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Investigation of the angular dependences of the velocities of ion-beam sputtering of metals for the synthesis of mask blanks

© M.S. Mikhailenk, A.E. Pestov, A.K. Chernyshev, N.I. Chkhalo

Institute of Physics of Microstructures, Russian Academy of Sciences,
607680 Nizhny Novgorod, Russia
e-mail: mikhaylenko@ipmras.ru

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An alternative material has been proposed as an absorber for a mask blank for lithography in the vicinity of a wavelength of 11.2 nm — Ni. It has been established in this work that the optimal angle for efficient sputtering of Ru, Be, and Ni targets by accelerated argon ion sources for fabrication of a Ru/Be multilayer structure with an upper Ni layer is an angle of 60° degrees. At this angle, the etching rate for all three materials is 35±5 nm/min at an argon ion energy of 800 eV and an ion current density of 0.5 mA/cm^2.

Keywords: lithography, photomask, X-ray mirror, ion sputtering, ion etching.

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Introduction

Increasing the resolution of the lithographic process involves reducing the wavelength of light, i.e. the transition to the so-called BEUV (beyond extreme ultraviolet) lithography. Various variants of wavelengths promising for this task are considered, for which there are intense sources of extreme ultraviolet (EUV) radiation and highly reflective multilayer X-ray mirrors [1–3]. The region in the vicinity of 11.2 nm is considered as one of the promising wavelengths, where there are intense Xe plasma emission lines and the possibility of synthesis of Ru/Be multilayer X-ray mirrors of normal incidence, which theoretically have the highest peak reflection coefficients [4]. Moreover, the paper [5] shows the possibility of synthesizing Ru/Be mirrors with record reflection coefficients and spectral width in the vicinity of the wavelength 11.4 nm to $R = 72.2\%$ and $\Delta\lambda_{1/2} = 0.38$ nm, respectively.

One of the most important elements of a lithographic installation is a photomask (mask). The photomask is a multilayer X-ray mirror with a pattern applied to the surface, which makes it possible to form an appropriate topology on silicon wafers, which eventually become chips. The pattern is formed in an absorbing layer having a low (close to zero) transmittance of X-ray radiation with a working wavelength of the lithographic unit (Fig. 1).

Accordingly, a blank for a photomask or mask blank is a mirror optimized for maximum reflection of the working wavelength, on the surface of which an absorbing layer is applied. Traditionally, thin Cr, Ta or TaN films with a thickness of no more than 100 nm [6] are used as an absorbing layer for the production of mask blank for EUV lithography. The dependences of the transmission coefficients on the wavelength for 100-nm Ta, TaN and Cr films are shown in Fig. 2, *a*. These dependencies show that the transmission in the vicinity of the wavelength 11.2 nm is 3–6% [7].

This paper proposes to use Ni films as an absorber. The dependence of the radiation transmission coefficient in the wavelength range from 9.5 to 15 nm is shown in Fig. 2, *b*.

Magnetron sputtering is the traditional method of synthesis of multilayer X-ray mirrors, however, sputtering using accelerated ion sources looks more promising for the manufacturing of mask blanks. Higher quality structure of the films is the advantage of this method. This is attributable to the fact that accelerated ions sputter the target more uniformly (i.e. single atoms fly out, since the sputtering coefficient usually lies near unity) in comparison with magnetron sputtering, when clusters of atoms can fly out from the target surface. Clusters that have flown off the target surface during sputtering can create both amplitude and phase defects, the presence of which can subsequently lead to errors in the topology of the chip. The phase defect leads to the deflection of the rays forming the pattern, which leads to its distortion on the plate (chip), and the amplitude

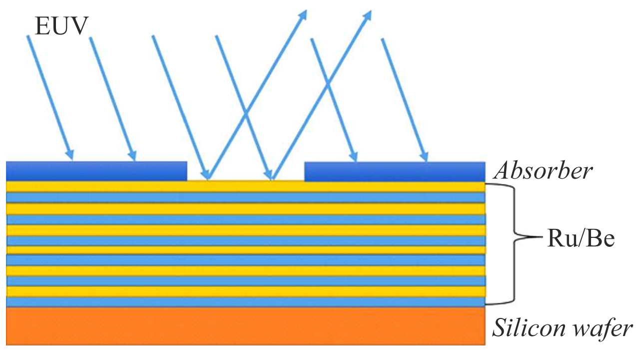

Figure 1. Scheme of the EUV mask for lithography.

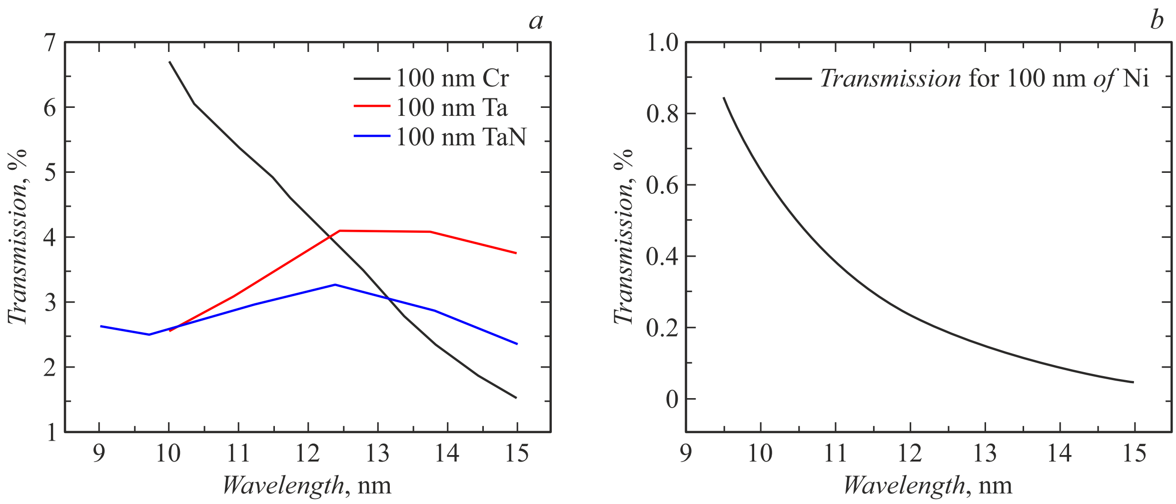

Figure 2. Dependences of the transmission coefficients of films with a thickness of 100 nm: *a* — chromium, tantalum and tantalum nitride; *b* — nickel.

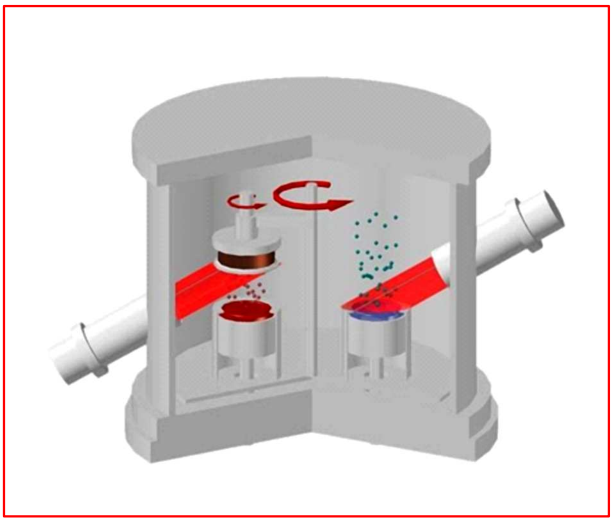

Figure 3. Diagram of target sputtering by a source of accelerated ions.

defect will obscure the reflected radiation, as a result of which the photoresist [8] may not light up locally.

As mentioned above, the optimal structure for the synthesis of a multilayer mirror at a wavelength of 11.2 nm is the composition of Ru/Be, and the most promising material for the absorber is — Ni.

The aim of this study is to determine the optimal angle of incidence (from the point of view of the maximum etching rate) of accelerated ions on the surface of Be, Ru and Ni targets for the synthesis of mask blanks.

1. Experiment description

The angular dependences of metal atomization were studied in this paper to optimize the synthesis process of blanks for photomasks. Metal films made of Ru, Be and Ni with a thickness of 0.5 μm deposited by magnetron sputtering on a silicon substrate were used as targets. Ion etching experiments were carried out on the bench [9] provided with three different sources of accelerated ions, as well as 5*D* table. The pressure of residual gases in the vacuum volume was at the level of $2\cdot10^{-6}$ Torr before the experiments. The samples were attached to a table, then an angle was set relative to the plane of the source aperture. KLAN-104M with a hollow cathode and an output aperture of ∅100 mm was used as a source of accelerated ions. The ion energy in all experiments was 800 eV. The „plateau “ of the energy dependence of the sputtering coefficient is observed in case of most materials in case of sputtering with Ar ions with an ion energy near 1000 eV, i.e. a further increase in energy does not lead to a noticeable increase in the amount of sputtered material due to deeper penetration of ions into the target [10]. The ion current density was 0.5 mA/cm^2. The etching depth was measured using a TalySurf CCI 2000 white light interferometer.

2. Results and discussion

Angular dependences of the etching rate for targets Ru, Be and Ni were obtained as a result of a series of etchings (Fig. 4).

It is possible to see different behavior of the etching rate dependences on the angle of incidence ions on the target surface on the obtained curves. The angular dependence of small charge numbers behaves as an increasing function $f(\Theta)\sim A/\cos\Theta$ (A — a constant determined from the experiment) as in this case for Be($Z=4$), and, conversely, it behaves as a descending function in case of large Z, as, for example, for Ru ($Z=44$). The dependence for nickel ($Z=28$) has two inflection points, however, the same

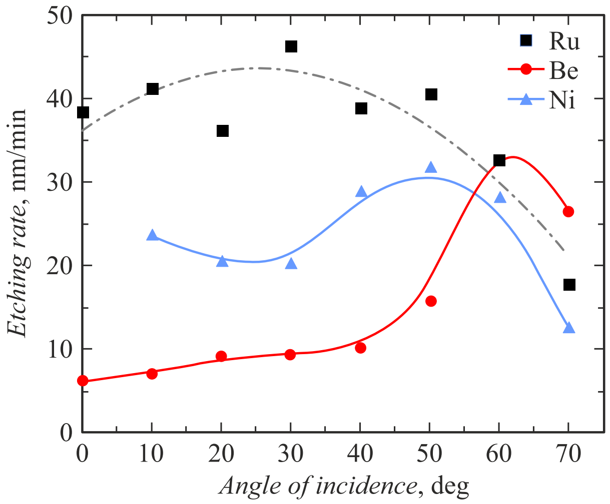

Figure 4. Angular dependence of the ion etching rate on the angle of incidence. Ion energy Ar — 800 eV. The ion current density — 0.5 mA/cm^2.

behavior is observed for other materials, such as for Al (Z=13), which is shown in [11].

The obtained data demonstrate that the optimal angle (where the etching rate is the highest), at which it is advisable to set an accelerated ion source for the most efficient sputtering of all three materials (Ru, Be and Ni) for manufacturing mask blanks for lithography in the vicinity of the wavelength 11.2 nm, is 60° to the normal of the target surface. The etching rate at this angle will be 35$\pm$5 nm/min for all three materials.

Conclusion

An alternative material is proposed as an absorber of the mask blank for lithography in the vicinity of the wavelength 11.2 nm — Ni. It was found in this paper that the optimal angle for effective sputtering by sources of accelerated argon ions of Ru, Be and Ni targets for the manufacturing of a multilayer Ru/Be structure with an upper layer of Ni is an angle of 60°. The etching rate for all three materials is 35$\pm$5 nm/min at this angle with an argon ion energy of 800 eV and an ion current density of 0.5 mA/cm^2.

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Conflict of interest

The authors declare that they have no conflict of interest.

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