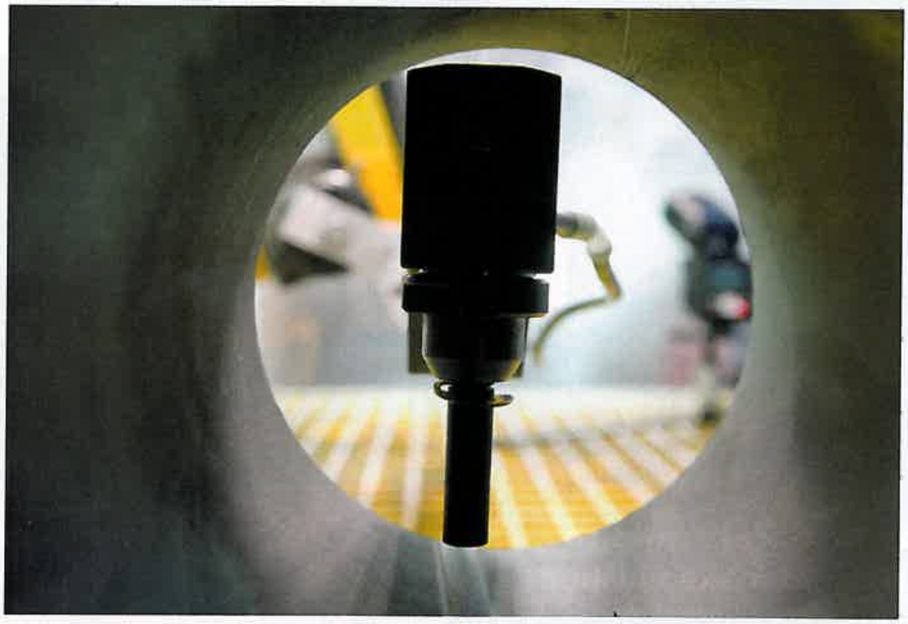
An Alternative Solution for Sputtering Targets for High-Volume Thin-Film Deposition



Low-temperature deposition of the inside of an aluminum tube using low-pressure cold spray. (Photo courtesy of CenterLine Windsor Ltd.)

Cold spray can produce high-quality, ultrathick metallic deposits of specially formulated metal powders with low oxide content and porosity

BY JULIO VILLAFUERTE AND DAVID WRIGHT

In common thin-film deposition processes such as physical vapor deposition (PVD) or chemical vapor deposition (CVD), a solid target and a substrate are placed together in a high-vacuum environment. Sputtering is one of several techniques whereby atoms on the target surface are ejected into their gas phase by bombardment with energetic particles, such as argon ions in a plasma jet. The evaporated atoms from the solid target are not in their thermodynamic equilibrium state; therefore, they tend to deposit on all surfaces within the vacuum chamber, including the intended substrate. In CVD, the evaporated target material further reacts with a chemically active gas in the chamber and at the surface of the substrate, resulting in compounds chemically bonded to the substrate. Thin-film deposition is used in a vast range of industries including renewable energy, microelectronics, heated glass, architectural glass, packaging, automotive, aerospace, and many others. There are hundreds of target materials on demand for hundreds of applications including pure metals, alloys, oxides, borides, nitrides, selenides, fluorides, silicides, sulfides, carbides, and other nonmetals.

High-volume thin-film deposition is used during the fabrication of hundreds of familiar consumer products such as calculators, toys, food packages, CDs, DVDs, hard drives, eyeglasses, jewelry, cell phones, microchips, and many others. High-volume thin-film deposition utilizes large vacuum chambers along with large rotatable sputtering targets. These targets typically consist of large water-cooled steel, stainless steel, aluminum, or copper tubes. The target material is generally bonded to the surface of these tubes by brazing, casting, or thermal spraying. Thermal spraying is often selected because of its ability to lay down composite target materials, ability for reapplication and restoration of these targets, and be-

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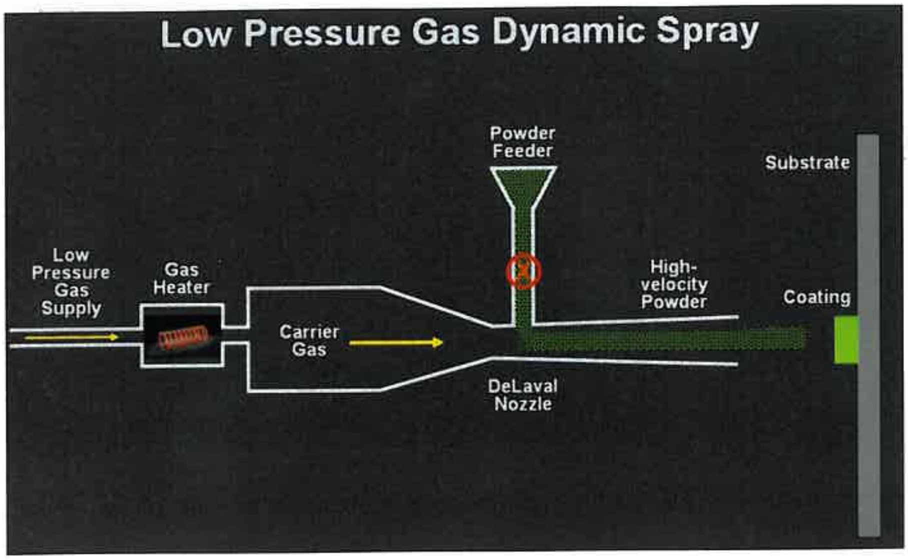

Fig. 1 — Schematic of the low-pressure cold spray system.

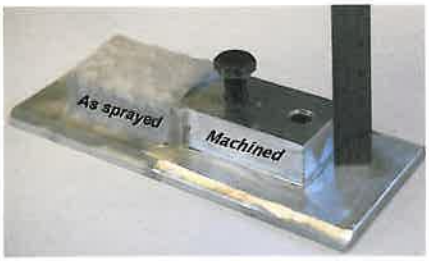

Fig. 2 — An ultrathick as-sprayed deposit made by low-pressure cold spray.

cause it does not have a physical limitation on the size of the target. However, thermal spray is generally used only in applications where material purity and density are not as critical. This is because thermal spraying does affect the metallurgical integrity of the spray material resulting in excessive porosity, oxides, and other undesirable phases, and it presents limitations for building up ultrathick deposits. The latter is particularly critical for high-volume thin-film deposition as the thickness of the target directly affects the economics of thin-film making.

An Alternative Manufacturing Process

Cold spray is one of the many names for describing a solid-state coating process that uses a high-speed gas jet to accelerate powder particles toward a substrate where metal particles plastically deform and consolidate upon impact. The term "cold spray" refers to the relatively low temperature involved in the process, which is typically much lower than the melting point of the spray material. Although the concept of cold spraying metallic materials onto substrates goes back to the early 1900s, it was not until the 1980s that the applicability of this technology was demonstrated and patented by the Institute of Theoretical and Applied Mechanics of the Academy of Sciences in Novosibirisk (Ref. 1) (high-pressure cold spray) and then by the Obninsk Center for Powder Spraying (Ref. 2) (low-pressure cold spray) in the former Soviet Union.

In cold spray equipment, air, nitrogen, or helium at certain pressures and temperatures are injected into a converging-diverging (DeLaval) nozzle to convert gas enthalpy into kinetic energy and subsequently accelerate the gas jet to supersonic speeds. The spray material in the form of powder can be introduced upstream of the nozzle (high-pressure cold spray), or downstream into the diverging section of the nozzle (low-pressure cold spray) — Fig. 1. At a given impact temperature, every material requires a minimum level of kinetic energy above which acceptable bonding may occur. Generally, the higher the melting point and mechanical strength of the spray material, the more kinetic energy is required to produce acceptable bonding at a given impact temperature. In cold spray, the type of gas, gas pressure, and gas temperature determine the amount of kinetic energy available to accelerate particulate. High gas pressures (above 700 lb/in.^{2}) and gas temperatures (above 600°C) with helium gas provide high kinetic energy levels; however, with limitations in economics and portability. On the other hand, many common engineering materials can be successfully cold sprayed at lower pressures (less than 300 lb/in.^{2}), gas temperatures (below 600°C), and using lower-cost carrier gases (nitrogen, air).

Since adhesion of the metal powder to the substrate and deposited material is achieved in the solid state, the characteristics of cold spray deposits are unique,

Fig. 3 — Various stand-alone configurations of low-pressure cold spray equipment, including auxiliary components. (Photo courtesy of CenterLine Windsor Ltd.)

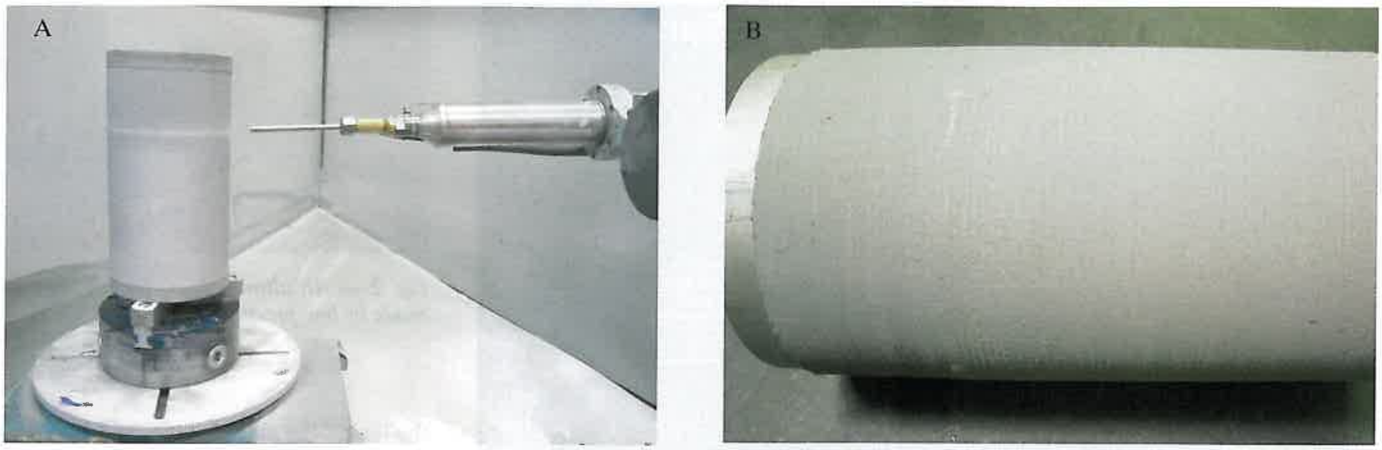

Fig. 4 — Refurbishing of indium-copper-based target for components for solar power generation. A — During the spraying process; B — as-sprayed condition. (Photos courtesy of Accuwright Industries.)

making cold spray suitable for depositing a wide range of traditional and advanced materials on many types of substrates, especially in nontraditional applications that are sensitive to the temperature of the process. Some characteristics of cold spray include the ability to form dense deposits with extremely low oxygen content, free of residual tensile stresses, grain growth, recrystallization zones, phase changes, and ability to deposit ultrathick coatings — Fig. 2. These attributes make cold spray suitable for depositing a range of temperature-sensitive materials in temperature-sensitive situations.

Utilizing Cold Spray for Sputtering Targets

Cold spray technology is a natural candidate for the fabrication of sputtering targets as it allows the target material to retain its original properties, does not induce metallurgical transformations or oxidation, and is able to produce ultrathick and fully dense coatings. Therefore, applicators are utilizing commercially available low-pressure cold spray equipment (Fig. 3) to fabricate or refurbish rotatable sputtering targets for the military, aerospace, energy, and medical industries. Whether for repairing jet engine parts or fabricating sputtering targets, many standard as well as specially formulated target materials can be applied by prequalified cold spray procedures (Ref. 3) without worries about metallurgical compatibility or dilution with the substrate. As an example, during flame spraying (one of a number of thermal spray processes that are used), coatings undergo thermal reactions such as phase changes, oxidation, and porosity, which make sputtering less effective and less productive. The cold spray process allows the chemistry of the spray material to be maintained in the deposit with virtually no porosity.

One practical example is the manufacturing, refill, and repair of indium-copper-based targets for thin-film deposition in the solar and microelectronics industries. Many of these targets are used to create thin films for photovoltaic, heat, and low-voltage transfer. Other target materials, such as Ni and Al based, can be used during the manufacture of battery cells. After basic surface preparation, standard or specially formulated spray materials can be successfully deposited by a prequalified cold spray procedure — Fig. 4. The density and bond strength of the cold-sprayed deposit typically exceed the minimum specifications for a sputtering target, i.e., less than 1% porosity and better than 5000 lb/in.^{2} bond strength.

Summary

Cold spray constitutes a family of emerging solid-state processes that expand the capabilities of traditional thermal spraying into unique applications that are either technically or economically prohibitive for traditional thermal spray. Cold spray can produce high-quality, ultrathick metallic deposits of specially formulated metal powders with low oxide content and porosity. Low-pressure cold spraying has become a reliable, accurate, and economical technique for the manufacturing or refurbishing of rotatable sputtering targets for high-volume thin-film deposition.♦

References

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