CIRP Journal of Manufacturing Science and Technology xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

CIRP Journal of Manufacturing Science and Technology

journal homepage: www.elsevier.com/locate/cirpj

Resource efficient low power laser cleaning of compact discs for material reuse by polycarbonate recovery

Claudio Leone [a,b], Silvio Genna [b], Alessandra Caggiano [a,c,*]

[a] University of Naples Federico II, Department of Chemical, Materials and Industrial Production Engineering, P.le Tecchio 80, 80125 Naples, Italy
[b] University of Naples Federico II, CIRTIBS Research Centre, P.le Tecchio 80, 80125 Naples, Italy
[c] Fraunhofer Joint Laboratory of Excellence on Advanced Production Technology, P.le Tecchio 80, 80125 Naples, Italy

ARTICLE INFO

Article history:
Available online xxx

Keywords:
Laser cleaning
Resource efficiency
Material reuse
Polycarbonate
Compact disc
Fibre laser

ABSTRACT

This paper deals with laser cleaning of compact discs with the aim to recover the polycarbonate layers and allow their reuse for further applications. A low power 30 W MOPFA and Q-switched pulsed Yb:YAG fibre laser is employed to ablate the metal substrate located between the polycarbonate layer and the outer serigraphy of the CDs. Compared to traditional cleaning processes, this method offers low environmental impact and greater flexibility of use. Two experimental test series are carried out to investigate the interaction mechanisms involved in the process and the effect of the process parameters on the mechanism of separation. The final aim is to identify the process conditions that could ensure a 100% cleaned surface without polymer degradation and evaluate the process time required to clean a CD.

Introduction

In the last years, resource and energy efficiency of products and processes has become a key issue in manufacturing decision-making due to increasing energy and material costs and their high environmental impact [1]. Energy efficiency is deeply examined at different levels, including process, machine, production line, and factory [2,3]. New approaches are directed towards the investigation of the environmental impact of products during their entire lifecycle. The so-called "cradle-to-grave" analysis studies the impact of a product from the raw material extraction, processing and transportation, to the finished product manufacturing process and eventually to its usage and end-of-life, as reported by Kara et al. [4]. In some cases, the energy and material value are still significant at the end of the product life: recovering this valuable content allows to reuse it for a second product lifecycle or even for a different application, according to a "cradle-to-cradle" approach. In line with this view, this paper deals with the recovery of polycarbonate layers through a resource efficient laser-based process consisting in low power laser cleaning of compact discs (CDs) for material reuse.

A CD is an optical disc employed to store sound or information in digital format. CDs generally consist of four superimposed layers: a polycarbonate disc layer (120 mm diameter, 1.2 mm thickness and 15 ÷ 20 g weight), a reflective metal layer made of aluminium, silver or golden alloy, a lacquer layer to prevent oxidation and a printed screen on the top of the disc. The first CD prototypes, which represent an evolution of LaserDisc technology, were developed in parallel by Philips and Sony in the mid-to-late 1980s [5]. The two companies then collaborated to produce a standard format and the related player technology which became commercially available in 1982 [5,6]. Since then, the CD market has gone through a continuous growth up to 2002 when more than 7 billion units were sold. Afterwards, following the diffusion of other digital formats (e.g. the so-called liquid music), the CD market significantly decreased and nowadays it amounts to approximately 3 billion sold units per year (in 2011) [7]. As regards the polycarbonate (PC) market, on the other hand, it reached around 3.7 million metric tons in 2012 (16% of which was used for Optical Media) and a further growth is expected in the next years [7]. The growing demand characterising the polycarbonate market calls for effective and efficient ways to recover PC material waste starting from its production up to the end of the products lifecycle. Polycarbonate scrap resulting from the polymerisation and compounding phases is generally efficiently recovered directly on-site. Post-production waste material leaving the industrial plants is currently recovered to an extent of about 90% in all European countries, where the majority is mechanically

* Corresponding author at: University of Naples Federico II, Fraunhofer Joint Laboratory of Excellence on Advanced Production Technology, Department of Chemical, Materials and Industrial Production Engineering, P.le Tecchio 80, 80125 Naples, Italy. Tel.: +39 0817682371; fax: +39 0817682362.
E-mail address: alessandra.caggiano@unina.it (A. Caggiano).

http://dx.doi.org/10.1016/j.cirpj.2015.01.005
1755-5817/

recycled to special polycarbonate and polycarbonate blend "recycling grades". Presently, post-consumer recycling of polycarbonate is common for applications where high volumes are available and no sorting is necessary, while in case of complex collection and/or dismantling/sorting steps, energy recovery is the option of choice [8].

Waste CDs, which are manufactured with top-grade high-quality PC, may represent an important and relatively cheap material source compared to natural sources. As a matter of fact, there is a high amount of CDs coming from industrial waste (about 1% of the total production) and from unsold stock, which have to be destroyed. Moreover, CDs are not long-lasting supports as they are subject to ageing phenomena, especially due to the metal layer oxidation. Therefore, the opportunity to separate the PC disc layer from the other layers of old and scrap CDs represents a valuable opportunity for material recycling and waste reduction. This is in full agreement with the EU directives on waste collection, reuse, recycling and disposal, which is driving industry towards new solutions for cost-effective and efficient recycling processes (EU Waste Framework Directive 2006/12/EC, 2008/98/EC and European Commission legislative proposal of 2 July 2014 [9–11]).

However a the key factor for the CDs recovery is the technology adopted for the PC recovery that requires, at the same time, low cost, low energy consumption (high energy efficiency) and low environmental impact.

Nowadays, different technologies are used to separate a polymeric film from substrate layers. Coberth and Ceyssons [12] have studied the use of abrasive fluidized bed machining, Miles et al. [13] the application of barrel finishing and polymers blasting, Shishkin et al. [14] the use of dry-ice blasting, Babets and Geskin [15] the waterjet and Operowsky [16] the chemical etching. As regards their application in CD cleaning, not all these processes are efficient for treating thousands of CDs simultaneously, neither are they flexible enough to be adapted to small batches. The use of abrasives or solvents could cause environmental problems and contamination of the recovered material. In addition, disposal of exhaust abrasives and chemical solutions after use should comply with the extremely severe EC directives. In the recent literature, a novel process to obtain polycarbonate separation in CD-Rs as well as DVD-Rs based on the use of cold arc discharge was presented by Lin et al. [17–19]. In this process, a high voltage-high frequency arc is used to instantaneously heat the metal cladding material. Due to the different expansion coefficient of plastics and metal cladding material, a fracture is generated and the coating layers can be easily stripped from the disc surface. 10 s are necessary to remove most of the layers from the surface of a single CD or DVD. However, an additional step is required to remove the remainder metal cladding.

Laser cleaning represents a promising alternative to the traditional cleaning processes. This method offers several advantages, including: absence of mechanical contact or tool wear, reduction of secondary pollutants (exhaust abrasives or chemical solutions), low energy consumption, greater flexibility of use and the possibility to work both small and large batches. Examples of applications of this process in paint or coating removal are reported in Schmidt et al. [20], Barletta et al. [21], Leone et al. [22], Singh et al. [23], Arif and Kautek [24], Chen et al. [25].

In the literature, there are only a few number of laser applications for CD or CD-R cleaning [26–30]. The technique presented in this research work is based on the application of a laser beam, moved through two galvanometric mirrors, following predetermined patterns to ablate the unwanted layers without damaging the polycarbonate layer [30]. In Fig. 1, two schemes of the CD laser cleaning process are illustrated. In the first one (Fig. 1a), the laser beam runs along a spiral path over the CD; in the second one (Fig. 1b) the laser runs along a linear path filling all the CD area. A novel process based on diode laser irradiation has been presented by Barletta et al. [28], with reference to the application on a Compact Disc-Recordable (CD-R). The purpose is to recover two of the main CD-R constituents, the PC substrate and the silver reflective layer, without any damage or thermal alteration of the PC substrate. In this process, the laser beam is used to ablate the cyanine layer placed between the metal substrate and the PC layer, following a spiral geometrical pattern. The minimum time required to clean a CD-R with a beam power higher than 250 W is 5 s. However, it is worth mentioning that the physical structure of a CD-R is rather different from that of a standard CD. As a matter of fact, in a CD-R the additional cyanine layer located between the PC layer and the metallization layer (organic dye for the pit realisation during writing) can be very easily burnt even with a low

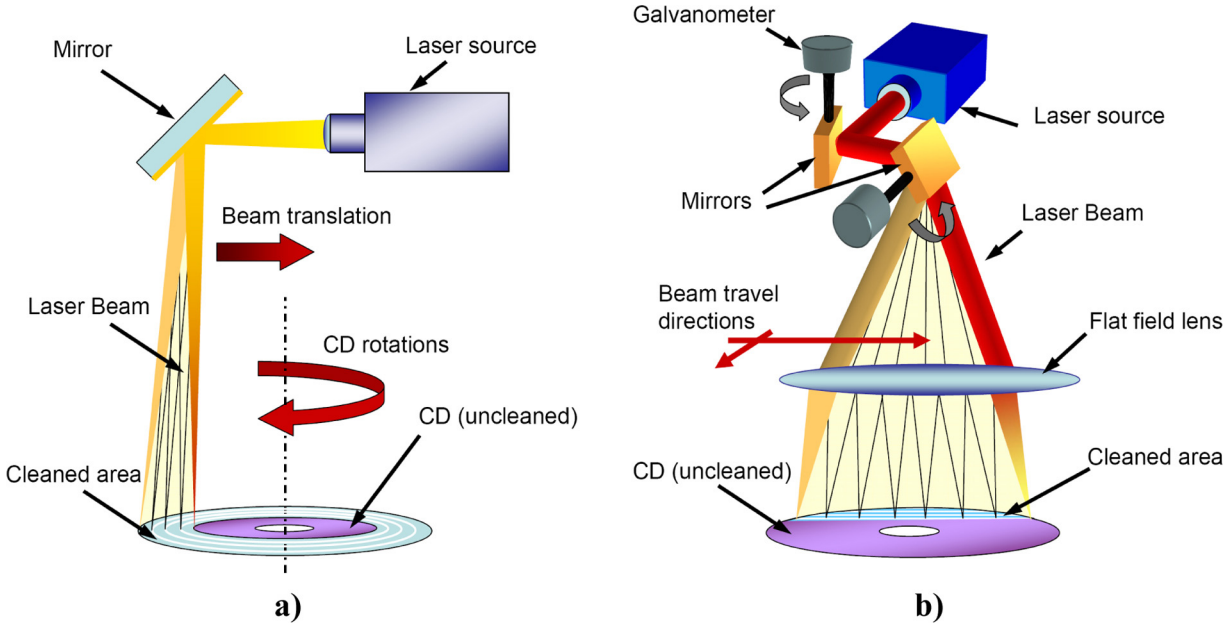

Fig. 1. Scheme of the CD laser cleaning process: (a) the laser runs along a spiral path over the CD; (b) the laser run along a linear path filling all the CD area.

Please cite this article in press as: Leone, C., et al., Resource efficient low power laser cleaning of compact discs for material reuse by polycarbonate recovery. CIRP Journal of Manufacturing Science and Technology (2015), http://dx.doi.org/10.1016/j.cirpj.2015.01.005