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Maskless optical microscope lithography system

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A simple maskless photolithography system employing an optical microscope, a motorized stage and a beam blanker is proposed. Based on a pattern design, the motorized stage shifts a resist-coated substrate exposed by a focused beam under a microscope. Microscale patterns are easily defined on a single nanowire without using a mask validating the application applying to the research requiring frequent changes or free-style designs in microscale test patterns. © *2009 American Institute of Physics.* [doi:10.1063/1.3266965]

The widely used optical projection lithography requires an expensive mask aligner; several optical masks are prepared by tedious procedures such as computer-aided design (CAD) and semiconductor processes. Since there is more and more interest in micron- or nanometer-scale research in many applications, the needs for a micron-scale test pattern in research is increasing. In researches on nanowires it is often required to make electrode patterns on the nanowires in order to measure their electrical properties. The position and the orientation of the nanowires on the substrate are not precisely controlled and in many cases they can be rather randomly located. The arbitrariness of the location of these nanowires precludes the usage of conventional optical projection lithography, since the predefined mask patterns may not be suitable for making electrodes on the randomly located nanowires. Electron beam lithography (EBL) is the most widely used technique for this purpose but its resolution is sometimes more than necessary, especially when the required minimum distance between the two electrodes at both ends of the nanowires is on the order of the micrometer range. The cost and complexity of the EBL are also factors that reduce its accessibility.

There has been an effort to remove the need of the mask in photolithography and the field of optical maskless lithography (OML) has recently been introduced.[1] The OML concept replaces a mask with a spatial light modulator (SLM), which basically provides a computer-controlled "dot-matrix" from the patterns.[2,3] The patterns formed on the SLM are then transferred to the photoresist on the substrate, optionally with the help of another array of lenses, such as the Fresnel lens array in a zone plate array lithography system.[4] The resolution of the OML system is at least as good as that of conventional projection photolithography, but with the added expense in the complexity of the system and the need of a high precision scanner in order to minimize the stitching error.

To reduce the time, and with better accessibility for the microscale pattern, we demonstrated the validity of a configurable mask using a liquid crystal display panel,[5] however it still requires improvement for the better formation of the shape, owing to the limitations such as the discreteness or size of the pattern. In order to overcome the difficulties found in the discreteness and the small size of the patterns, we propose a maskless photolithography system that employs an optical microscope with a motorized stage and a home-made pattern analysis computer software, which can be easily realized at the laboratory level for achieving a free-style microscale patterning without following complicated semiconductor processes in order to fabricate masks.

The proposed optical microscope lithography system consists of motorized stages and a beam blanker switch, both of which are controlled by our home-made computer software and attached to an optical microscope, as shown schematically in Fig. 1. Light sources used in an optical microscope usually have a wide wavelength spectrum including the ultraviolet range which can be used to expose many commercial photoresists. The diameter of the focused beam of the microscope can be further scaled down to a microscale with the help of an aperture. Therefore, it is possible to use this focused beam as a "pen" to draw the designed patterns on the photoresist spun on the substrate, which is mounted on the motorized stage. The movement of the stage can then be controlled according to predefined paths corresponding to the designed pattern. This simple lithography system has the advantages of an enhanced accessibility at the laboratory level since it uses a normal optical microscope, and has a high flexibility since the desired patterns can be designed by CAD software, without using a hard mask.

In order to develop a prototype of the proposed lithography system, two motorized stages (SGSP20-35, Sigma-Koki, Japan) were employed; each one moves in one of the two normal directions of the stages plane. The value of the minimum step size, which is defined as the unit distance by which the stage can move, is 1 μm. While the stages are moving to the next exposed pattern points after finishing exposing one pattern, the beam should be turned off to avoid any exposure to an undesired part on the sample. A beam blanker, composed of a current-controlled mechanical switch to which a screen is attached, is placed in any point along the light path from the light source to the substrate, which turns off the beam by blocking it with a screen. The on or off status of the beam blanker switch is controlled by the same computer software which controls the movement of the

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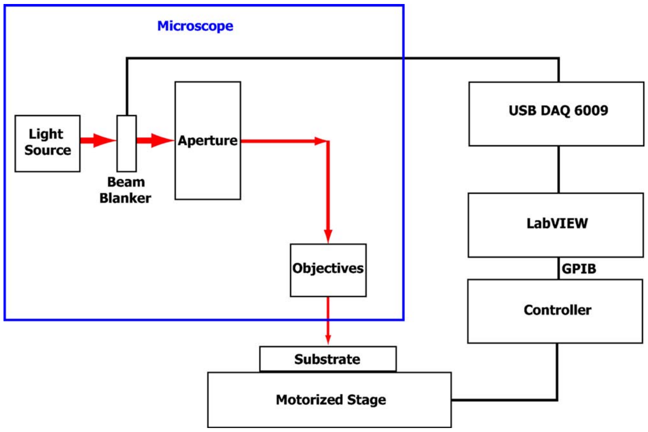

FIG. 1. (Color online) The schematic diagram of the optical microscope lithography system. The movement of the motorized stages is controlled by a LABVIEW program according to the patterns defined in the design files. The beam blanker switches on or off the light path between the light source and the aperture in accordance with the patterns.

stage, which has been programmed with LABVIEW (National Instruments, Austin, TX).

The aperture size was set to about 200 μm, and the corresponding diameter of the focused beam was about 10 μm when the magnification value of object lens was set to 100X. The minimum feature size of the currently implemented system was less than 10 μm (line and space pattern), but the resolution could be further optimized with a smaller diameter of the focused beam, which could be achieved by a smaller aperture, and taking into consideration the minimum step size of the stages. The aperture and the screen of the beam blanker were inserted into the free slots for the optical filters of the optical microscope (BX41M, Olympus, Japan).

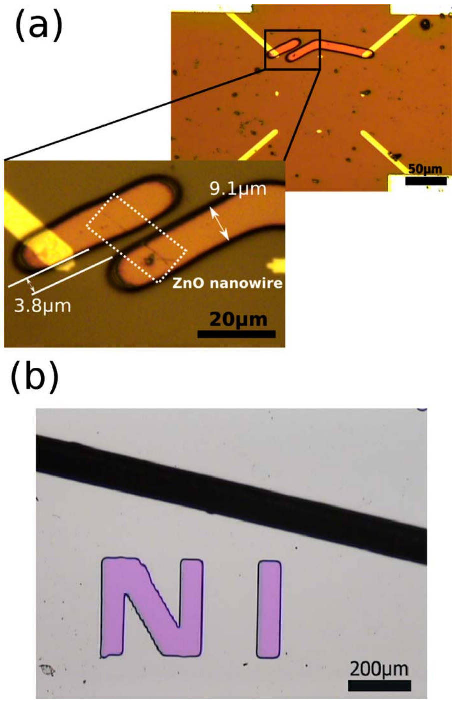

FIG. 2. (Color online) (a) The two-electrode pattern contacting a ZnO nanowire fabricated with the proposed lithography system. (b) The test pattern of text "NI." The slanted black shadow line denotes a human hair with a diameter of 150 μm for the comparison. Note that different values of aperture size [~200 and ~1 mm for (a) and (b), respectively] were used to minimize the exposure time.

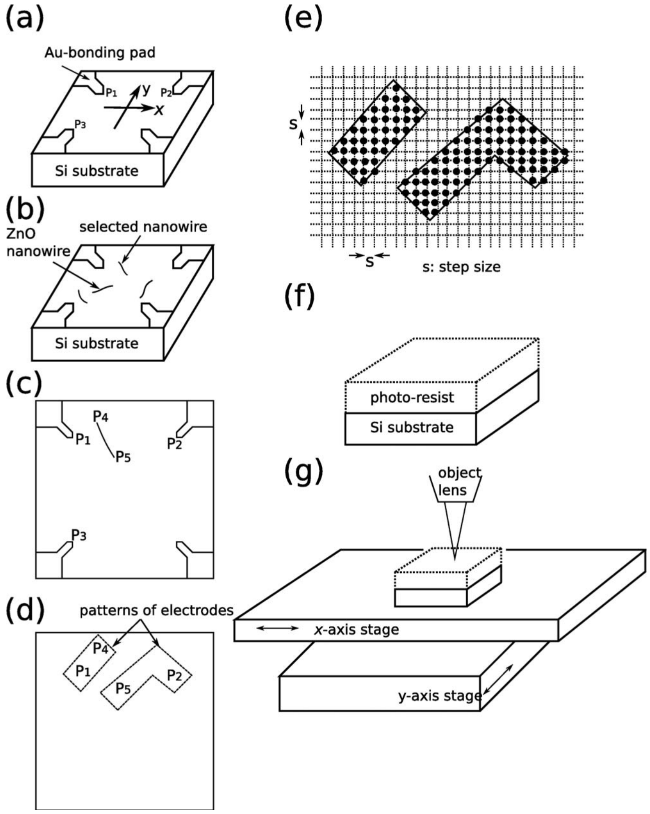

FIG. 3. The fabrication processes of the two-electrode pattern contacting a ZnO nanowire. (a) Gold bonding pads are patterned on a Si substrate, where the relative positions of the patterns are known and assigned to the arbitrary coordinates, for example, P_1, P_2, and P_3. (b) The ZnO nanowires are deposited on the substrate and the location with an orientation is recorded with respect to the coordinates of the prepatterned electrodes. (c) The two end points of the selected nanowire are assigned to the two coordinates, P_4 and P_5, on the optical micrograph. (d) The patterns of the two electrodes are defined by our home-made CAD software such that the electrodes contact two of the prepatterned bonding pads and connect the selected nanowire. By matching the reference coordinates (P_1, P_2, and P_3) to the corresponding positions of the bonding pads on the substrate, the two-electrode patterns can be aligned to the selected nanowire on the substrate. (e) Patterns of the electrodes are analyzed by the control software and the set of coordinates are generated. The control software moves the stage according to these coordinates so that each corresponding point on the substrate can be exposed to the focused beam of the microscope for a specific amount of time (dwell time) before moving to the adjacent point which is separated by a step size. (f) The photoresist is spun on the substrate. (g) The points in the pattern file are aligned to the corresponding points on the substrate and the exposure begins.

One of the tasks of the control software was analyzing the structures in the pattern file and generating the scan-lines accordingly. Every structure in the pattern file was basically polygonal and could be filled with a set of parallel scan-lines. By moving the stage along one scan-line after the other with the focused beam of the microscope fixed at one position, the whole pattern was then be exposed. The algorithm for analyzing the polygons and generating the scan-lines was the polygon-filling algorithm,[6] which analyzed the vertices of the polygon and generated the set of scan-lines filling the polygon.

The step size has to be properly selected according to the patterns to be exposed. The control software was implemented in such that the movement of the stage should follow each scan-line, of which the distance between each point stays the same as the value chosen by the user. The waiting time of the stage before moving to the next point on the scan-line, which is the dwell time, can also be tuned depending on the optimum dose of the photoresist.

The two-electrode pattern contacting a zinc-oxide (ZnO) nanowire, shown in Fig. 2(a), was fabricated with the proposed lithography system and the detailed procedure of the fabrication steps are illustrated in Fig. 3. In Fig. 3, each electrode has a linewidth of ~10 μm and has a ~4 μm separation. The ZnO nanowires were deposited on the silicon oxide-silicon substrate where the gold bonding pads and the electrodes were patterned by conventional optical projection lithography (shown on each corner of the upper image). After locating a target nanowire by inspecting with the optical microscope, two electrodes were patterned at the specific positions in order to connect the target nanowire and the prepatterned gold electrodes. This pattern can be used to fabricate a ZnO field-effect transistor after depositing metal into the pattern with a back gate. Depending on the purpose of the microscale patterns, postprocesses such as reactive ion etching, wet-etching, or the lift-off process with multilayer resists can be accomplished after defining the pattern of the resist.

The value of the aperture size and the step size can be optimized in order to minimize the exposure time. For example, the electrode patterns on the nanowire shown in Fig. 2(a) were exposed with an aperture size of ~200 μm and the large features in Fig. 2(b) were patterned with an aperture size of ~1 mm. By tuning the value of the aperture size and the step size, the exposure time can be optimized.

A simple maskless photolithography system employing an optical microscope and motorized stages was proposed and successfully demonstrated. The system will be very useful in patterning various microscale designs with a low cost, and can be extended to large-scale electronic circuit patterns, such as the printed circuit board.

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