Characterization and Integration of New Patterned Nanostructure Deposition Cluster Tool

The purpose of this project is to provide support of a new capability being brought to LLNL in support of multiple programs. The new capability is a unique physical vapor deposition tool to address the generation and integration of advanced initiation system components and to fabricate membranes for gas and liquid separation applications for carbon management and water purification efforts, respectively.

Project Goals

This is the first year of a three-year project to support a state-of-the-art DC-pulsed magnetron cluster tool for the fabrication of low-volume, high-energy-density nanostructure components. Current component fabrication methods have limitations in mask alignment, source performance, film stoichiometry, and defect repeatability. These limitations affect component miniaturization and yield. Our goal is to overcome the limitations, and apply our multifaceted engineering expertise through designing, modeling, and characterizing critical process equipment for the fabrication and integration of nanostructure components with energy densities 10 to 100 x greater than what is currently available.

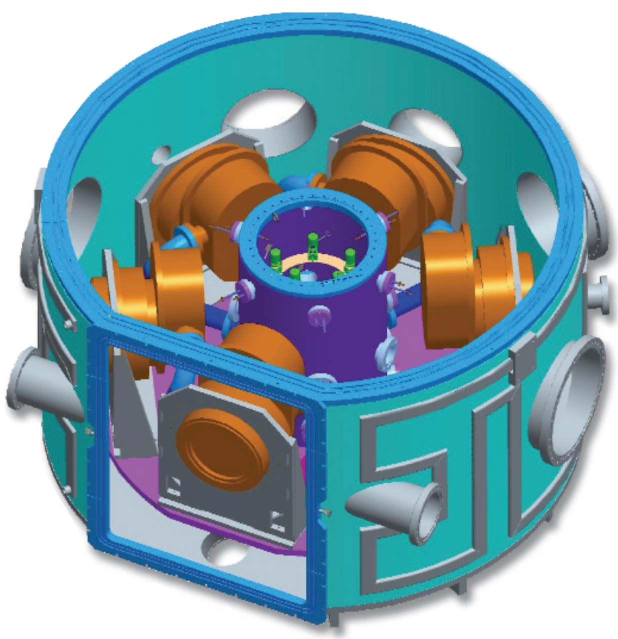

Figure 1. Isometric view of the main process chamber.

Relevance to LLNL Mission

The first deposition technology will be a cluster that has a reactive sputter process. In addition, this cluster will allow the deposition to occur through precisely placed shadow masks. This technology combination enables LLNL to build electrical components and circuitry without resorting to photolithographic processes. The cluster can then be used for advanced initiation system technologies with high-energy electrical components. These next-generation systems will have greater safety and reliability. Further miniaturization of components and development of high-energy circuitry with the cluster tool is crucial to meet volume constraints and cost goals. Since the tool can produce nano-layered oxides, materials research opportunities are also opened in the areas of superconductors, high-powered laser coatings, and catalysts.

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FY2005 Accomplishments and Results

Accomplishments to date have included the design of the main chamber (Fig. 1); enhanced design of the robotic sampling transport system, as well as the shadow mask; contract award for a high-density plasma source tailored to our applications; and contract award of the substrate system required to make high-energy-density components.

As part of the design of a sputtering tool for physical vapor deposition, it is necessary to obtain uniform reactive gas concentrations across the deposition surface to maintain film stoichiometry. Using Star-CD, we created a computational fluid dynamics (CFD) model of the surface and reactive gas injection ring to gain an understanding of the flow mechanics.

One question facing us was whether the inlet flow would come in the form of a jet from the nozzles or a stream that quickly dispersed once it entered the chamber. Based on the assumption of a constant mass flow, Star showed that at higher pressures (between 0.25 and 1 ATM), the stream enters the chamber and maintains coherence. This can be seen by the velocity of the inlet gas in Fig. 2. In this case, the stream slowly entrains the gas around it until it collides with the other inlet streams at the middle of the chuck. At lower pressures (between 0.0010 and 0.0625 ATM), however, the stream cannot maintain its coherence, as seen in Figs. 3 and 4. Here, with such low pressures around it, the stream is quickly pulled apart and disperses throughout the chamber.

Chief amongst the questions left unresolved is that of the molecular concentration of oxygen at the deposition surface. With its continuum assumption, Star was not able to get to low enough pressures to discern the appreciable density differences that must occur within the deposition chamber.

Thus, future modeling of the physical vapor deposition apparatus needs to account for the transition regime between the continuum approximation and rarified gases. The most likely candidate for such modeling is a direct simulation Monte Carlo (DSMC) code.

FY2006 Proposed Work

The goal for FY2006 is to test and characterize a new high density plasma source for producing reactive films with higher packing densities at increased deposition rates than current sputtering methods. Efforts will also include managing the integration and installation of the tool into a new cleanroom.

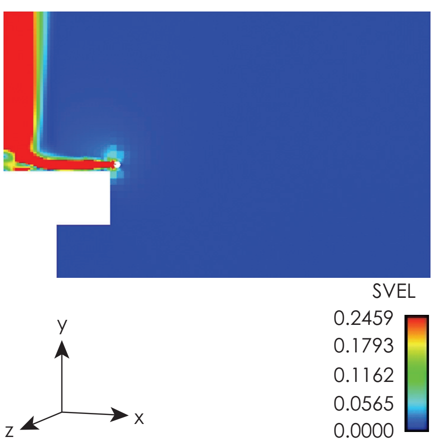

Figure 2. The stream at 1 ATM (760 Torr): the stream into the chamber maintains its coherence, as seen by the velocity profile of this radial slice of the model at the inlet.

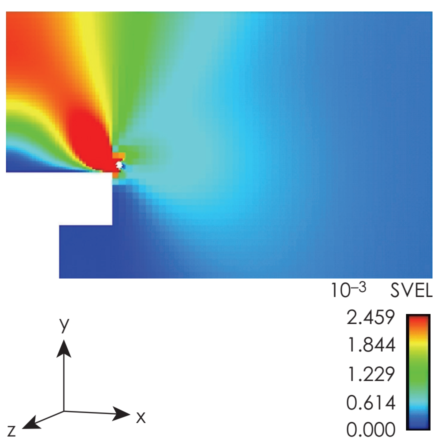

Figure 3. The stream at 0.001 ATM (0.760 Torr): the stream quickly begins to disperse throughout the chamber, as seen by the velocity profile of this radial slice of the model at the inlet.

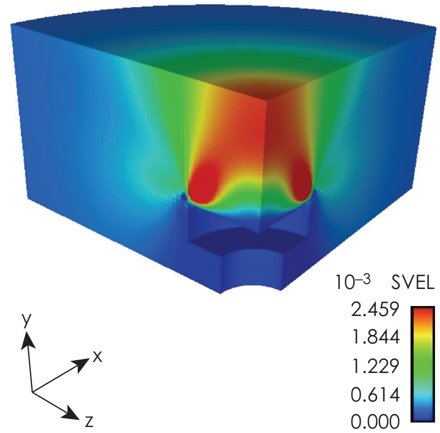

Figure 4. Three-dimensional map of the reactive gas velocities at 0.001 ATM (0.760 Torr).