1. Introduction

Thermal spray is a directed melt-spray process in which materials in the form of powder, wire or rod are fed into a thermal source where in the particles are melted and propelled onto a prepared substrate. The resultant deposits are comprised of splat based assemblage of discrete particles resulting in a “brick-wall” structure with thicknesses ranging from 50 microns to millimeter dimensions. Over the years, thermal spray technology has emerged as an innovative and unique industrial manufacturing processing for fabrication of advanced coatings from a range of materials spanning from low melting plastics to complex multi-component alloys and refractory ceramics. Wide ranging industries in recognition of thermal spray’s versatility and inherent economics, have introduced the technology into the realm of medium and high volume rate manufacturing. Industrial sectors that routinely rely on thermal spray coatings include aerospace, energy, heavy machinery, paper and pulp, transportation and even biomedical implants. The main advantages of the process are:

- Versatility with respect to feed materials (metals, ceramics & polymers in wire, rod, powder)
- The capacity to form deposits on wide ranging substrates at low substrate temperatures
- Ability to apply deposits at high throughput onto complex shapes in a cost effective manner.
- Non-equilibrium synthesis of novel materials and phases.

The majority of past and contemporary thermal spray applications are in the field of protective coatings, where the principle function of the overlay coating is to protect the underlying substrate from heat, contact damage (e.g., wear) or the surrounding operational environment (corrosion). Examples include thermal barrier coatings for protection of hot section superalloys in energy and propulsion gas turbines, wide ranging hard metal cermets and advanced alloy coatings in situations involving abrasion, sliding or erosion wear, passive and active (cathodic) protection in corrosive environments are among the most dominant of applications [5-8]. In most of these situations, the coatings can at best be classified as ‘passive materials’ and typically do not contribute to physical or chemical functional response other than providing a barrier function. As such, the applications of thermal spray in truly functional systems; i.e., where the deposited materials must provide an electronic or sensory function, is to date limited in scale and scope. However, new opportunities are now emerging in advanced functional surfaces, including dielectrics, electrical conductors, magnets, sensors and solid oxide fuel cells. In these new applications, thermal spray offers advantages for manufacture of deposits over large area substrates and for the creation of complex conformal functional devices and systems. Perhaps the most significant current functional application of thermal spray lies in the manufacture of solid oxide fuel cells, involving layered material architecture of high temperature ceramics and
metals. There is considerable research underway in this field and is deserving of a focused review in itself and therefore not addressed here. This extended abstract seeks to examine the applications of thermal spray technology in thick film or mesoscale electronic devices and sensor materials where there is clearly an untapped opportunity.

A detailed review of the past attempts and contemporary advances is shown in reference 1.

2. Thermal spray of functional materials

Thick film electronics based on devices with dimensions in the 10 micrometer to millimeter dimensions represent a multi-billion dollar industry. They rely on ceramic and metal components built typically via screen printing techniques with appropriate co-firing at temperatures ranging from 700°C up to 1400°C, depending on the nature of the ceramic material or device. This technique although the mainstay of the power electronics industry has limitations as it’s built on traditional 2D stacking and co-firing. There are numerous applications for example component integrated electronics and thick film sensors where there is a need to integrate electronics/sensors with a structural component. Furthermore, many applications seek ceramic or metallic interconnect and device integration with polymeric carrier materials. It is in these situations that thermal spray offers a novel extension to traditional thick film technology.

Thermal spray offers the ability for high throughput with in situ application of metals, ceramics and polymers in most cases without requiring significant thermal input to the substrate. The technology also can be adopted for 3D manufacturing and customizable for a range of dimensions. The process also has significant materials versatility along with ability to integrate with other hybrid manufacturing systems (e.g. laser annealing or micromachining). Thermal spray can readily fabricate insulated metal substrates but through specialized configurations can be used for fine scale printing or direct writing. This has led to its considerable interest for the technology in electronics and sensor manufacturing. Figure 1 shows a picture representation of potential opportunities for thermal spray in functional materials and electronics.

Fig.1: Illustrative examples of functional coatings and patterned structures produced by thermal spray: Top left solid oxide fuel cells (courtesy Juelich Research Center), bottom left direct write antenna, center top illustration of direct write thermal sprayed thermocouple on component (courtesy Mesoscribe Tech., actual instrumented components built), top right multilayer inductor all fabricated with blanket and direct write thermal spray and bottom proton scintillator coatings as made and with protons.

Critical challenges remain for realization of this potential. The key issue is understanding the process-structure-property relationships for functional systems. The rapid heating and rapid cooling of the thermal spray process can affect both extrinsic (porosity, interfaces) defects but also intrinsic materials issues including metastability, stoichiometric variations, oxidation/trapped states etc. The technology can only be harnessed if adequate material properties are achieved. Progress in process science, technological precision and enhanced understanding of materials behavior has allowed slow but steady penetration of the technology into applications and expected to grow over the coming decades.

3. References