Available online at www.sciencedirect.com

SCIENCE DIRECT®

Microelectronic Engineering 77 (2005) 95–102

MICROELECTRONIC ENGINEERING

www.elsevier.com/locate/mee

Origins of debris and mitigation through a secondary RF plasma system for discharge-produced EUV sources

E. Vargas López *, B.E. Jurczyk, M.A. Jaworski, M.J. Neumann, D.N. Ruzic

Plasma-Material Interaction Group, University of Illinois at Urbana-Champaign, Physics, 103 S Goodwin Avenue, Urbana, IL 61801, USA

Received 9 April 2004; received in revised form 28 July 2004; accepted 1 September 2004
Available online 8 October 2004

Abstract

RF plasma based mitigation has been studied as an improved debris mitigation scheme for extreme ultraviolet (EUV) sources. The RF plasma ionizes sputtered neutral debris and, when used in conjunction with a collimator (also known as a foil trap), inhibits that debris from reaching the collector optics. An ionization fraction of 61 ± 3% has been measured. In addition, increased scattering of the ion component of the debris has led to a decrease in erosive flux reaching the diagnostics. Results from in situ high-precision quartz crystal oscillators, ex situ surface characterization (Auger, XPS), and secondary plasma characterization is presented for a series of mitigation schemes, including a foil trap in conjunction with the RF plasma.

Keywords: EUV; Debris mitigation; Lithography; Dense plasma focus; DPF; Secondary plasma; RF plasma; Ionization fraction

1. Introduction

Next generation extreme ultraviolet photolithography (EUVL) sources require several orders of magnitude improvement in the reduction of debris for component lifetime and to maintain stable operation [1]. Inductively coupled secondary plasma-based debris mitigation techniques for use on EUVL sources are described below. They are based on a concept pioneered by the iPVD reactors used in industry and here [2].

The *I*llinois *D*ebris-mitigation *E*UV *A*pplications *L*aboratory (IDEAL) consists of a dense plasma focus discharge source operating on the order of 15 J/pulse, 30 Hz rep rate, and 3 kV. Tests have been conducted with argon gas to generate plasma environmental conditions and debris profiles similar to that experienced in industry [3].

* Corresponding author. Tel.: 6306776520; fax: 2173332906.
E-mail address: vargaslo@uiuc.edu (E. Vargas López).

0167-9317/$ - see front matter
doi:10.1016/j.mee.2004.09.005

2. Theory

Consider a plasma source shown in Fig. 1. A dense pinch plasma is produced close to the anode of the source. During the pinch, energetic ions are created in the dense hot plasma and then move outward in all directions. A fraction of these ions strike the electrodes producing low-energy sputtered atoms. In addition, some of the ions incident on the electrodes reflect from the anode and cathode creating a source of medium-energy gas atoms. Another fraction of the highly energetic ions produced in the pinch travel the same path as the collected photons that are produced, and head straight toward the collector optics. This is not an exhaustive list of debris sources. Sudden heating of the electrodes can lead to atomic vaporization, ablation of molten material or other effects. All of these source terms are collectively referred to as 'debris'.

The collector optics lifetime problem arises because the sputtered electrode atoms accumulate on the mirror surfaces and decrease its reflectivity. Likewise, the energetic ions impinging on the surfaces will erode the mirror material. Surface roughening caused by these phenomena will ultimately degrade the mirrors if no mitigation scheme is in place.

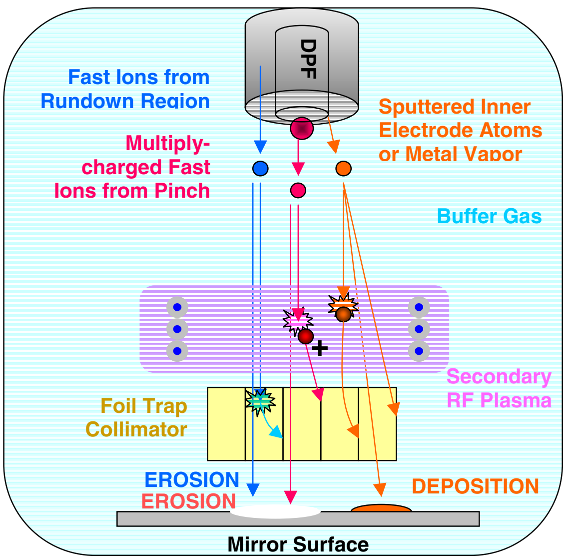

Fig. 1. The debris sources and their effect on the collector optics. The RF plasma and the foil trap combine to mitigate the debris and minimize erosion/deposition on the mirror surface.

2.1. Sputtered electrode debris

At high enough system pressures, such that the mean free path for a sputtered neutral atom is much less than the dimensions of the device, the sputtered electrode debris becomes a diffusive source. In our experiment, the center electrode is made of copper. The mean free path for sputtered atoms in a background gas has been the subject of numerous works [4,5]. Those calculations show that the mean-free-path, λ, for Cu in Ar can be given by

$$\lambda[\text{cm}] = \frac{9.2}{P[\text{mTorr}]}.$$

Typical DPF pressures are >15 mTorr. At these levels, the mean free path (<0.61 cm) is sufficiently small for the diffusion approximation to be valid.

2.2. Energetic ions

The energetic ions (and neutrals through charge-exchange) that arrive at the collector optics can be calculated to first order by simply looking at the uncollided flux after traveling a distance x. It is given by $I(x)$

$$I(x) = I(0)\exp\left(\frac{-x}{\lambda_{\text{in}}}\right).$$

where $I(0) = I$, and is the mean-free-path for ion–neutral collisions. Charge exchange has a higher probability, but it does not change the direction of the particle nor its energy. The ion–neutral mean free path is given by

$$\lambda_{\text{in}} = \frac{1}{n\sigma_{\text{in}}},$$

where σ_{in} is the ion–neutral elastic scattering cross section and n is the gas density. The ion–neutral elastic scattering cross section has the value of about 3×10^{-16} cm^2 at 1 keV for Ar^+ in Ar [6,7]. Therefore for $P = 15$ mTorr, $\lambda_{\text{in}} = 6.91$ cm. For $x = d = 15$ cm, $I(C_1) = 0.11\,I$ energetic ions or neutrals per pulse. Therefore, a significant