Translation Certification

I, Friedemann Horn, European patent attorney and patent translator having a good command of both the English and the Japanese language in the relevant technical field, hereby certify that the attached document is, to the best of my knowledge and belief, a true and complete translation from Japanese into English of the content of the PCT patent application published in WO99/49504A.

Munich, Germany
Dated this April 22, 2013

Signature of the translator

Translation from Japanese into English of WO99/49504

DESCRIPTION

PROJECTION EXPOSURE METHOD AND APPARATUS

Technical Field

The present invention relates to a projection exposure method and apparatus for use in transferring a mask pattern onto a photosensitive substrate in a lithography process performed to manufacture devices such as, for example, semiconductor devices, imaging devices (CCDs or the like), liquid crystal display devices, or thin film magnetic heads, and more particularly to a projection exposure method and apparatus using a liquid immersion method.

Background Art

In the manufacture of semiconductor devices or the like, a projection exposure apparatus is used to transfer the image of a pattern on a reticle as a mask to each shot area on a wafer (or a glass plate) coated with a resist as a photosensitive substrate via a projection optical system. Conventionally, step-and-repeat type reduction projection exposure apparatuses (steppers) have been frequently used as projection exposure apparatuses. Recently, however, attention is also being given to step-and-scan type projection exposure apparatuses, which synchronously scan and expose the reticle and the wafer.

The resolution of the projection optical system provided in the projection exposure apparatus becomes higher as the exposure wavelength employed decreases and as the numerical aperture of the projection optical system increases. Consequently, with the miniaturization of integrated circuits, the exposure wavelength used in projection exposure apparatuses decreases every year and the numerical aperture of projection optical systems gradually increases. While the currently dominant exposure wavelength is the 248 nm of a KrF excimer laser, an even shorter wavelength of 193 nm of ArF excimer lasers is also coming into practical use.

Furthermore, the depth of focus (DOF) is as important as the resolution when performing an exposure. The resolution R and the depth of focus δ are expressed by the following equations, respectively:

$$R = k_1 \cdot \lambda / NA \qquad (1)$$

$$\delta = k_2 \cdot \lambda / NA^2 \qquad (2)$$

where λ is the exposure wavelength, NA is the numerical aperture of the projection optical system, and k1 and k 2 are the process factors. As apparent from the equations (1) and (2), the depth of focus δ decreases when the exposure wavelength λ is reduced and the numerical aperture NA is increased in order to improve the resolution R. Conventionally, projection exposure apparatuses perform exposure with the surface of the wafer aligned with the image plane of the projection optical system by autofocusing, and for this reason, the depth of focus δ preferably has a certain width. Therefore, methods for substantially increasing the depth of focus that have been conventionally suggested are the phase-shift reticle method, the modified illumination method, and the multilayer resist method.

As described above, conventional projection exposure apparatuses tend to have a shorter depth of focus due to a reduction in the wavelength of exposure light and an increase in the numerical aperture of the projection optical system. Moreover, even shorter exposure wavelengths are being studied in order to keep up with the tendency toward higher degrees of integration of semiconductor integrated circuits. Therefore, the depth of focus will be too narrow if things continue as' they are and it could lead to insufficient margins during exposure.

Accordingly, a liquid immersion method has been proposed as a method for substantially shortening the exposure wavelength and increasing the depth of focus. With this liquid immersion method, the space between the lower surface of the projection optical system and the surface of the wafer is filled with liquid such as water or an organic solvent, thus taking advantage of the fact that the wavelength of the exposure light in the liquid is 1/n of the wavelength in air (where n is the refractive index of the liquid, normally approximately 1.2 to 1.6), thereby improving the resolution as well as magnifying the depth of focus about n times.

If the liquid immersion method is simply applied to the step-and-repeat type projection exposure apparatus, the liquid spills out from the space between the projection optical system and the wafer when stepping the wafer to the next shot area after completion of exposure of one shot area. Therefore, it is necessary to supply the liquid again and it is difficult to recover the liquid. In addition, if the liquid immersion method is temporarily applied to a step-and scan type projection exposure apparatus, the exposure is performed while moving the wafer and therefore the space between the projection optical system and the wafer needs to be filled with the liquid while moving the wafer.

In view of the above viewpoints, it is an object of the present invention to provide a projection exposure method capable of stably keeping the space between a projection optical system and a wafer filled with liquid when applying the immersion method even if the projection optical system and the wafer relatively move. It is another object of the present invention to provide a projection exposure apparatus capable of performing the projection exposure method, a method for efficiently manufacturing the projection exposure apparatus, and a method for manufacturing an advanced device using the projection exposure method.

Disclosure of the Invention

According to the present invention, in a first projection exposure method for illuminating a mask (R) with an exposure beam and transferring a pattern on the mask (R) onto a substrate (W) via a projection optical system (PL), when the substrate (W) is moved in a predetermined direction, a predetermined liquid (7) is caused to flow in a moving direction of the substrate (W) so as to fill the space between the front end of an optical element (4) on the substrate (W) side of the projection optical system (PL) and the surface of the substrate (W) with the liquid (7).

According to the first projection exposure method of the present invention, a liquid immersion method is applied to thereby fill the space between the front end of the projection optical system (PL) and the substrate (W) with the liquid. Therefore, the wavelength of exposure light at the substrate surface can be reduced to 1/n (where n is the refractive index of the liquid) compared to the wavelength in air and the depth of focus is increased to about n times of the value obtained in air. Furthermore, when the substrate is moved in the predetermined direction, the liquid is caused to flow in the moving direction of the substrate. Therefore, the space between the front end of the projection optical system and the surface of the substrate is filled with the liquid even while the substrate is moved. Moreover, if foreign matter adheres to the substrate, the foreign matter can be washed away by means of the liquid.

Subsequently, according to the present invention, a first projection exposure apparatus for illuminating a mask (R) with an exposure beam and transferring a pattern on the mask (R) onto a substrate (W) via a projection optical system (PL), includes a substrate stage (9, 10), which holds and moves the substrate (W); a liquid supply device (5) which supplies a predetermined liquid (7) in a predetermined direction via a supply pipe (21a) so as to fill the space between the front end of an optical element (4) on the substrate (W) side of the projection optical system (PL) and the surface of the substrate (W); and a liquid recovery device (6), which recovers the liquid (7) from the surface of the substrate (W) via a discharge pipe (23a, 23b) disposed together with the supply pipe (21a) in such a way that an area irradiated with the exposure beam is arranged between the discharge pipe and the supply pipe in the predetermined direction, wherein the liquid (7) is supplied and recovered while the substrate (W) is moved in the predetermined direction by driving the substrate stage (9, 10).

According to the first projection exposure apparatus of the present invention, the first projection exposure method of the present invention can be performed by using the pipes.

It is preferable to provide a second pair of a supply pipe (22a) and a discharge pipe (24a, 24b) in an arrangement obtained by rotating the pair of supply pipe (21a) and discharge pipe (23a, 23b) by substantially 180°. In this case, if the substrate (W) is moved in a direction opposite to the predetermined direction, the space between the front end of the projection optical system (PL) and the surface of the substrate (W) can be continuously filled with the liquid (7) in a stable manner by using the latter pair of pipes.

Furthermore, if the projection exposure apparatus is of a scanning exposure type, which synchronously moves and exposes the mask (R) and the substrate (W) with respect to the projection optical system (PL), the predetermined direction is preferably the scanning direction of the substrate (W) during the scanning exposure. In this case, also during the scanning exposure, the space between the front end of the optical element (4) on the substrate (W) side of the projection optical system (PL) and the surface of the substrate (W) can be continuously filled with the liquid (7), whereby the exposure can be performed in a stable manner with high accuracy.

Furthermore, it is preferable to provide one pair or two inverted pairs of a supply pipe (27a) and a discharge pipe (29a, 29b) in a direction perpendicular to the predetermined direction in an arrangement corresponding to the pair of the supply pipe (21a) and the discharge pipe (23a, 23b). In this case, also while the

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