High aspect ratio tungsten grating on ultrathin Si membranes for extreme UV lithography

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Perspective

High aspect ratio tungsten grating on ultrathin Si membranes for extreme UV lithography

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Abstract
Extreme ultraviolet lithography is one of the modern lithography tools for high-volume manufacturing with 22 nm resolution and beyond. But critical challenges exist to the design and fabrication of large-scale and highly efficient diffraction transmission gratings, significantly reducing the feature sizes down to 22 nm and beyond. To achieve such a grating, the surface flatness, the line edge roughness, the transmission efficiency and aspect ratio should be improved significantly. Delachat et al (2015 Nanotechnology 26 108262) develop a full process to fabricate a tungsten diffraction grating on an ultrathin silicon membrane with higher aspect ratio up to 8.75 that met all the aforementioned requirements for extreme ultraviolet lithography. This process is fully compatible with standard industrial extreme ultraviolet lithography.

Keywords: extreme ultraviolet lithography, ultrathin membrane, high aspect ratio, tungsten, diffractive optics

Lithography, as the mainstream technology used for semiconductor manufacture, greatly promoted the development of the integrated circuit (IC) [1, 2]. Down-scaling of IC scaling by decreasing the size of node and improving the resolution has become the main source of progress to develop faster computers and higher-density data storage, which were predicted by Gordon Moore a few decades ago [3, 4]. Currently, high-volume IC manufacturing uses optical double-patterning methods and immersion lithography at the wavelength $\lambda = 193$ nm to reach the 22 nm node, which is very difficult because of fundamental limitations [4, 5]. Hence, how to fabricate sub-20 nm patterning features has been of interest in the field of research. Recently, several novel techniques such as nanoimprint lithography [6], helium bean patterning [7], electron beam lithography [8] and the self-assembly method [9] have been proven to reach even sub-10 nm resolution. Among all of the possible technologies, particular interest has been devoted to extreme ultraviolet lithography (EUVL) [4, 5, 10].

EUVL, which makes use of extreme ultraviolet rays as the light source, has been considered as the leading technology for next-generation nano-electronics at the 22 nm node and beyond in semiconductor, very large-scale ICs [11]. Their theoretical printing features can reach $\lambda/4$ resolution using optical methods, below 4 nm size [4]. But for high-volume manufacturing in industry, EUVL research still involves a broad range of topics, including the source, tools, resists, projection optics and masks [12]. Diffraction gratings with higher quantity and diffractive efficiency are urgently needed as one of the crucial optical elements to produce interferometric fringe patterns. Because of its extensive use in microelectronics and its very high transparency in the extreme ultraviolet domain (approximately 5–40 nm), silicon membranes are particularly desired for EUVL as transmissive optics. Compared to a silicon nitride membrane [13, 14], the silicon thin film exhibits a higher transparency at the same thickness [14].
Large-scale areas (i.e., in the millimeter range) together with a well-controlled flatness and high groove depth are the basic requirements for EUV optics. But, such requirements cannot be satisfied for ultrathin silicon membranes using the state of the art etching process [15, 16]. In addition, this conventional method induces a compressive stress at the oxide/silicon interface [17], and results in irremediable deformation or even destruction of the membrane. Several novel strategies have been proposed to release stress to avoid bending. One is to use elastically strained layers to release its strain elastically by lateral expanding to stretch the Si membrane. Constancias et al. were the first to develop and patent a successful method for fabricating large-scale ultrathin silicon membranes with more than 85% transmittance to support grating for EUV application in 2009 based on direct bonding with thermal difference [18]. With the support of excellent transparency of the silicon membrane, higher diffraction efficiency of the grating has been achieved in the EUV domain made with materials such as niobium or molybdenum that allow phase shift gratings with low attenuation [19]. This innovative method has also been extended to the fabrication high efficiency transmission optics in EUVL by depositing 90 nm thick molybdenum on ultrathin silicon membranes as a grating using the plasma sputtering method by used Constancias et al [14]. Furthermore, such a grating could be designed for EUVL with efficient exposure even at second order diffraction for ultra-high resolution resist patterning, down to 10 nm half pitch.

In issue 39 of nanotechnology, Delachat et al. reported a full fabrication process of high aspect-ratio (∼6) diffraction gratings made of tungsten features on flat (planarity <10 nm), ultrathin (100 nm) and large area (diameter of 1 mm) circular silicon membranes using a pseudo-Bosch etching method. This process is perfectly compatible with microelectronics and allows fabricating high resolution and highly efficient extreme ultraviolet transmissive diffractive optics for EUV applications. On the other hand, tungsten is a dense material which is an efficient absorber due to its high absorption coefficient in the EUV domain. Therefore, the combination of subtractive patterning and accepting aspect ratio makes the fabrication of very high-resolution optics (<30 nm) feasible. In addition, the thermal expansion of tungsten is relatively similar to that of silicon, which further helps to prevent the severe deformation or even destruction of the optics which occurs during post-processing.

In their work, Delachat et al. solved a series of issues in the use of tungsten on a large silicon membrane. Firstly, they demonstrate that the microstructure in the region (near 8 mTorr) of residual stress is almost fully removed by dense α-W phase with fine grains. Secondly, a pseudo-Bosch process is employed, which allows tightly controlling the pattern profile through the appropriate choice of SF$_6$ and CF$_3$F$_8$ gas flow ratio. Then the vertical and lateral etching rate of W directly on the membranes was further efficiently controlled by the temperature. Perhaps the most intriguing result by Delachat et al. is that pseudo-Bosch tungsten etching yields high aspect ratio (up to 8.75) gratings that are suitable for the fabrication of highly efficient diffractive optics with variable dimensions down to 30 nm and high resolution down to 25 nm half pitch on silicon membranes. In addition, this process is fully compatible with state-of-the-art microelectronics, which facilitates the industrialized and standardized production of high resolution diffractive optics for EUVL. However, further studies are required to test the final performance when used as grating, such as the actual diffraction efficiency and the final resolution.

The work by Delachat et al. develops a full fabrication process of high aspect ratio diffraction gratings made of tungsten on circular ultra-thin Si membranes over a significant area through a pseudo-Bosch process for EUVL. The process integration with thin film deposition and etching for the fabrication of a grating may markedly influence the design and development of gratings and continues to be developed and/or optimized.
References