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Improving copper plating adhesion on glass using laser machining techniques and areal surface texture parameters

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ABSTRACT

Glass is a promising substitute substrate material being evaluated for electronic packaging technology. Improving the electroless copper plated layer adhesion of the glass is one of the most important considerations for development of the technology. An excimer laser (248 nm) was used for structured texturing of glass surfaces (to improve adhesion) by changing mask dimensions, laser operating parameters and overlapping pitch spacing, and therefore producing a range of micro-scale features. Electroless plated copper adhesion strength was assessed using quantitative scratch testing, demonstrating that micro-patterned structures can significantly improve copper/glass adhesion. New ISO 25178 Part 2 areal surface texture parameters were used to characterise the surface roughness of ablated glass surfaces, and correlated to the scratch testing results. Highly correlated parameters were identified that could be used as predictive surface design tools, directly linking surface topography to adhesion performance, without the need for destructive adhesion quantification via scratch testing.

1. Introduction

Glass is a promising substitute substrate material which is being developed for use in electronic packaging technology and high density interconnect applications [1]. However, metallisation on smooth glass surfaces is difficult due to the physical, chemical and mechanical mismatches between the metal coating and the glass substrate [2,3]. Without adequate adhesion, metallised coatings tend to delaminate and not perform the task for which they are intended. Improving the plated layer adhesion is, therefore, one of the most important considerations for development of glass substrate technology, although previous work has mostly considered the development of the interface chemical layers to promote active surfaces for copper deposition, or physically channelling glass and back-filling with copper [4], rather than relying on discrete surface modification.

The fundamental principles relevant to an understanding of the influence that interfacial roughness may have on adhesion have been well developed and discussed [5,6], with surface pretreatment being one of the decisive factors for achieving a high-quality adhesive joint [7]. Previous work has identified that micro-columnar array (MCA) structures, produced by laser surface modification, could enhance the adhesive bonding strength for metals, alloys and ceramics [8–10]. The idea that adhesion depends on the mechanical interlocking of the adhesive with surface roughness is frequently discussed in the literature and is believed on a wide scale. According to this idea, mechanical adhesion occurs by the penetration of adhesives into pores, cavities and other irregularities on the surface of the substrate [11]. Therefore, increasing the roughness and structure formation on the glass substrate surface is thought to be a key enabler to improving copper/glass coating adhesion performance.

Whilst a number of mechanical or chemical techniques can be used to etch or machine glass [12], excimer lasers can be more effectively used for machining micro-structures on glass because of their potentially high machining accuracy [13]. Excimer laser systems are capable of machining micro-structures with feature sizes typically of the order of 1–100 μm and are applicable for glass-based materials [14]. Compared to visible wavelength lasers, the short UV wavelength range and pulse time (~20 ns) of eximer lasers allows the beam to be focused to a smaller spot, to obtain higher intensities and to have a smaller heat-affected zone at the work piece [15] for the effective removal of material from a target area. Likewise, such laser attributes allow for high resolution and high absorption in machining, which are important in making micro-structures with glass-based materials.

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Depending on the electron-lattice coupling characteristics of the target material, excimer lasers are used in micro-machining applications to remove material from substrates, through the ablation mechanism, by either photo-thermal or photochemical mechanisms, or by a combination of the two [16,17]. The photochemical mechanism is often referred to as a non-thermal process because the material removal is caused by direct chemical bond decomposition as energy is absorbed, whereas in the photothermal process, the absorption laser energy is converted to lattice vibrational energy (thermal) causing melting and vaporisation of the material [18].

Glass can be removed without generating a large amount of heat during ablation, which can damage or shatter the surrounding material as a function of initial micro-cracking. This issue is especially important for brittle materials, although post-machining annealing techniques can be used to mitigate micro-cracking. The ablation mechanism with different glasses depends strongly on the composition of the glass. For a krypton fluoride (KrF) excimer laser, photons with a wavelength of 248 nm have an energy of approximately 5 eV, which is sufficient to break chemical bonds, causing a sudden pressure increase within the absorption region and ejecting material in an explosive manner into vapour and particles [19]. Since excimer laser pulse durations are short, the interaction with the material occurs very rapidly, and the opportunity for thermal damage to the surrounding material is minimised. Subsequent development of laser technology is focussing on establishing the benefits of using nanosecond, picosecond and femtosecond laser sources for materials modification, with work being reported on the patterning of glasses, semiconductors and dielectrics [13,20].

Whilst much work has been published over the years concerning the development of excimer laser systems and associated materials modification studies, comparatively little work has been reported concerning the relationship between laser operation parameter settings and machined surface roughness, especially in the context of the new ISO 25178 Part 2 areal surface texture parameters that have been developed over recent years for three dimensional surface texture characterisation [21–23]. When measured and reported, the surface texture of ablated structures has normally been assessed in the form of 2D surface profiles and ISO 4287 profile parameters, such as *Ra* [24].

The research reported here considers how to improve the mechanical adhesion of electroless copper plating to a glass substrate, as a function of laser machining parameters, and the production of a variety of novel micro-patterns. The result is complimented by an analysis of the applicability of ISO 25178 Part 2 areal parameters in the context of using them to describe these machined surfaces, correlating them with traditional scratch testing results of adhesion quality, and using them as potential predictive design indicators for the quality of the plating adhesion between copper and glass. The measurement of ISO 25178 Part 2 areal parameters would then obviate the need for destructive quantitative testing. It should also be noted that the eventual aim of the longer-term research and development, is to be able to machine circuit tracks into glass, thus large area surface patterning or structuring is desirable.

2. Laser setup

A KrF excimer laser (model EMG 203, Lambda Physik), operating at 248 nm, was used for machining commercially available uncoated CMG specification glass. CMG was chosen as a substrate material due to its thermal expansion coefficient, a key requirement for prototype glass substrates in order to minimise differential thermal expansion and residual stress with respect to silicon-based components. CMG glass is a borosilicate-type glass with a nominal cerium dioxide content and highly absorbing of light with a wavelength shorter than approximate 320 nm, providing a comparatively low ablation threshold and accurate ablation contours [13]. The glass sheets were supplied as square samples (lateral size 40 mm × 40 mm, thickness of 100 μm and 500 μm respectively).

The duration of each laser pulse was fixed at 20 ns. The laser beam passed through a beam delivery system (consisting of several optical components for beam expansion, shaping, scanning and image projection) that folded the beam in the vertical and horizontal directions and then projected onto the mask plane where it was passed through different sized and shaped mask apertures (1:10 image reduction at the work piece), thus tailoring the shape and size of the beam at the work piece as shown in Fig. 1 [15]. Note that the glass substrates were mounted on a computer numerically controlled (CNC) *X–Y* table using G-Code programming. The laser system parameters included: output fluence or energy density, shots per area, and repetition rate; these being varied and optimised according to the surface topography requirements of the samples. Different brass masks with square, circular and triangular apertures (typically 1 mm in side length) were placed at the mask plane to tailor the size and the shape of laser beam projected onto the work pieces.

3. Laser operation parameters study

Energy density, shots per area and pulse repetition rate are routinely used parameters in the literature [25,26]. These basic laser operation parameters were investigated systematically before the production of structured surfaces. This investigation was achieved by machining a matrix or grid of ablated features using a 1 mm circular mask, with one laser parameter being investigated per grid (e.g. energy density) – single position ablation producing vertical wells at each grid position. Mask dragging techniques were not employed at this stage.

3.1. Laser fluence

The energy density or the laser fluence, which is typically measured in [J cm^{-2}], represents the energy input delivered into the work piece per unit surface area. This parameter is important for characterising the interaction process between the laser radiation and the work piece processing quality. Both the output pulse energy and attenuator position setting, which determine the energy density of the excimer laser, were pre-set by the CNC control system and, therefore, contributed to the etched depth and surface texture of the machined profiles. Energy density

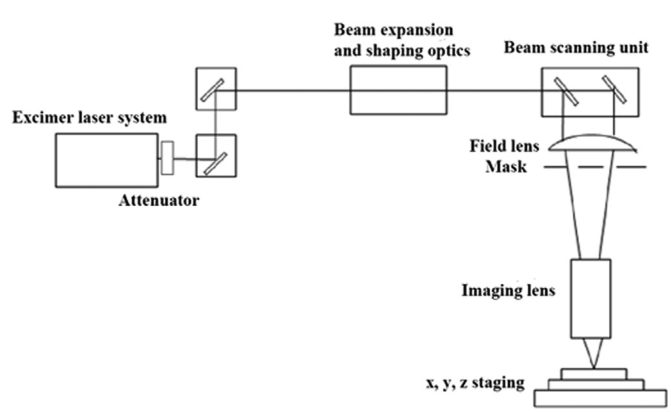

Fig. 1. Schema showing the excimer laser setup.