Environmentally Sound Photoreactive Cleaning

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ABSTRACT

A new laser-based dry processing tool and technology for semiconductor cleaning and surface conditioning is presented. The technology was originally developed for photoresist removal, but has been successfully applied to a wide variety of applications and end uses. This paper will describe the technology and XLC-100 system being commercialized.

Keywords: photoreactive, cleaning, dry processing, ultraviolet laser

1 INTRODUCTION

Current cleaning methods used in the manufacture of semiconductor, thin film head, MEMS, solar cells and CD's use large footprint, complex tools such as wet benches and plasma ashers, along with significant volumes of toxic and corrosive chemicals and highly purified water [1]. There are several problems with current methods, including the high cost of the equipment used to clean, the cost of the chemicals and water, and the cost of waste treatment of by products. Further, the solvents and corrosive chemicals used throughout the world to make these devices are being slowly banned from industrial use to protect our planet and human health.

Finally, technology itself is making the current wet cleaning methods obsolete because devices in all fields are getting smaller to a point where liquids cannot penetrate the fine structures to do the cleaning; additionally, films used to make these devices are more damage sensitive, and with each technology generation, it is becoming more difficult to get good yields due to chemical damage. It has become very clear from these trends that a non-damaging, lower cost, dry cleaning method would be highly desirable. Economics and technology changes will drive manufacturers to use a new method.

2 THE TECHNOLOGY AND PRODUCT

A new type of cleaning system was developed and patented that uses laser light and gas to clean and condition surfaces. This is a dry process using near ultraviolet laser radiation and reactive gases such as oxygen. In the past, prior art attempts to clean with gas have been done with deep ultraviolet excimer lasers [2]. The experts in cleaning claimed that cleaning could not be done with wavelengths of radiation longer than 300nm [1].

Over the past 10 years, UVTech has build five generations of cleaning systems, culminating in the XLC-100, a small footprint tool with only four moving parts that is reliable and easy to use. The XLC-100 automatically processes cassettes of substrates using pre-determined gas recipes. The system typically uses oxygen and ozone gas to perform the cleaning, and has no waste-treatable by-products. A small solid-state laser provides the energy source for the XLC-100, providing long-term stability without need for servicing, a significant improvement over excimer laser technology. The XLC-100 system is shown below.

Figure 1: XLC-100 Laser Cleaning System (pat. pend.)

3 THE RESULTS

The data in figures 2 and 3 show the AFM (atomic force microscope) and XPS (x-ray photoelectron spectroscopy) results from silicon wafer analysis following the removal of positive photoresist films using the standard oxygen/ozone gas recipe in the XLC-100 system. The photoresist removal recipe was optimized over time until complete removal was achieved without damage to the wafer surface. The carbon detectability limit was reached and repeated on samples for over one year before testing was concluded.

The graph below shows the results of multiple experiments where the XLC-100 was used to remove a blanket coating of Rohm & Haas 1818 photoresist from unpatterned silicon wafers. The oxygen/ozone gas and laser light completely removes the organic film down to the limit of detectability of the analytical method.

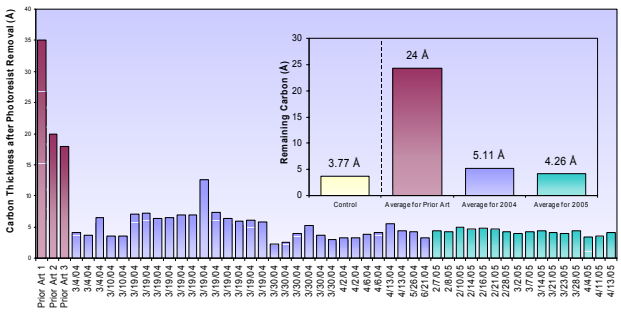

Figure 2: XPS Analysis data from multiple experiments over a three-year period.

In semiconductor cleaning applications, complete cleaning must be accompanied by the complete absence of any surface damage [3]. The atomic force microscope is the instrument of choice to analyze a surface, and the AFM photos below show a silicon wafer surface before and after cleaning with the XLC-100, revealing that there is not substantive change in the surface post-cleaning. Current wet cleaning methods add some degree of surface roughening to the silicon wafer surface, a problem that can reduce the product yields.

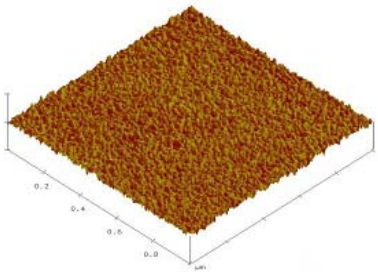

Figure 3: AFM image of a control sample of silicon with a RMS deviation of 1.54Å

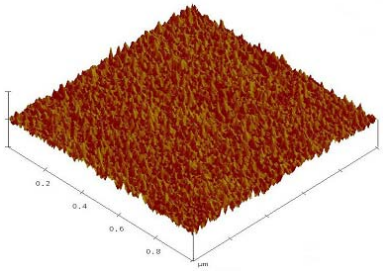

Figure 4: AFM image of a sample of silicon where Rohm & Haas 1818 was removed on the XLC-100. The RMS deviation of the sample is 2.43Å.

4 THE APPLICATIONS

The combination of laser light and gas open up a wide range of potential applications for this new technology. While initially focusing on cleaning, the XLC-100 system has been tested in several key process steps used in semiconductor processing, including annealing of metal films, curing of polymer layers, growing of oxides, and other oxidation and reduction reactions. These are summarized below.

4.1 Direct Imaging

The XLC-100 in this application is a direct lithography tool for curing a polymer film. Following programmed exposure of various shapes, the exposed coating is developed in a developer and the imaged areas are cross-linked into a hardened epoxy, and become the final parts. In the examples below, the gear structure is part of a MEMS (micro electronic mechanical systems) device.

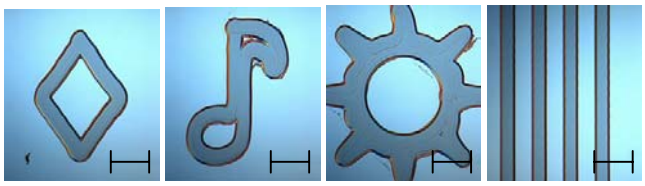

Figure 5: Direct imaging of an epoxy polymer with the XLC-100. The scale in each image is 500µm long.

4.2 Copper Annealing

The scanning laser beam along with a specific gas recipe can be applied to thin film annealing applications. Many of the films used in semiconductor processing require annealing to remove stresses or re-arrange the structure of the material. The example below was a 'proof-of-concept' test to make copper reach its melting point. The principal advantage of the XLC-100 is that the process does not require any heating, and the laser interaction with the film, at near-visible UV wavelengths, results in 'cold flow' due to the very short wavelength of light and its scattering outward away from the substrate. This is a low cost, rapid and a thermal process to replace oven and furnace anneals.

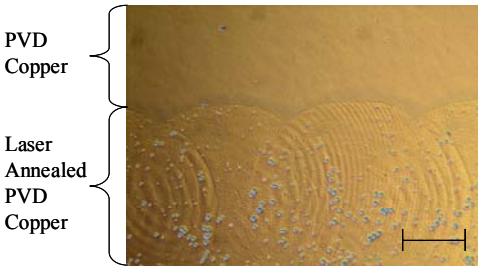

Figure 6: 1500Å of PVD copper annealed with the XLC-100. The scale in this is 125µm long.

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4.3 Copper Oxidation

The photo below shows a wafer where 1500 angstroms of PVD (photodeposited) copper has been oxidized with three different sets of scanning parameters to produce three different thicknesses of copper oxide. The gas recipe for this was a standard oxygen/ozone mix. Oxidation, like annealing, typically involves oxide furnaces, high heat, and is not a naturally clean process. The XLC-100 oxidation process occurs at room temperature, is rapid, and inside the system nitrogen purging keeps everything very clean.

Figure 7: Three 'bands' of copper oxide grown with the XLC-100 tool and process.

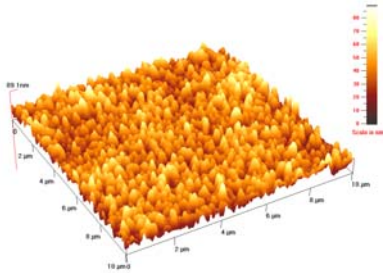

Figure 8: AFM image of a copper oxide surface with a RMS deviation of ~16Å.

4.4 Selective Film Removal

A common problem in semiconductor processing is the removal of a build-up of resist from spin coating wafers, called 'edge bead'. The thick resist around the rim of wafers caused contamination later in processing, impacting yields. The XLC-100 system in this example was programmed to write a circular pattern around the rim of the wafer, and in less than 1 minute, with the oxygen/ozone gas flowing, the edge bead is quickly and cleanly removed.

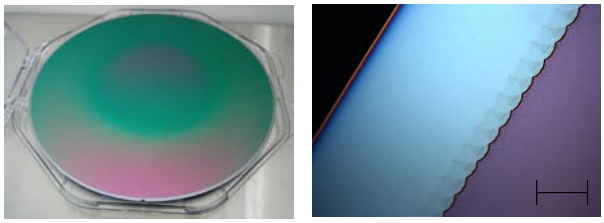

Figure 9: 200mm wafer with resist edge bead removed (left) and close up of removed resist (right). The scale in the image is 500µm long.

4.5 Ion Implanted Photoresist Removal

The most difficult organic film removal application in semiconductor processing is removal of high dose ion implanted photoresist. The ion implantation process creates a thin, carbon-like crust on top of the resist layer, and very corrosive chemicals are used to get this off in a complex, multi-step process. The photographs below shows how high dose ion implanted resist is removed in two short, dry steps using the XLC-100.

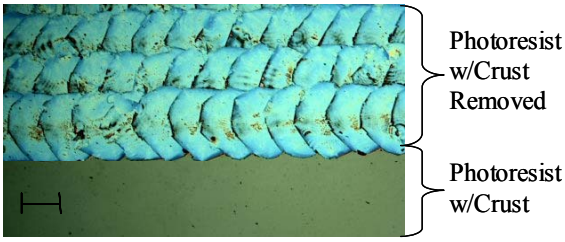

Figure 10: Step 1 – The carbonized crust is removed with a proprietary gas recipe leaving the soft underlying photoresist intact. The scale is 200µm long.

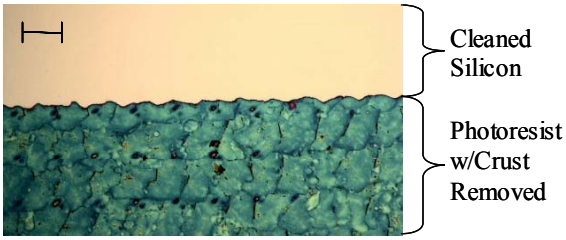

Figure 11: Step 2 – The underlying photoresist is removed with an oxygen/ozone recipe. The scale is 200µm long.

The UVTech process replaces the current method which requires a large wet bench with large volumes of acids and deionized water, a microwave plasma asher, and an alcohol dryer [4].

5 SUMMARY

A new environmentally sound surface cleaning technology and product has been developed and is being commercialized in multiple industrial applications, including thin film heads, optical elements, and other electronic and semiconductor devices. The technology is based on the interaction of laser radiation and gases, and the product is a small footprint, reliable system with only four moving parts that has passed all the major required compliances for insertion into state-of-the-art manufacturing lines. There are both issued and pending patents on the system and the technology [5].

REFERENCES

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[5] UVTech Information Memorandum, Internal UVTech publication of UVTech Systems Inc., April, 1995.