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Hard coatings by plasma CVD on polycarbonate for automotive and optical applications

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Abstract

In many applications, plastic surfaces need coatings as a protection against abrasion or weathering. Leybold Optics is developing Plasma CVD processes and machinery for transparent hard coatings (THC) for polycarbonate parts. In this paper we present the current features and remaining challenges of this technique. The coatings generally show excellent adhesion. Abrasion resistance is superior to commonly used lacquers. Climate durability of the coating has been improved to pass the tests demanded by automotive specifications. Current activities are focused on improving the durability under exposure to UV radiation. Estimations show that our high-rate plasma CVD hard coating process is also economically competitive to lacquering.

Keywords: Plasma CVD; Transparent hard coatings; Polymer substrates; Weatherability

1. Introduction

Glass is increasingly replaced by plastics in many fields due to advantageous properties: lower weight, higher freedom of design and higher safety (no splintering). Disadvantages of plastics compared to glass are softer surface and sensitivity to weathering. These disadvantages are compensated by transparent hard coats. Thus, many ophthalmic lenses, a variety of displays and in recent years, almost all car headlight lenses and some glazing components have been made from plastics instead of glass. The most common plastic material for these applications is polycarbonate. Today, the hard coating is commonly applied as lacquer. The lacquering technique has some disadvantages:

– scrap rate is high, especially on parts with complex geometry, and
– involved chemical solvents cause environmental concerns.

Leybold Optics is developing a vacuum plasma CVD process for applying a transparent hard coat on plastic parts.

2. Requirements

We identified two main application fields for transparent hard coat on plastics:

– optical applications, such as eye glass lenses or display covers, where the hard coat is combined with additional optical functionality such as anti-reflection coatings, and
– protective coatings of transparent plastic parts in the outer skin of automobiles, such as head lamp lenses or glazing parts.

For the first application, we have shown an industrial solution in the past [1]: the OPTOLINE machine combines plasma CVD hard coat including a diffraction index matching layer with a reactive sputtered anti reflection coating.

Requirements for the second field – transparent hard coat for automotive applications – are summarized in

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Table 1
Requirements for transparent hard coats on plastics in automotive applications

Property	Requirements
Economical	
Coating cost	<10 €/m^2
Cycle time	<5 min
Coating area	>0.3 m^2
Mechanical	
Adhesion (cross hatch, tape test, 2 peels)	No delamination
Abrasion resistance (Taber™ Test, 1000 cycles, 2 × 500 g, CS-10F)	Δ Haze <4%
Optical	
Transmission, haze	>70%, <1%
Color	neutral (a^*, b^* ~0)
Thermal durability	
Heat storage (28 days at 90 °C)	No visible defects
Boiling water (2 h)	
Temperature change (10 cycles: 4 h at 90 °C and 80% R.H., then 4 h at −40 °C)	
UV weathering	
WOM-Test (3000 h WOM Florida)	No visible defects

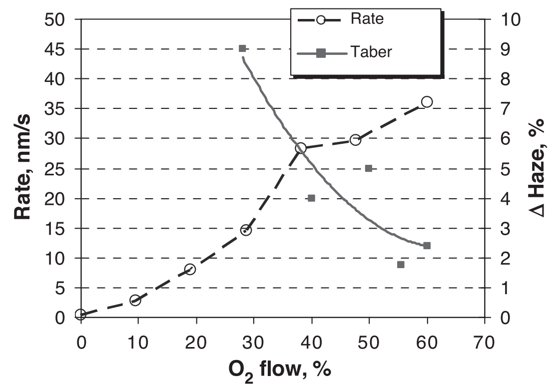

Fig. 2. Influence of oxygen flow during the THC process on the deposition rate (open symbols) and the abrasion resistance (filled symbols; measured as haze increase after 1000 cycles Taber™ Test, 2 × 500 g, CS-10F) of coatings.

Table 1. These requirements are derived from automotive industry specifications.

3. Experimental

3.1. Selection of coating technology

To find a suitable coating technique, we considered the specified coating properties. The following arguments lead us to select the Plasma CVD technique for transparent hard coatings:

A) Coating costs below those of current lacquering solutions (approximately 10 €/m^2) must be reached. Thus, the machine's contribution to coating costs in the range of 200,000 € per square meter (of machine size) per year must be distributed onto many production cycles. Estimations show that the machine has to run at least 12 cycles per hour, each producing a 4 to 5 μm thick coating. Conclusion: a deposition rate of >1 μm/min is necessitated by economic considerations. The same requirement follows from combination of substrate molding machine and hard coating machine in the manufacturers work flow.

B) The plastic substrates are damaged by high temperatures, UV radiation or high energy ion bombardment. Thus, we need a "soft" deposition technique, running at substrate temperatures well below the glass temperature of the polycarbonate substrates (approximately 130 °C) and avoiding high UV or ion flux intensities.

C) The elastic properties of the coating need to be adjustable: thermal expansion coefficients of substrate and the desired glass coating differ. Thus, simple quartz coatings on polycarbonate crack and delaminate very fast under thermal stress. To meet specified thermal durability, the coating has to match the elastic proper-

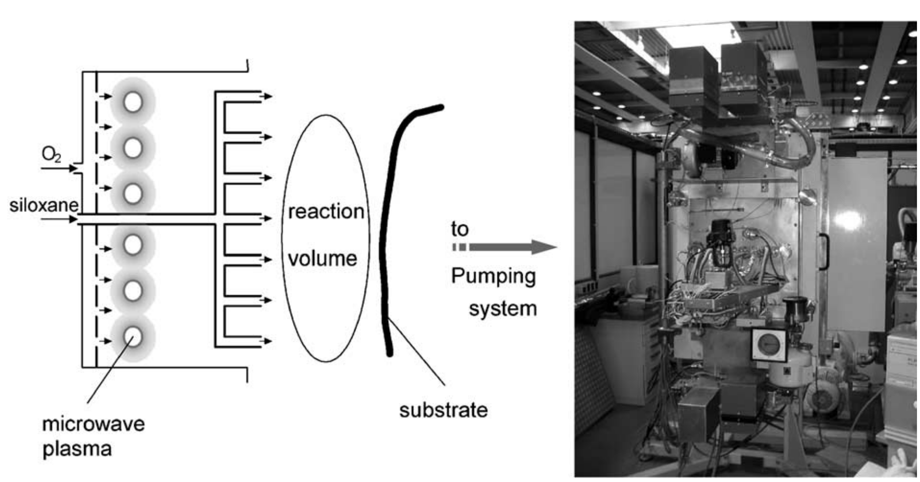

Fig. 1. Left: schematic of Plasma CVD reactor, right: One of our laboratory Plasma CVD machines (coating area approximately 0.3 m^2).