

Advances in CPL, Collimated Plasma Source & Full Field Exposure for Sub-100nm Lithography

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Abstract

In the world of micro- Lithography, several options exist for obtaining features below the 100nm level. Options include a variety of methods which range from additional process steps in etch, multilayer resist systems, or expensive throughput limited direct write E-beam systems. Each comes with a handful of trade offs in uniformity, repeatability and cost. Collimated (LASER) Plasma Lithography (CPL), on the other hand offers a full field exposure with minimal process intervention to obtain resolution below the 100nm barrier. CPL, uses a membrane 1x proximity mask and a collimated light source with energy peaking at 11 A°. By using a mask, an entire 22mm x 22mm field (30mm x 30mm with the next generation) can be exposed at once regardless of chip density, removing any throughput concerns as well as placement, stitching and typical E-beam machine flaw defects. Collimation, provides a predictable flux of energy to ensure minimal global divergence and energy level variation. Energy at 11 A°, allows for a high level of uniformity and penetration within the resist, without introducing resolution compromising scattering or standing wave effects.

This Paper will demonstrate the capabilities of CPL as well as the advantages over traditional lithography in obtaining features below 100nm. We will also depict process techniques which take full advantage of improvements in CAR, and experiments which suggest reduction possibilities through variables in mask fabrication.

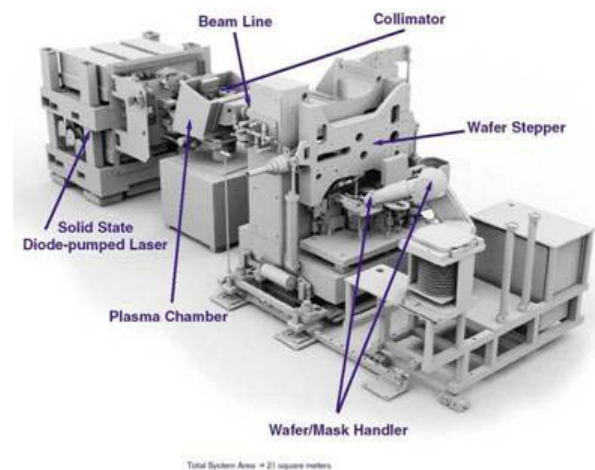
Introduction:

Collimated (LASER) Plasma Lithography has evolved from concept to reality in the NanoPulsar II exposure system. The system is comprised of three main components; Source, Beamline and Stepper.

Each subcomponent, while simple in fundamental contribution to the whole, includes a diverse collection of scientific breakthroughs and engineered solutions.

The **Source**, provides energy at 11Å wavelength via LASER produced plasma from an array of diode-pumped solid-state Nd:YAG lasers. Once produced, collimation

begins by channelling the energy into a high transmission **Beamline** through bundles of poly capillary fibers which distribute and steer the light in a laminar flux. Mask (1x membrane) and wafer are presented to the beamline by the **Stepper** in close proximity gap (10-15µm) configuration for the duration of the exposure.



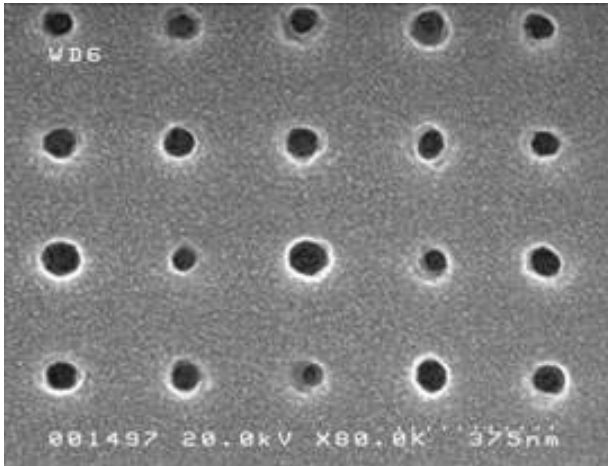
While the intent of this paper is to concentrate mainly upon the collective whole of the system and the lithographic capabilities, operational descriptions are available for the reader as a prelude to the lithographic application.

Findings

Based upon the exposures achieved in the beamline test stand, 100nm lines and space lithography can be accomplished with minimal effort. Isolated lines will have results which challenge the limits of resist as will contacts. Proof of 60nm lines and sub 60nm contacts was also obtained in the same exposure setting.

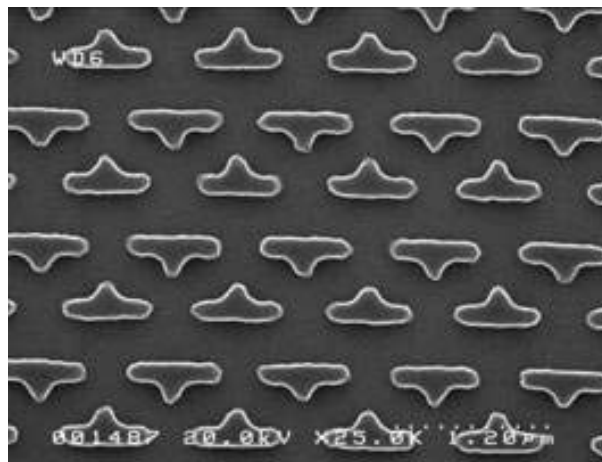
CPL has realized many benefits of the last 20 years of lithographic learning by sharing resist and phase shifting experimentation. Recent attention to the soft-X-ray realm, have brought new tools and migration of optical practices into play. Experiments in X-ray masks which offer reduction have been modelled and proven. Resist

developments have been tremendous with samples reaching 60mJ/cm² sensitivities and below.



60nm contacts and below

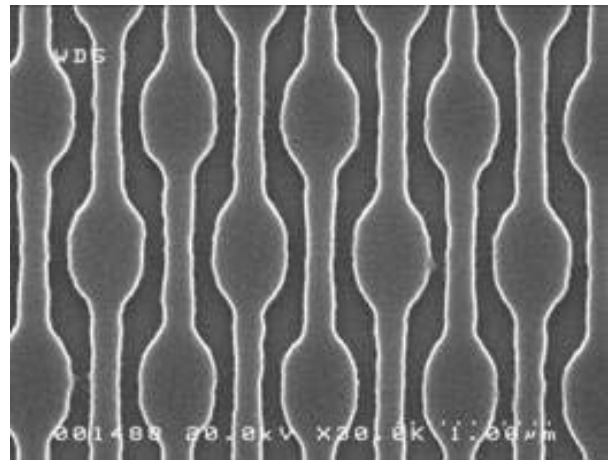
Aspect ratios of 3:1 or more are possible with sidewall slopes better than 85° on average due to the nature of the energy and ability to effectively penetrate deep through the resist. Traditional proximity effects also do not apply, however a similar property can be created and controlled by means of gap / dose control. Given all parameters of exposure, Dose and Gap will largely outweigh all other factors to be the major contributors for lithographic image control. Fortunately, both are easily handled by the system.



120nm T-structures

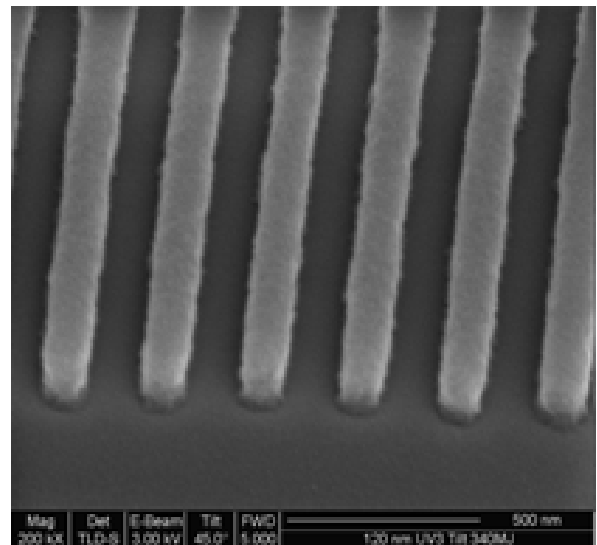
Benefits of full field lithography can be measured in yield, throughput and effort (inspection burden). Having qualified mask allows the lithographer to focus on the resolution and process manipulation by getting reliable – repeatable imaging. System owners of E-beam pattern generators can spend as much energy keeping the system monitored and calibrated as they do using it for production, such a task is not present with CPL. CPL, by

using a mask, has no constraints for data transfers and processing nor will the system have tool generated defects such as stitching and butting errors, which magically come and go throughout the course of a wafer.



130nm lines with pads

Resist surface qualities are less of an issue due to the transparency of films, organics, and foreign materials. CAR will get the exposure energy required to fuel the PAC to completion.



120nm line space pairs

It is the author's opinion that CPL will continue to gain momentum, attract and inspire lithographers from all next generation efforts as it becomes a tangible solution to the problems they face.

Conclusions

The NanoPulsar II exposure system consists of a reliable array of diode-pumped solid-state Nd:YAG laser system, X-ray generation chamber, Collimator, Beamline and Stepper.

The LASER power is focused in the target chamber to generate plasma emitting a 1.1nm wavelength energy. An average power of 24 Watts into 2π steradians is generated in the target chamber which is a record 9% of the incoming LASER power. The energy is then collimated into a 22mm square exposure area and transmitted via Helium beamline where it is then used in a close proximity exposure within the Stepper to complete the CPL System.

The NanoPulsar II is a fifth generation stepper which employs several innovations to aid in seamless manufacturing lithography. Overall speed of the system is greatly improved and multi-task processing is implemented to ensure timely processing of wafers. Incoming substrates are transferred to the system via a 6 axis robot to a pre-align station. Variations in wafers, rotation and course alignment is handled prior to mounting the wafer in the exposure position. Once loaded, a patented **AWIS** is used in Through the Mask alignment for better than 50nm overlay accuracy. Revamped alignment targets which offset mask and wafer images increase image quality during metrology and result in improved overlay.

The Mask and wafer stage is based upon the vertical stages of the previous models which were designed to accommodate the energy of a synchrotron ring, or traditional point source. Once aligned, the interferometer controlled stage is locked into position for the duration of the exposure, (5nm accuracy). The Helium charged beamline extends to complete the exposure path to the mask plane. Framing blades, which are integrated into the beamline provide a flexible shutter system to match chip size requirements.

Characteristics of the system show excellent uniformity throughout the 22 x 22mm exposure area with no global divergence traditionally associated with point sources.

Wafers can be run in either a field by field alignment mode or globally. Other additions to the system include the ability to run batches and handle multiple wafers concurrently. Stages support a single size wafer, and can be changed to accommodate up to 200mm wafers.

Masks are built on 2um Silicon carbide membranes formed on 100mm wafers, mounted in a standard Pyrex ring and have isolated features down to 70nm. Diamond membranes are also used with a variety of absorbing material such as Gold and Tantalum.

Exposures are made with a single flash per field with real time dose monitoring and have excellent reproducibility of mask features. Exposing an entire field at a time means high levels of confidence in internal structures and absence of tool related contribution of defects. Unlike E-beam systems, the use of a masks increases confidence of feature lithography by not worrying about things such as stage travel, systematic errors and tool anomalies during exposure. Printing defects due to Foreign Material (FM) is minimized thanks to the transparency of would be contaminates at 1.1nm wavelengths. Additionally concerns for coatings formed by out-gassing resist are reduced due to the lack of any fixed final objective. The Mask is the final objective, and can be cleaned if required. Effects of contamination would be noticed in a slight drop in efficiency, yet would not compromise resolution.

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ACRONYMS:

AWIS: Adaptable Wavelength Illumination System

CPL: Collimated Laser Plasma Lithography

CPS: Collimated Laser Plasma Source

CAR: Chemically Amplified Resist