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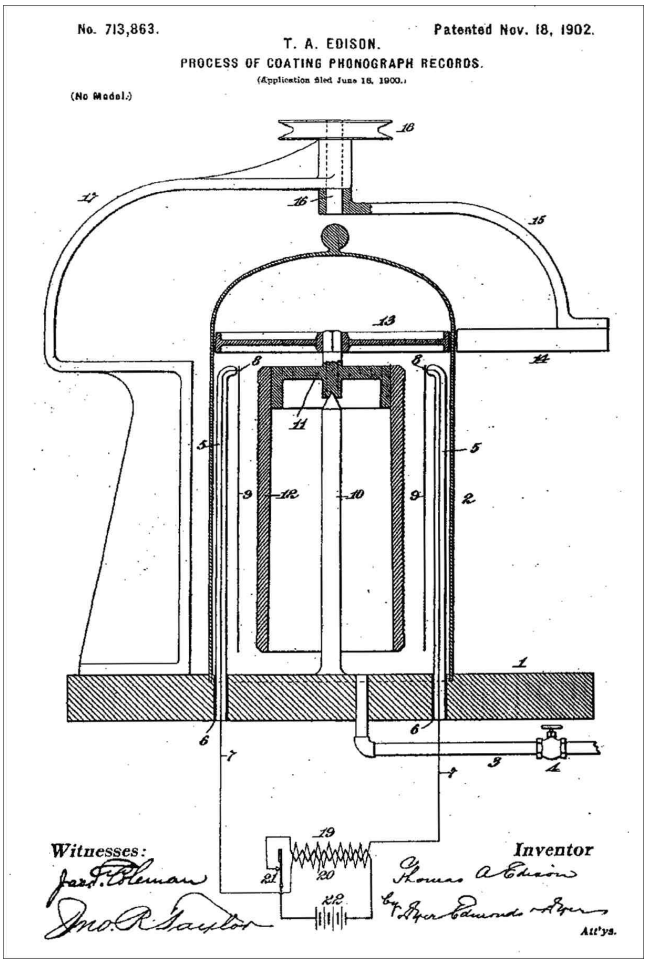
PVD: The Beginnings

Physical vapor deposition (PVD) is a vacuum coating process in which a material is vaporized from a solid or liquid surface and then transported through a low-pressure (vacuum) gaseous, or plasma environment to a surface where the material condenses and possibly reacts with a gaseous material or co-deposited material to form a compound (reactive deposition).

Vaporization is usually accomplished by sputtering, arc vaporization or thermal evaporation. Sputtering, because it does not require a very good vacuum, was the first vaporization technique used to deposit films in a vacuum. Sputter deposition of metal films was first reported by Grove (1852) and Plücker (1858), and developments in sputter deposition were continuous after that. On the other hand, the use of arc vaporization and thermal evaporation for depositing "useful" films in a vacuum has a somewhat nebulous beginning.



Sputter deposition of gold on a rotating wax cylinder (from Edison patent #713,863; November 18, 1902).

Film deposition by arc vaporization in a vacuum was first reported in 1877 by Wright, who studied the optical properties of the deposited films. Thomas Edison's patent, "Art of Plating One Material with Another," was filed in 1884 and granted September 18, 1894. At first, Edison was not aware of Wright's work, which led to a long (10-year) discussion with the patent office. Finally, Edison was granted a patent on the basis of a "continuous" arc, compared to Wright's "pulsed" arc for vaporization. (Edison termed Wright's arc a "pulsed arc," which he also called a "laboratory curiosity.") Edison tried to use arc vaporization to coat his wax phonograph recordings, but found that too much heat was generated for the delicate wax recordings. In a 1956 paper in the journal, *Nature*, Holland questioned whether Edison was using a true

"vacuum arc" or a "gaseous arc" because of the state of vacuum technology at that time.

Thermal evaporation from surfaces in a vacuum was studied by Stefan in 1873 and Hertz in 1882, but they did not report using it to form films. Film deposition by thermal evaporation from crucibles in a vacuum was reported by Nahrwold in 1887 and Kundt in 1888. Edison covered thermal evaporation to form films in his 1894 patent (applied for in 1884), but apparently did not use the process commercially. In his patent, Edison discussed resistively heating electrical conductors to "incandescence" for vaporization and to "plate" nonconducting materials on carbon that were then resistively heated to vaporize the nonconducting material. Heating a solid to "incandescence" for evaporation would limit the materials that could be evaporated, and Edison made no mention of using a wetted-filament type of evaporation. Edison was more interested in arc vapor deposition than thermal vaporization in that patent. Pohl and Pringsheim generally are credited with developing thermal evaporation from a resistively heated, wetted filament for depositing films in a vacuum in 1912.

In Edison's 1894 patent, he discussed masking as a way to form patterns of the deposited film on a surface. He also discussed making freestanding foils by separating the deposited film from a surface using a soluble intermediate material (release agent). In 1915, Edison patented a process for using sputter deposition to form freestanding refractory metal foils that were then fabricated into filaments for his light bulbs.

In 1902 (applied for in 1900), Edison patented a process for sputter-depositing gold on his wax recordings (using both a "silent" and a "brush" discharge), then building the coating thickness to be a freestanding structure by electroplating. After removing the wax, this freestanding structure became the "master" for pressing his celluloid phonograph cylinders. This technique allowed faithful duplication of the grooves in the original wax recording. The patent (#713,863, dated November 18, 1902) was entitled "Process of Coating Phonograph Records." A figure from the patent accompanies this article. The figure also shows a rotating fixture driven by an external rotating magnet. It is interesting to note that, 95 years later, a breakthrough in semiconductor metallization was made by sputter-depositing a "seed layer" of gold on the surface and then building up the deposit thickness by electroplating copper. This metallization technique allowed very small surface features (less than 0.5 microns wide) with high depth-to-width (aspect) ratios to be filled without voids.

Sputter deposition was the first practical vacuum coating process, followed by arc vapor deposition. Both faded in importance with the development of thermal evaporation in the mid-1930s. In the 1970s and 1980s, both sputter deposition and arc vapor deposition regained their importance as vacuum coating processes. Thomas Edison played a little-recognized role in the beginnings of PVD processing—a role that is mostly evident through his patents.

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