Chapter 3

NEW METHODS FOR LASER CLEANING OF NANOPARTICLES

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1. INTRODUCTION

There are several types of laser cleaning, based on different underlying physical processes. The first one is called “ablative cleaning”, where the undesirable particle or thin film is deleted from the surface due to direct ablation. Arthur Schawlow carried out the first demonstration of this type of cleaning. He proposed the "laser eraser" in 1965, using different absorptivities of paper and ink to remove the ink without damaging the underlying paper (Schawlow, 1965). Ablative cleaning is the basis of an important technological process related to laser cleaning of organic contamination on microelectronic devices (Hong, 2002). Another important application of the ablative mechanism is in laser cleaning of artwork, e.g. painting restoration and cleaning of antique marble (Zafiropulos, 2003). However, the application of this method for a selective ablation of nanoparticles from the surface is questionable because of the strong decrease in absorption of nanoparticles with decreasing size.

The second type of laser cleaning is the so-called “Steam Laser Cleaning (SLC)” (the term was suggested by A. C. Tam (Zapka, 2002)). A high particle removal efficiency can be achieved with this method when a thin liquid film is present on the substrate surface during laser irradiation (Assendel'ft, 1988; Petrov, 1989; Zapka, 1991). SLC is achieved with the momentum transfer during the explosive vaporization of the liquid layer. This is quite a complicated process and many papers were devoted to the
analysis of this process (Lang, 2004; Lang, 2003; Leiderer, 2002). It was found that the cleaning threshold for SLC is practically "universal" (Lang, 2003; Mosbacher, 2000). It does not at all (or at most weakly) depend on the particle size and material. The process of bubble nucleation in liquid is assumed to play the basic role here. This method can provide the removal of at least 100 nm sized particles from a solid surface (Lang, 2003; Mosbacher, 2000; Zapka, 1991).

The IBM group found another important regime of laser cleaning – the so-called "Dry Laser Cleaning (DLC)." Initially it was assumed that the acceleration of the particle arises due to thermal expansion of material during nanosecond pulse laser heating (Tam, 1992) and the small particles do not perturbate the local field around the particle. However, recent publications (Münzer, 2002; Mosbacher, 2002b; Graf, 2005) have proven that in DLC, scattering of radiation by contaminant particles plays an important role in the cleaning process. For example, a small transparent particle can work as a near-field lens, which leads to a strong field enhancement. Depending on particle size, material and geometry the field enhancement may be up to a factor of 100 (Luk'yanchuk, 2000b). This produces a nonstationary 3D distribution of temperature which can give rise to local ablation. It has great potential in technological applications of nanostructuring of surfaces (Denk, 2003; Huang, 2002; Lu, 2000; Mosbacher, 2002a; Mosbacher, 2001; Münzer, 2001) and imaging of near-field distributions (Leiderer, 2004; Münzer, 2002; Wang, 2005).

The fourth successful idea in laser cleaning utilizes the excitation of nonlinear surface acoustic waves and phonon focusing (Kolomenskii, 1991, 1998). However, this method also leads to surface destruction and cannot be applied for cleaning of microelectronic devices.

Lately the method of small particle removal, based on the action of pulsed laser-induced plasma and shock waves, attracted a lot of attention (Cetinkaya, 2002; Hooper, 2003; Lee, 2001; Lim, 2004, 2005; Wanderwood, 2003). In this method the laser initiated plasma and shock waves during optical breakdown above the surface in the surrounding media lead to particle removal. Particles over 1 μm can be efficiently removed by this method.

The efficiency of different laser cleaning methods was summarized in (Kane, 2002). From the tables in that paper it can be clearly seen that the smallest size of removed particles was in the order of 100 nm in diameter (papers published before 2002). This is comparable to the capabilities of megasonic cleaning systems (Vereecke, 2005), which are used at present in semiconductor device fabrication lines, but do not meet the future requirements in this field. The International Technology Roadmap for Semiconductors (ITRS, 2004), is considering a 1/2 pitch of 50 nm which