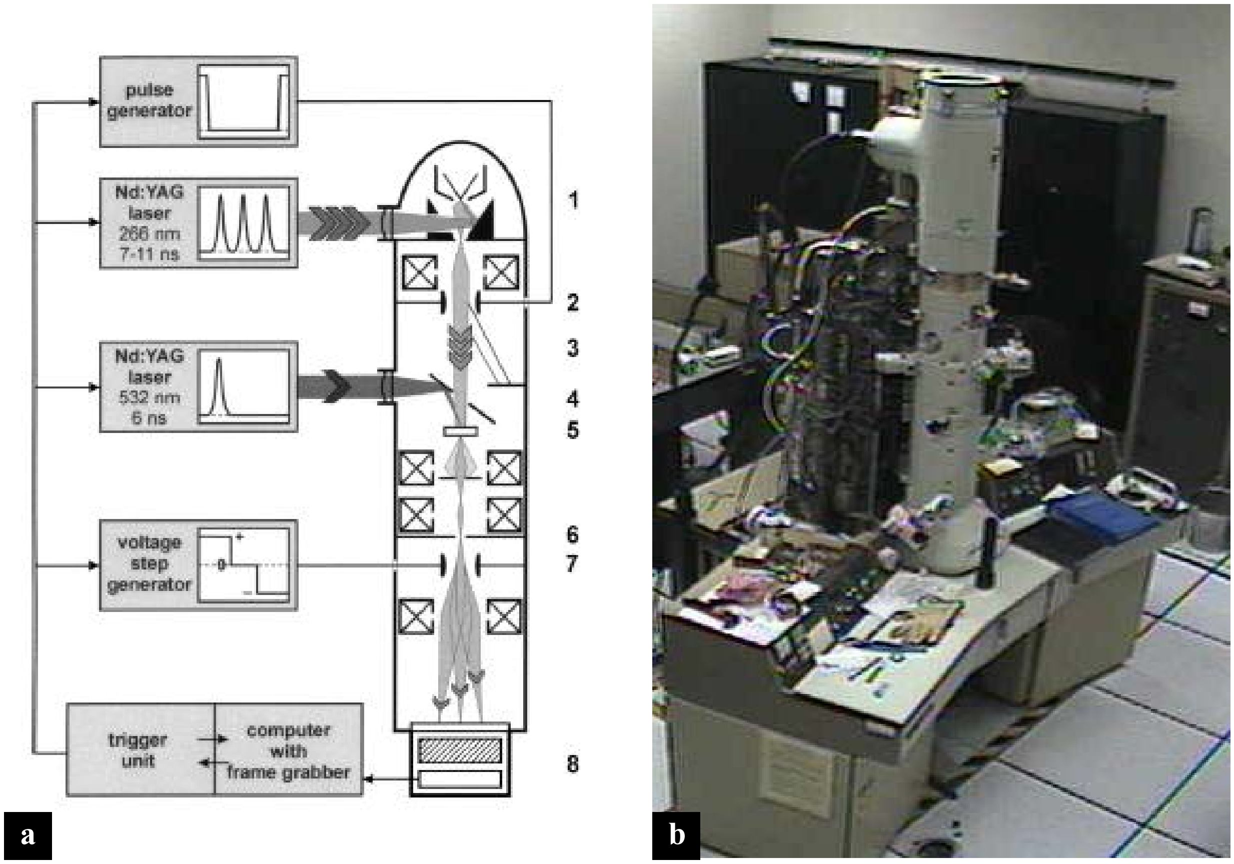

FIG. 1.
(**a**) Dynamic transmission electron microscope (DTEM) with a pulsed cathode exciting ultraviolet laser and another time-linked specimen stimulating laser. (1) Laser, mirror and electron gun, (2) beam blanker, (3) incident electron pulses, (4) laser and mirror, (5) specimen, (6) field aperture, (7) removable frame shifter, (8) image detector [2].
(**b**) JEOL 2000FX microscope column engineered for DTEM at LLNL.