DEVELOPING BASE TECHNOLOGIES FOR TOMORROW'S SMART TEXTILES

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Abstract

To provide textile modules for smart clothes, we developed low-pressure plasma metallization processes to produce electrically conductive filaments. An insulating coating based on polymeric materials has been applied using either dip coating or overjacketing extrusion. In addition, we melt-spun bicomponent polymer optical fibers that can be applied as near-to-body sensors.

1 Introduction

Electrically conductive (e-) and optical (o-) textile fibers with good flexibility, robustness and haptics are essential for integration of electronics into textiles. The objective of this research is to develop textile core modules which enable the design and manufacturing of truly wearable functional clothes.

Technologies and processes like co-spinning fine silver wires, use of conjugated polymers or metal coating on yarns and textiles can be used to create electrically conductive fibers. Recently we have developed a low-pressure plasma sputtering process to deposit a smooth 100-200 nm thin silver layer on common mono- or multifilaments [1]. To prevent corrosion and unwanted contacting of the conductive coatings, a proper insulation is necessary.

Dip-coating is a simple and inexpensive method to deposit a liquid film on the surface of textile fibers. The film thickness depends on multiple factors like fiber diameter, withdrawal velocity and rheological properties of the fluid [2]. UV-curable polyurethane (PU) aqueous dispersions give high performance thin flexible coatings which exhibit excellent physical properties and good chemical and mechanical resistance [3].

An interesting aspect about UV-curable coatings is that the uncured portions can be easily removed while the cured coatings have excellent washing fastness. This makes them very promising candidates for selective inter-connects in textiles.

Wire coating is an extrusion process in which either the molten polymer is extruded continuously over an axially moving wire (tubing-type die) or the wire is pulled through the extruded molten polymer (pressure-type die) [4]. It is widely used for the sheathing of electrical wires and cables [5,6]. The goal of our activities is to transfer the wire coating technique to polymeric filaments. To achieve a differentiation from the coating of wires, the more general term "overjacketing extrusion" will be used for this approach.

Polymer optical fibers (POF) have been implemented in textiles for a wide range of applications in illumination and sensing [7,8]. The flat and flexible structure of POF fabrics enriches the range of products with optical functionalities while maintaining look and feel of a textile.

However, most commercially available POFs are based on poly(methyl methacrylate) (PMMA) and possess diameters exceeding 200 µm to facilitate light transmission. As a result, the respective fibers show insufficient bendability and handicap textile production and application. Using bicomponent melt-spinning technology we developed highly flexible prototype POFs that fulfill the requirements of textile processes.

2 Experimental

For e-fibers, plasma-metallized polyamide 6.6 (PA 6.6) monofilament fibers (diameter: 78.5 µm) with a 200 nm silver layer were produced as starting point.

The metallization was performed using an optimized magnetron sputtering process enabling the continuous and uniform coating of fibers [9,10]. Sputter-deposited Ag layers show a dense morphology yielding a resistivity of <10 Ω/cm on the PA 6.6 monofilament fibers.

To achieve an insulating layer, coating solutions were prepared using a UV-curable PU dispersion, carboxymethylcellulose (CMC, high viscosity rheological agent) and photoinitiators. Dip-coating was done on a custom-built continuous liquid film coating machine with two drying units and one UV-curing chamber (Figure 1).

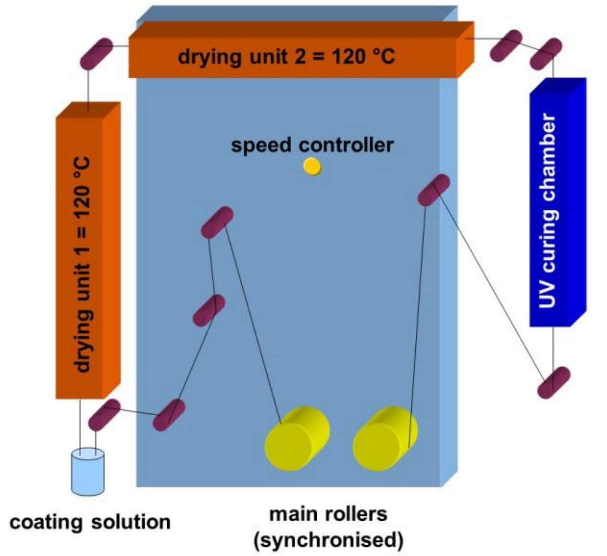

Fig. 1: Schematic drawing of the dip coating machine.

Coating experiments were performed using withdrawal speeds in the range of 1.5 to 8.8 m/min. Temperature in the drying chambers was maintained at 120°C. A UV-curing lamp with power ranging from 60 to 120 W/cm was used.

As an alternative, overjacketing extrusion was taken into consideration, where the monofilament passes through the core of a crosshead extrusion die and is coated with the polymer melt (Figure 2).

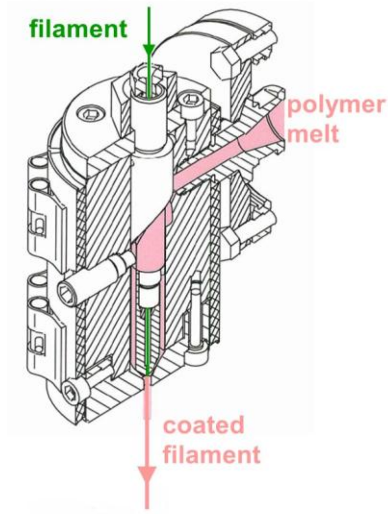

Fig. 2: Overjacketing crosshead extrusion die.

After the coating process, the filament is cooled in air or water. The coating velocity (typical range for the current laboratory setup: 5 to 300 m/min) is determined by the action of the take-up unit situated after the cooling zone.

Using our pilot bicomponent melt-spinning plant, we produced POFs in a single-step process. As core material a well-processable cyclo olefin polymer (COP) is used. The fluorinated sheath polymer chosen provides the desired fiber flexibility, and its comparatively low refractive index maintains the light within the transparent core.

3 Results and Discussion

Our low-pressure plasma sputtering process yields silver coated fibers enabling the development of e-textiles that behave and perform like conventional textiles in terms of robustness, flexibility and haptics, but are capable to be used as interconnection platform for technology empowered clothing.

Thin insulating coatings have successfully been applied to conductive plasma-metallized monofilaments by dip coating processes using UV-curable PU dispersions. SEM images of the coated fibers show that the coatings are smooth and uniform (Figure 3). Clean surfaces within the multi-step/multilayer processing were found to be a key parameter.

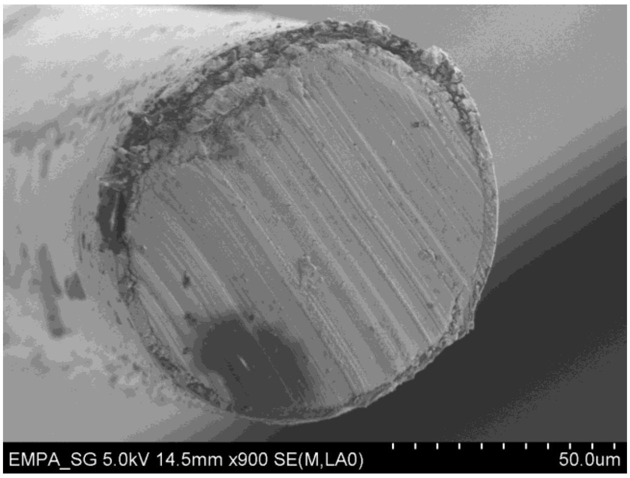

Fig. 3. Cross-sectional SEM image of a PU coated PA6.6/silver fiber showing uniformity and thickness of the coating.

As expected, according to the LLD theory developed by Landau, Levich and Derjaguin for dip-coating of fibers using Newtonian fluids [11], the resulting coating thickness increases with increasing dispersion viscosity and withdrawal speed. We have achieved coating thicknesses as thin as 800 nm using a pure PU dispersion at the withdrawal speed of 1.5 m/min.

Although the UV cured coatings have good overall properties, there are some inherent restrictions of the dip coating process in terms of velocity range, achievable coating thickness, polymer types and multifilament coating. Overjacketing extrusion has the potential to overcome these limitations, which makes it a very promising complementary method to dip coating. In contrast to the dip coating procedure, a higher coating velocity leads to thinner coatings, giving the possibility to achieve thin coatings even at high velocity, or thick coatings also at low velocity.

We succeeded in producing highly flexible bicomponent POFs on a melt-spinning plant. The o-fibers can for example be applied as near-to-body sensors for monitoring functions. Due to irregularities in the core-sheath interface, the light attenuation is still too high (around 10 dB/m). There is ongoing work to overcome this problem.

Two different sensors based on o-textiles were developed. The first sensor principle is a pressure sensor in which POFs were integrated into an atlas weave (Figure 4).

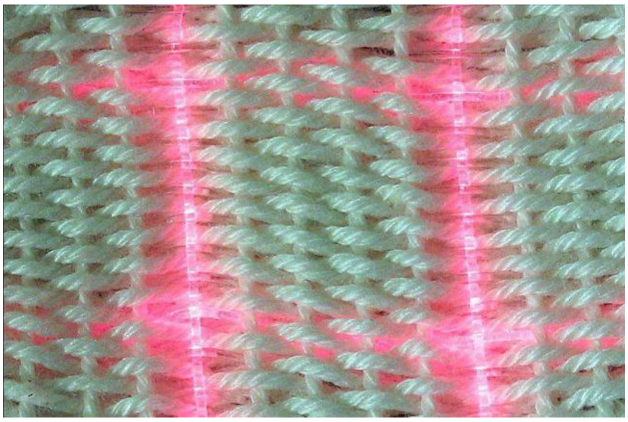

Fig. 4. Pressure sensitive woven fabric with embedded POF [12].

Due to the rubbery material property (thermoplastic and elastic silicone) of the POFs, the fiber cross-section changed under pressure, disrupting light transmission (Figure 5). As a result we could produce a location-dependent touch- and pressure-sensitive fabric.

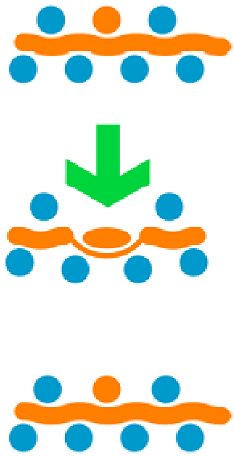

Fig. 5. Schematic representation of the pressure sensor function of elastic POFs.

The second sensor principle was realized using woven and embroidered samples of POFs to build a wearable pulse oximeter inside a cotton glove. Light with two different wavelengths was used to measure the oxygenated and the deoxygenated hemoglobin, respectively. From the adsorption, the arterial oxygenation (SpO_2) could be calculated.

4 Conclusions

Conductive plasma-metallized fibers were successfully produced and dip-coated with UV-curable PU dispersions. Good insulation and mechanical properties which are essential for integration of these e-fibers in textiles are obtained. By optimizing the critical parameters of dip-coating, micro- and nanoscale coatings on fibers can be achieved. Overjacketing extrusion is a very promising complementary method to dip coating, extending the range to higher coating thicknesses and additional polymer types.

Bicomponent melt-spinning of core-sheath monofilaments proved to be a promising way to produce POFs that can be integrated into textiles using standard weaving, knitting or embroidery techniques. These POFs enable the development of highly flexible fabrics for sensing and irradiation applications. In combination with the electrically conductive fibers, these core textile modules enable the design and manufacturing of truly wearable functional clothes.

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