Abstract

This dissertation describes the invention, design, construction, experimental evaluation and modeling of a new physical vapor deposition technique (U.S. Patent #5,534,314) for high rate, efficient deposition of refractory elements, alloys, and compounds onto flat or curved surfaces. The new Directed Vapor Deposition (DVD) technique examined in this dissertation was distinct from previous physical vapor deposition techniques because it used low vacuum electron beam (e-beam) evaporation in combination with a carrier gas stream to transport and vapor spray deposit metals, ceramics, and semiconducting materials. Because of the system's unique approach to vapor phase materials processing, detailed analyses of critical concepts (e.g. the e-beam accelerating voltage and power required for evaporation, the vacuum pumping capacity necessary to generate specific gas flow velocities exiting a nozzle) were used to reduce to practice a functioning materials synthesis tool. After construction, the ability to create low contamination films of pure metals, semiconducting materials, and compounds via this new method was demonstrated, and oxide deposition using an oxygen-doped gas stream in combination with a pure metal evaporant source was shown to be feasible. DVD vapor transport characteristics were experimentally investigated with deposition chamber pressure, carrier gas type, and e-beam power being identified as major processing parameters which affected vapor atom trajectories. The low vacuum carrier gas streams employed in DVD showed a dramatic ability to focus the vapor stream during transport to the substrate and thereby enhance material deposition rates and efficiencies significantly under certain process conditions. Conditions for maximum deposition efficiency onto flat substrates and continuous fibers were experimentally identified by varying chamber pressure, carrier gas velocity (Mach number), and e-beam power. Deposition efficiencies peaked at about 0.5 Torr when coating flat or fibrous substrates. Higher Mach numbers led to higher efficiencies below the efficiency peak, but above the peak this Mach number trend reversed. Increasing e-beam power decreased the magnitude of the deposition efficiency peak and shifted it to higher chamber pressures. Fiber coating experiments revealed a maximum deposition efficiency over twice the level expected for pure line-of-sight deposition, and scanning electron microscopy revealed that, for conditions of maximum efficiency, vapor was depositing simultaneously on the front of the fiber facing the incoming vapor and on the fiber's sides and back. The vapor transport and deposition trends appeared to result from vapor atom collisions with gas atoms in the carrier flow, collisions which affected vapor atom form (single atom or clusters), location in the flow, and interaction with the substrate (leading to line and non-line-of-sight coating). Atomic vapor transport in DVD was investigated using Direct Simulation Monte Carlo (DSMC) methods and biatomic collision theory (BCT). For atoms transported to a flat surface perpendicular to the vapor-laden carrier gas stream, the velocity vector during transport and impact location were calculated, making possible determination of adatom deposition efficiency, spatial distribution, impact energy, and incident angle with the substrate. Model results compared favorably with random walk predictions, independent experimental data of sputter atom energy loss, and low e-beam power experimental results. The model suggested that the atoms deposited in a DVD process had a low impact energy (< 0.1 eV) and a broad incident angular distribution with the substrate. The DSMC and BCT models were used to design an improved DVD system with significantly enhanced deposition efficiency.