High Speed Dry Coating Process for Wide Webs: Integration for Plasma Treatment Metal Deposition with Polymer Coatings

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ABSTRACT:

Always there is a need for new coating technologies that do not utilize solvents, have minimal waste, and are relatively safe to implement. An environmental friendly vacuum based process is described here. That utilizes monomers which are solvent- and water-free and results in high quality polymer coatings. The coating process can be implemented in conventional vacuum coating plants and can be combined with in-line plasma treatment and metallizing to create unique and high value-added products. The polymer coatings are produced by flash evaporating radiation curable monomers which form a vapor that is condensed onto a web substrate and cured with UV or low energy electrons.

The vacuum polymer coating process has shown great success in functionalizing surfaces of films, woven and non-woven fabrics, paper and foam substrates. Properties such as oil and water repellency and wettability, release, antibacterial and other chemical functionalities are easily achievable with thin coatings. When combined with metallization or sputtering, a modified metallizing plant with plasma/metal/polymer ability is capable of producing a wide range of multifunctional products. Thin coatings can be deposited at speeds as high as 1000ft/min. This combined with low monomer material cost, results in an economical and cost-competitive process that has already transitioned into production.

Flash Evaporation Vacuum Coating and Radiation Curing[1-6]:

The flash evaporation and radiation crosslinking for polymer coating is based on a vacuum deposition, solvent free, process that produces high quality, uniform films with various thicknesses (0.05 - 5.0 µm). This high rate process starts by depositing a radiation curable (EB or UV) formulation onto a variety of web substrates, such as polymer films, metal-coated films, fibers, textiles, non-woven, and paper that are mounted on a rotating drum. The monomer layer moves under a broad radiation source where it is cross linked. For coatings, a single layer of polymer can be deposited on each pass without any loss of throughput.

Figure 1 shows a schematic diagram of Sigma's dual evaporator vacuum coating system. This system can simultaneously deposit one or two polymer coatings with metalization, if needed. Each deposition station is completely independent from the others and can be turned on and off separately.

VACUUM POLYMER COATING CHAMBER **VACUUM METALLIZING AND POLYMER COATING CHAMBER**

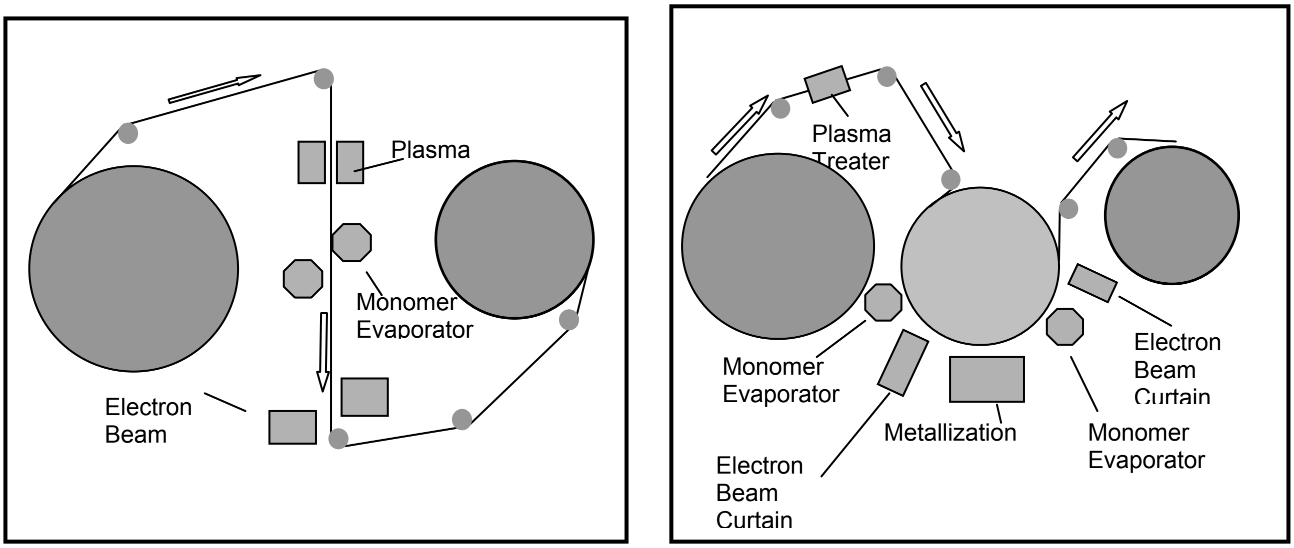

Figure-1: Polymer Multilayer (PML) Coating Systems

This technique has the important advantage of speed compared to other deposition processes. The evaporation method can deposit layers as much as several microns thick at line speeds up to 1000 feet per minute. This is more than 10 times faster than equivalent thickness metallic layers can be deposited and nearly 1000 times faster than the speeds for equivalent thickness polymer layers. The nonevaporation (direct liquid deposition) method is only capable of speeds in the 100_200 feet per minute range. However, this is still faster than conventional deposition processes speeds. In addition, the direct liquid deposition method permits layers from about 10 μm (0.0004 inches) in thickness to as thick as 0.1 inches.

A second advantage of this technique is that this process is a vacuum process that is fully compatible with inline, simultaneous vacuum deposition of other materials (such as metals or oxides) by sputtering or evaporation. This allows for inline deposition of other layers in the same chamber without breaking vacuum.

The monomer materials that can be used with this process are polyfunctional or mixtures of monofunctional and polyfunctional acrylates, vinyl ethers, cycloaliphatic or epoxy. It is desirable for the monomers or monomer mixtures to have an average of at least two double bonds. This reactivity assures a high speed cross-linking when exposed to the electron beam or ultra-violet radiation, which is accomplished by the opening of the double bonds. Acrylate functionality has been incorporated in a number of oligomers to provide a wide ranging family of radiation curable materials with a broad spectrum of polymer properties. In vacuum, the monomer formulations are flash evaporated at temperatures above their boiling point and well below the decomposition point, and thus are not degraded (cracked) by the deposition process. The absence of unreactive degradation products, combined with initial monomer purity, results in polymers with very low levels of volatile components.

Multifunctional monomers/oligomers were selected for the formation of high quality polymer composites for several reasons, including the following:

- Rapid cure response ensures economical production speed
- A wide selection of molecular structures makes it possible to tailor-make materials with specific properties, for example hydrophobic/hydrophilic and oleophobic/oleophilic
- They form polymers with 100% solids which allows vacuum processing
- Environmentally safe solvent free process

VACUUM BASED FUNCTIONALIZATION

Wet chemistry treatment for various substrate materials is well established and it is continuously evolving to meet new material and product needs. Vacuum based surface functionalization methods include metallization (sputtering CVD, etc), plasma treatment and vacuum polymer coating.

- Multilayer capacitors
- Hybrid film capacitors
- Printable metal flakes (conductive and non-conductive)
- ITO flakes
- Pigmented colored coating
- Self-healing LE coatings
- Patterned metallized surface (selective metalization)
- Reticulated light diffusing coating
- Anti-fog coating
- Release coating
- Leveling coating
- Ultra high barrier coating and free standing sheets (flex glass)
- Functional breatheable coatings for paper, fabrics and non-woven materials
- Multilayer organic reflectors (optical filters)
- IR and RF coatings

EXAMPLES

Vacuum Metallization

Vacuum metallization has been used to produce a great variety of products. The quality and functionality of metallized substrates may be enhanced by integrating the metallization process with plasma pretreatment and polymer coating after metal deposition. Some vacuum metallized applications are listed below:

Packaging Barrier Films: For that application moisture and oxygen permeability is very critical. Better barrier means longer shelf life for the product.

Window Blinds: A large quantity of metallized fabrics is used to produce roll, vertical, and horizontal blinds, both for decorative and energy saving applications.

Construction: Breathable insulation in the form of metallized paper and non woven polymers is widely used to reflect heat while minimizing mold and mildew formation.

Decorative: Metallized fabrics for garments and metallized paper for labels.

Functional Clothing and Tent Fabrics: Metallized fabrics are used as liners for enhancing insulation without adding weight. Similarly camping gear such as sleeping bags and tents utilize metallized fabrics to improve insulation values without affecting weight and breathability.

Medical: Specialty blankets and tapes

Automotive: Metallized fabrics are widely used in automobiles to provide engine and exhaust heat insulation.

Filters: Metallized filter media such as non woven polypropylene is used to produce electrostatic filter systems and air filters with EMI shielding properties.

EMI and RFI Shields: Foams and fabrics are metallized to produce electromagnetic shields for gasket materials, cable shields, covers and liners for motors, avionic boxes, cable junctions, antennas, portable shielded rooms, window drapery, wall coverings and electrostatic dissipating garments.

Protective Clothing: Fire protective suits designed to reflect infra red radiation, garments for workers in microwave and radar communication industries, and clothing for EMI testing personnel.

Military: Multitude of military applications for Infra Red signature reduction that include jackets, shirts, garments, tents and tarps.

Plasma Treatment

Vacuum plasma treatment has been used for some time in the finishing process of specialty fabrics. Plasma treatment has been shown to have several chemical and physical effects which include:

Activation and cleaning: attributed to generation of free radical species and plasma ablation of contaminants such as lubricants and low molecular weight polymer. This improves fabric dye uptake, adhesion and printing quality,

Plasma grafting and polymerization: produced by adding to the plasma hydrocarbon gases and other functional monomer vapors that polymerize on the fiber surface. Such grafted layers can be used to create hydrophilic and hydrophobic surfaces. Unlike simple surface activation and cleaning, this process is relatively slow.

Surface microroughness: also related to ablation and particle bombardment, can be used to change the “feel” properties of some fabrics and it can produce an anti-pilling effect on wool.

METHODOLOGY

The vacuum polymer coating process has all the basic technological, environmental, material, and process cost elements, to compete with mature solvent and water based coating methods. The pretreatment and polymer coating is performed as a batch process in a vacuum chamber which occupies a relatively small amount of real estate. Figure 1, shows a schematic of the vacuum chamber with the necessary equipment to treat and coat one or both sides of a web.

Process technology was developed to overcome several major technical challenges:

- Combining plasma surface treatment with vacuum deposition of radiation curable monomers in one process. This is an in-line process with very short time (milliseconds) between plasma treatment and deposition of a liquid monomer layer. Plasma functionalization will create reactive species (ions and free radicals) on the fiber surface which will react with the monomer molecules. Covalent bonds are formed between the fibers and the cured polymer coating, that lead to strong durable coatings that can resist degradation from washing and cleaning cycles. This technique combines the advantages of plasma treating (covalent bonding to the substrate) and thin polymer film coating on highly activated surfaces.

- Condensing the monomer/oligomer vapor on the plasma treated fibers forms a homogeneous thin liquid layer that covers the entire surface of each individual fiber without connecting fiber to fiber and blocking the pores. This maintains the porosity and breathability of the substrate. The radiation cured film has excellent adhesion to the plasma treated fibers. Figure 2 shows SEM pictures of coated (commercially available) and uncoated non-woven polypropylene that is used to produce oliophobic filter media. The micrographs show no evidence of polymer between fibers, and air permeation tests also show no significant difference between the two samples. This is a result of conformally depositing the liquid monomer from a vapor phase state, in contrast to conventional liquid based methods that exhibit limited levels of conformality.

Non Coated Fabric **Coated Fabric**

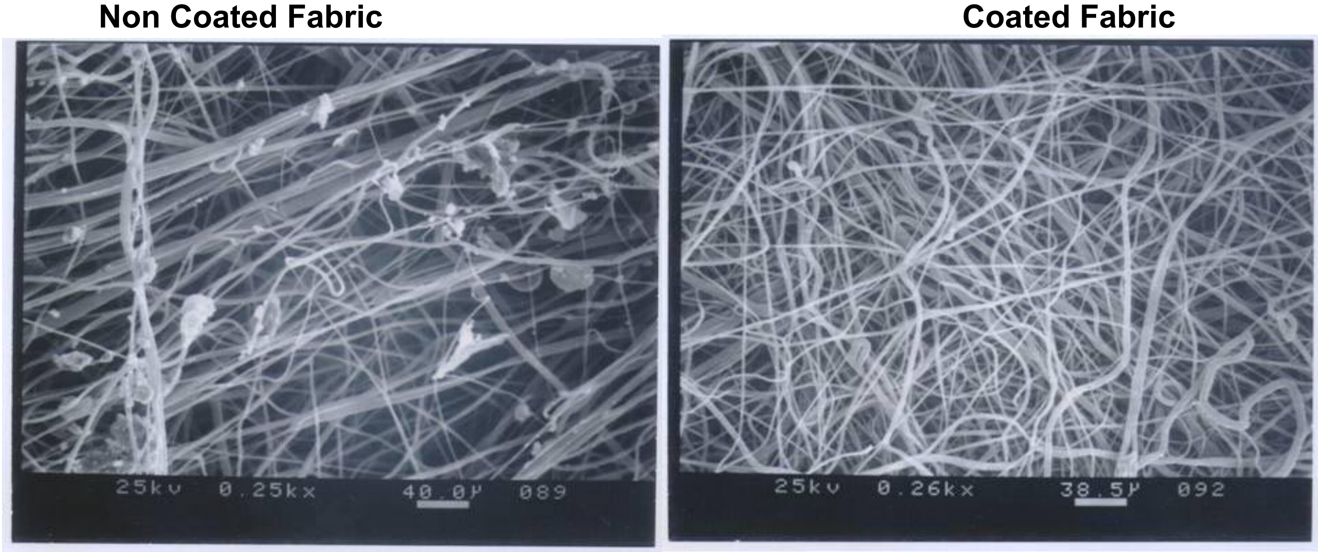

Figure-2: Non-Woven Polypropylene, Surface Functionalization with no Effect on Breathability

CONCLUSION

Vacuum deposited polymer coatings on various substrates provide a real alternative to conventional solvent and water based coating processes. Highly functional coatings can be obtained. Coatings with submicron thickness can be used to replace liquid based fluoro treatments and coatings and wax impregnation processes, which are facing environmental and recycleability issues. The totally enclosed vacuum chamber is environmentally friendly, allowing fluoro, chloro and other hazardous monomer formulations to be processed safely. Monomer materials are 100% solids, and most are of low cost. When considering the low coating thickness, the high speed of deposition, and the relatively low energy consumption, the flash evaporation vacuum polymer coating process is cost competitive with mature liquid based coating technologies and applications are expected to grow.

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