Preparation of RIT for 157-nm Lithography

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Abstract – This project investigated the feasibility of 157-nm Vacuum UltraViolet (VUV) Lithography and its' possible utilization as a future source to extend the capabilities of optical lithography. In addition, this project undertook the initialization of VUV lithography here at RIT by the conversion of a 193-nm ArF excimer laser to a 157-nm F_2 excimer laser source. The investigation of the completed body of work on 157-nm lithography led to the conclusion that this technology is viable and may represent the last frontier with respect to optical lithography. The excimer laser at RIT was successfully retrofitted for 157-nm operation and exhibited RIT's first excitation at this wavelength on May 11, 1998.

I. INTRODUCTION

The general trends for today's semiconductor industry include the reduction of required feature sizes and the increase of on-chip density. As these trends continue, it places additional pressure on the ability of the lithography and etch community to produce viable features which can be utilized by the rest of the process. Much of this pressure lands upon the ability of lithography to successfully project and resolve images of features approaching 0.2μm (200nm). This is complicated by the approaching duality perceived in the lithography community.

It is generally noted that optical lithography, currently the dominant technology, has limits and that these limits are being approached rapidly. In this light, technologies external to optical lithography are under investigation, in search for the next major production lithography technology. These technologies include but are not limited to x-ray, EUV, e^- beam, ion beam, and SCALPEL. Many of these technologies have demonstrated promise within the confines of the research and development laboratory, but few have displayed the ability for integration or widespread use into the traditional production environment. This aspect alone is critical for the adoption of a new technology.

The deficiencies of the competing technologies and the search for a technology closely compatible with current applied processes leads to the investigation of the extension of optical lithography. Development over the last decade in lithography has seen the adoption of 436-nm (H-line), 365-nm (I-line), 248-nm (KrF), and 193-nm (ArF) wavelengths for use in production environments. The search for a source producing a useable wavelength below 193-nm, has produced the 157-nm F_2 laser. This new wavelength offers the possibility to satisfy many of the current desires for lithography. This technology offers the ability to produce features well below 0.1 μm (100nm), have increased process latitude over 193-nm lithography, have compatibility with current processes and materials, a readily available source, and relatively low expenditure. These characteristics make VUV technology an extremely attractive candidate for the near future of extreme lithography.

II. BACKGROUND

Evidence of 157-nm radiation has existed since 1977. This wavelength is produced by the $2^3\Pi_g \rightarrow 1^3\Pi_u$ transition observed under the excitation of F_2 gas. [3] This results in a quantum energy of 7.91 eV for the 157-nm photon. [2]

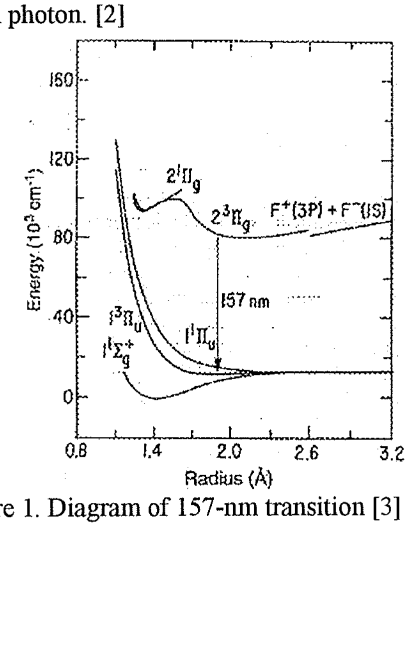

Figure 1. Diagram of 157-nm transition [3]

Since its discovery, the 157-nm source has found many uses including Laser Enhanced Chemical Vapor Deposition and ablative imaging processes. Until recently the F_2 excimer source has not come under investigation as a possible lithography source. Very early work was done at Bell Laboratories in the 1980s. This work was followed up by recent work done at Lincoln Labs. The work done at Lincoln labs included materials research, source characterization, and feature resolution. The work indicated the process latitude gained at 157-nm, the compatibility of this wavelength with current materials, and the ability to resolve features utilizing the F_2 source. With the use of a PolyVinylPhenol (PVP) silylation resist process and a dry, Reactive Ion Etch (RIE), develop, Lincoln Labs was able to successfully image 0.08 μm features. [1]

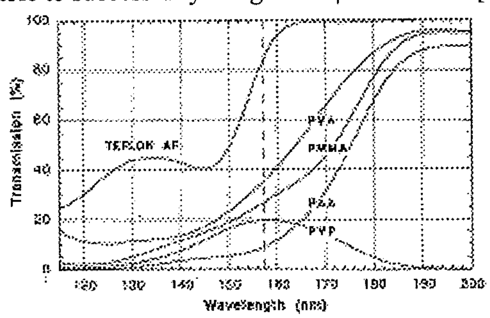

Figure 2. Graph of the transmission of typical resists versus wavelength [1]

Substrate materials are a concern at 157-nm. Typical mask substrates such as fused silica become relatively opaque at this wavelength. This leads to the search for new materials to be used in optics and as mask materials. Two of the major candidates are fluoride derivatives, Calcium Fluoride (CaF_2) and Magnesium Fluoride (MgF_2). MgF_2 has higher transmission at VUV wavelengths but is considerably birefringent. This makes it a poor candidate for optics or mask substrates. CaF_2 on the other hand is considerably less birefringent but is a somewhat brittle material and has the possibility to solarize under intense prolonged radiation. With the use of extremely high grade cerium free CaF_2, these problems can be overcome. [2]

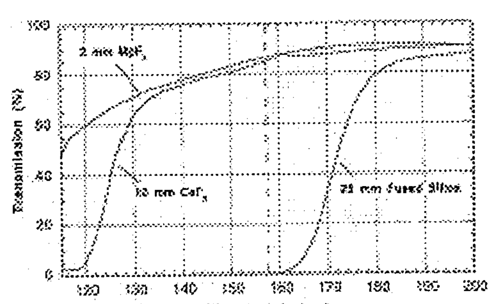

Figure 3. Graph of the transmission of substrate candidates [1]

The F_2 excimer laser source itself is a concern related to this technology. This source has been employed for various other purposes in the industry but it has demonstrated poor efficiency in the past. This has lead to numerous investigations into improving the efficiency of the laser. Despite this drawback, the F_2 excimer laser is regarded as a precise source, offering a pre-linewidth narrowing spectral full-width at half-maximum of about 17 pm. This may make it unnecessary to employ further linewidth narrowing in excess of what is currently done at 193-nm.

This constitutes the entirety of the work related to optical lithography utilizing the 157-nm wavelength.

One last element of this technology that is primarily a consideration, not a drawback, relates to the technologies name, Vacuum Ultra Violet lithography. As seen with the investigation of the mask substrates, many materials become far too opaque at wavelengths this short. This is true for air as well. 157-nm radiation is heavily absorbed in air, requiring all paths traveled by the beam to be in an evacuated state. This mandates that all elements of the laser source, mask and optics, and wafer exist in a closed chamber.

III. EXPERIMENT

RIT houses a Lumonics series 700 pulsed excimer laser. This laser was originally a KrF 248-nm source and was then converted to an ArF 193-nm source. For the investigation of VUV lithography at RIT, this laser was converted to a F_2 source of 157-nm emission.

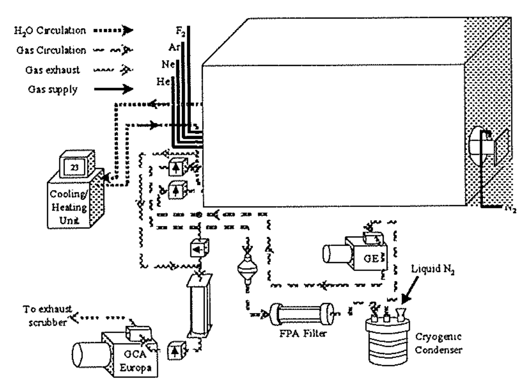

Figure 4. Diagram of RIT's excimer laser setup

Several aspects of laser operation had to be considered in the retrofit of this laser.

First, it must be understood that the normal operating conditions of the source produce gas contaminants inside the laser cavity, which deposit on the exit

surfaces, absorb 157-nm emission, and increase the difficulty involved in gas ionization. Control and removal of these contaminants is critical to maintain the stability of the laser output and to maximize gas lifetime. In this system a cryogenic gas processor was used. During operation the gas is circulated through a series of filters and then passed through a liquid nitrogen (LN_2) cooled chamber. This system removes particulates via filters and collects contaminants via condensation within the cryogenic unit. Proper operation of this unit was verified at 193-nm ArF operation before attempting a more critical F_2 gas fill. The unit was cleansed using a fluorine based passivation recipe provided by Lumonics. During the conditioning of the system, a clogged Millipore filter was discovered and due to the lack of a quick replacement and in the interest of time, a short section of copper tubing was used to bypass the filter.

Second, the optics of the laser must be replaced with optics effective at the wavelength of the desired output. The laser contains two main optics; a front mirror that is only partially reflective and acts as an output coupler and a rear mirror which is highly reflective. For this conversion, the current MgF_2 ArF compatible front mirror was left in place. Normally the rear cavity window is a transparent window and the rear mirror is external to the cavity. In this case, etalons can be used to control the rear mirror. This allows the user to precisely tune the output beam of the laser. Unfortunately in this case, this would require the entire rear mirror and etalon assembly to be enclosed and evacuated. This would severely complicate the hardware modifications to the laser. To circumvent this complication, the rear window was replaced with an ArF mirror sputtered with Aluminum with 1% silicon content, to act as the rear mirror. It was the intent of the project to utilize an evaporated pure aluminum film but due to equipment complications, the previously mentioned film was substituted.

The third consideration involved the enclosure of the beam path at the output end of the laser and the ability for samples to be tested. A 4" long beamline was constructed out of 1½" PVC pipe. A fused silica mask blank was attached to the end of the beamline with epoxy. To purge the beamline, a N_2 inlet fitting was placed near the mask blank and a vent hole was drilled in the other end. During operation a pressure of about 8 psi was maintained in the beamline. The entire beamline assembly attached via a compression fitting to a fixture bolted to the front coupler assembly.

During cryogenic processor conditioning with the fluorine passivation gas fill, a strong red emission was observed. This red emission corresponds to a second, visible transition in F_2 excitation. This was an early sign that F_2 excitation was possible with the laser setup and that 157-nm emission output might be possible.

The proper F_2 gas fill was not known for the series 700 Lumonics laser. In order to attempt a fluorine gas fill, a recipe from a different laser setup was adapted. This was done by entirely empirical means. The basic fluorine gas fill is a mixture of a specific amount of 5% fluorine (in helium) and then a balance of helium to a desired operating pressure. RIT purchases 5% fluorine in neon instead of helium. Varying initial amounts of fluorine from 27 to 98 mbar were tried. Balance pressures ranging from 3090 to 4010 mbar were tried. Other conditions varied were the repetition rate from 10 to 80 pps (pulses per second) and the excitation voltage from 25 to 39 kV.

RIT does not have a detector capable of characterizing the high energy output of the laser operating at 157-nm without being damaged. In order to detect the presence of 157-nm radiation, two phosphors were chosen, Tantalum Zinc Oxide ($Ta_2Zn_3O_8$) and Yttrium Oxide doped with Europium(Y_2O_3:Eu). These phosphors were suspended in isopropanol and then coated on the inside of the beamline mask blank. The emission of the laser was expected to cause the phosphors to fluoresce.

IV. RESULTS AND CONCLUSIONS

Investigation into the body of work completed on VUV lithography resulted in very positive conclusions regarding the possibility of the implementation of this technology into industry. The F_2 excimer laser source is currently available and recent innovations have increased the lasers' efficiency considerably. The 157-nm wavelength has been shown to be remarkably compatible with the materials and knowledge base already established for DUV lithography and beyond. In addition, the resolution enhancements possible with this technology while still operating within the realm of optical lithography make it an extremely attractive candidate for the future of lithography.

	193-nm		157-nm	
NILS	0.65NA		0.70NA	
Req'd	σ=0.2	σ=0.8	σ=0.2	σ=0.8
2.5	110 nm	140 nm	81 nm	110 nm
2.0	93 nm	110 nm	70 nm	87 nm
1.5	86 nm	93 nm	65 nm	70 nm
1.0	68 nm	79 nm	51 nm	60 nm
pitch	300 nm		225 nm	

Figure 5. Simulation of resolution limits for conventional illumination at 193-nm and 157-nm [4]

The retrofit of RIT's Lumonics series 700 excimer laser was successful. After several attempts at different lasing conditions and different phosphors, 157-nm exitance was observed. The gas fill which first showed real evidence of the new wavelength was 98 mbar of F_2 and a balance to 4010 mbar of helium. Under this pressure, no lasing was observed when the laser was run at 37 kV and 40 pps. When run at 39 kV and 10 pps the laser operated erratically. The cavity was then evacuated to 3500 mbar and run from 35 kV and 10 pps to 37 kV and 80 pps. At this condition, the Yttrium oxide fluoresced pinkish-orange with reasonable intensity. To confirm that the fluorescence was a result of 157-nm emission, the beamline was disconnected from the N_2 purge and air was blown into the cavity. The fluorescence greatly diminished within seconds of the air fill and resumed its original intensity shortly after the N_2 was reattached. This confirms the presence of 157-nm radiation and its illumination of the phosphor causing the fluorescence. This was the first emission of 157-nm radiation at RIT.

These early tests of the F_2 excimer laser source were done under less than optimal conditions. Future work may include replacing the rear mirror with an evaporated aluminum lens, alignment of the rear mirror, further investigation of laser operating conditions, materials characterization, and early surface imaging lithography.

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