Widefield Microscope for Projection Maskless Micropattern in Photolithography Applications

Chayanisa Sukkasem, Suejit Pechprasarn, Suvicha Sasivimolkul, and Phitsini Suvarnaphaet*

College of Biomedical Engineering, Rangsit University, Pathum Thani, Thailand
*Corresponding author, E-mail: phitsini.s@rsu.ac.th

Abstract

Widefield microscopy refers to a technique to illuminate the light to the whole sample. The primary function of a microscope is not only resolving details of the specimen but also enlarging the size. Though the microscope's applications are mostly serving as a magnifying device, however, its optical alignment could be modified reversely. In this work, we propose to modify the widefield microscope for projection micro-pattern without the mask that would be utilized in the photolithography process. Herein, we used LED as a light source in Köhler illumination where the light was condensed and projected onto a transmission LCD by the three-compound lens, namely a collector lens, a field lens, and a condenser lens. The light passed through the transmission LCD originated the desired pattern to be projected through an objective lens, where it is adjustable for 4x and 10x magnifications. The objective lens was used to reduce the transmission pattern size to the micrometer scale before projecting on the substrate. To observe the image plane of the pattern, we can use a beam splitter added into the alignment to reflect the pattern back to a CMOS sensor. Based on this alignment, the pattern can be designed easily using a computer program such as Microsoft PowerPoint. Consequently, the minimum size of a micro-scale pattern can be reduced to 10 µm when the projected image was exposed on the substrate, i.e., linear line, droplet array, grating, and T-junction. This work can be applied towards cost-effective photolithography applications where the mask for patterning would not be needed.

Keywords: *Widefield microscopy, Projection maskless micropattern, Microfabrication, Optics, Instrumentation*

1. Introduction

In a general view, a microscope is an essential device used in various fields of biomedical studies in order to magnify and resolve small details down to 0.2 µm which is a limitation of visible light (Chen, Zheng, & Liu, 2011). Because of the abilities of the microscope, it would help scientists to work easier and more effective, especially in the medical field trip and school laboratory. For the optical view, the system of the microscope is conventionally aligned based on a basic of widefield technique. It is one of the illumination methods that could be modified and developed to more advanced techniques. For example, Pechprasarn et al. (2018) have shown the modified widefield microscope for low-cost automated whole-slide imaging applications (S. Pechprasarn et al., 2018). The widefield illumination system consisting of three lenses, namely a collector lens, a field lens, and a condenser lens, was used to shine the light upon the whole sample and was combined with a motorized stage in 3-dimensional movement. Therefore, this microscope could capture and stitch images for a large-scale area. Such illumination is called Köhler illumination (Dawe, Schantz, Abramowitz, Davidson, & Hutmacher, 2006). This method does not only give even illumination onto the sample with condensed and uniform light but also reduces artifacts in images wherein they are useful in phase contrast imaging, differential interference contrast microscopy, and projection photolithography (Love, Wolfe, Jacobs, & Whitesides, 2001)

Photolithography, so-called optical lithography, is the main process for the fabrication of semiconductor (Ronse, 2006) and microelectronic industries such as integrated circuits (IC) and micro-electro-mechanical systems (MEMS). This technology has allowed printing of scaffolding pattern in printing technology and microfluidic fabrication in a laboratory on a chip. This technique uses the exposure of UV light with a wavelength between 193-436 nm to transfer the pattern through a photomask onto a substrate that requires a photoresist coating (Li & Wang, 2012; Pimpin & Srituravanich, 2012). The photoresist is a combination of a film-forming agent that is sensitive to the irradiated light. The photoresist area, which is unprotected, can break down in the development (Pimpin & Srituravanich, 2012). Therefore, the photolithography technique is most widely used in small patterning as well as microchannel fabrication

(Ali et al., 2013) where the photolithography process is used to create the platform in a biosensor system. Pechprasarn et al. (2016) have enhanced the sensitivity in the optical biosensor via grating platform in which the micro-patterning needed the photolithography technique (Suejit Pechprasarn et al., 2016).

However, the limitation of this technique involves the fabrication of the photomask process and its cost. When the mask designer creates a new pattern, it leads to the new mask fabrication. This process produces the difficulty of patterning, manufacturing time and costs leading to disruption of innovation (Menon, Patel, Gil, & Smith, 2005; Seok Park et al., 2009). Recently, maskless photolithography has been developed. This system integrates either the digital micromirror device (DMD) or spatial light modulator (SLM) instead of the photomask. The maskless photolithography technique is cost-effective, flexible, and time-saving (Jun Zhong, Qing Gao, & Li, 2013).

In this work, we introduce an idea to modify the widefield microscope to be the maskless projection system for micropatterning. The optical alignment has been developed by adding the optical component and projection device using liquid crystal display (LCD) to project the pattern image, like turning the light ON and OFF. The pattern passed through the LCD will be then minimized and transferred to the substrate. This maskless patterning system based on the widefield microscopy leads to a uniform projection of pattern image. In addition, the modified system provides cost-effective maskless patterning giving more flexibility in pattern design.

2. Objectives

1. To study and design the optical alignment of the widefield microscope for projecting image.
2. To construct the modified widefield microscope for projection maskless micropatterning which is to be useful in photolithography applications.

3. Materials and Methods

In order to study and design the optical system for the widefield microscope-based maskless patterning projection system, we first illustrated the schematics of optical components and alignment conditions for image implementing.

3.1 Implementation of conventional widefield microscope system

The optical system of the widefield microscope consists of a light source, an illumination optical system, objective lens, tube lens, and CMOS sensor, respectively. The schematic of the optical system for a conventional widefield microscope is shown in Figure 1.

Based on the instrumentation system, the light source produced the light passing through the alignment of the system. In conventional, many types of lamps in the commercial microscope are available such as halogen, xenon, and arc lamp, including LED. The illumination of the optical system was designed to create the condensed and uniform light to expose onto the whole sample. Köhler illumination provided the condensed and uniform light through three lenses which are the collector lens, field lens, and condenser lens, respectively. The field diaphragm was also placed between the field lens and the condenser lens in order to control the field of the image plane and adjust the intensity of the light. As a result, the light passing through this illumination will be achieved the proper light intensity onto the sample. Objective lens was used to magnify and resolve sample details in which there were 4x, 10x, 40x and 100x magnifications. The higher the magnification, the higher the resolution can achieve. The resolution which is the ability to resolve two points in the image significantly involves the ability to gather light, or so-called numerical aperture (NA). The NA, therefore, is used to measure how much the light can be collected. The high magnification lens having very short working distance provides the high NA value. In the experiment, we used the NA value of the objective lens as same as that of the condenser lens in Köhler illumination. The NA value can be calculated from a reflective index of the lens related to the light cone angle that the lens can be collected (Mansfield, Studenmund, Kino, & Osato, 1993). In general, there are two types of objective lens, i.e., finite conjugate and infinite conjugate objective lenses. The finite conjugate lens will focus the light from the specimen at the focal plane of the objective lens. On the other hand, the infinite conjugate lens will create the parallel rays, the light is not focused. So, tube lens must be required in an optical system with using the infinite conjugated objective lens to adjust the focal length of the light from the objective lens. The last component was the CMOS sensor adopted from the sensor of a digital camera for recording the image and manipulate in a computer program. This conventional system has manipulated the referred results related to the resolution and the optimization via Köhler illumination technique.

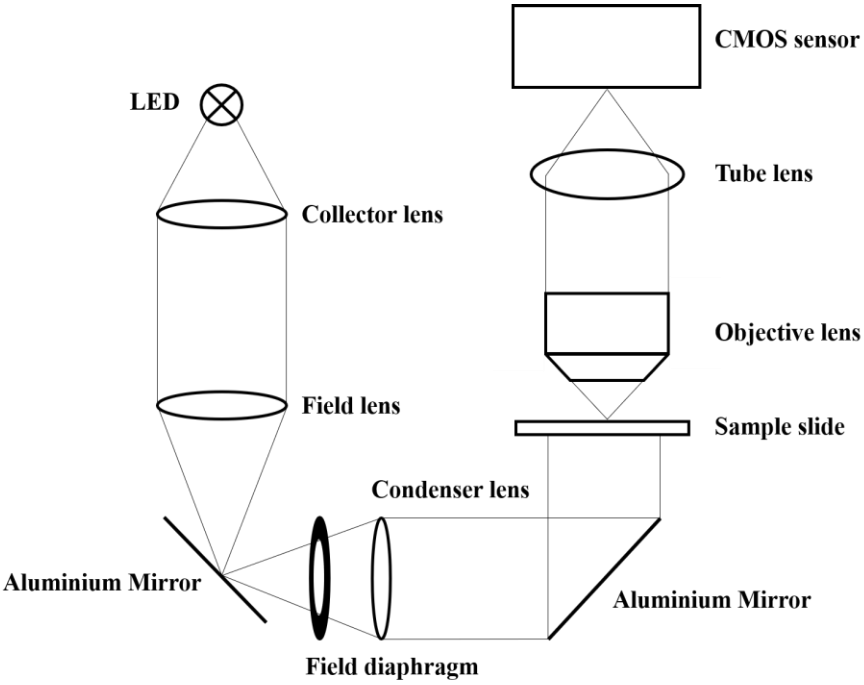

Figure 1 Schematic of the optical alignment of conventional widefield microscope

3.2 Modification of widefield microscope-based maskless patterning projection system

To transform the conventional widefield microscope into the modified widefield microscope for the projection system of micropatterning, we have designed the optical alignment as shown in Figure 2 which use the same technique as in Köhler illumination. The optical components inserted were two parts, that are, the patterning used as the light obstacle and the monitoring used for capturing the picture for further processing.

Figure 2 shows the system of the modified widefield microscope. The selection of the light source for the photolithography was considered depending on the wavelength which can engrave the photoresist on the substrate. Some experiment used a halogen lamp with 405 nm wavelength (Lee, 2010; Love et al., 2001). However, in this experiment, we have proposed to demonstrate the setup of the projection microscope for micropatterning. This work thus used the 50 watts warm white LED with approximately 600 nm as a light source of the system.

The illumination system was similar to the conventional widefield microscope that uses Köhler illumination. In this system, the light was illuminated to the transmission LCD plate where the pattern can be created easily using a computer program, for example, the Microsoft PowerPoint and Paint. The pattern composing black and white patterns will obstruct as an analogy between OFF and ON light, respectively. This provides the flexibility to design the new pattern dependent on the applications. In addition, the transmission LCD has controlled the area and field of view of designing patterns matching to the minimizing lens. Thus, we can remove the field diaphragm from the illumination system. The pattern on the transmission LCD was carried by a convex lens and reduced its size using the finite conjugated objective lens. The pattern image whose size was reduced was projected onto the substrate. In the monitoring part, the image of the pattern on the substrate can be reflected back from the objective lens to the CMOS sensor adopted from the digital camera where the beam splitter was placed as in the figure.

This system has been demonstrated both of the projection microscope and the monitoring of the pattern simultaneously serving the precision and the pattern correction to be engraved of the desired microfabrication.

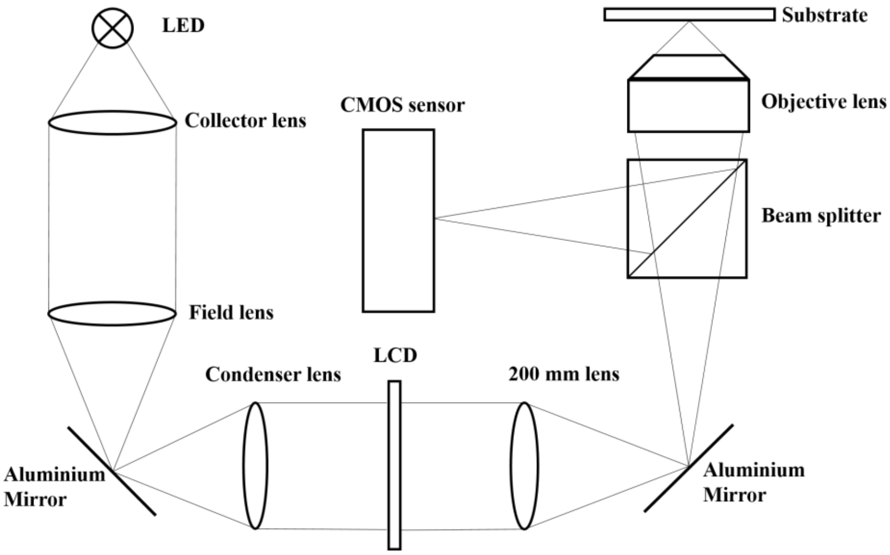

Figure 2 Schematic of the optical alignment of modified widefield microscope for projection maskless micropattern

3.3 Patterns and optical alignment testing

Figure 3 shows four patterns as the sample to be demonstrated the projection onto the substrate. There are a linear line, droplet array, grating, and T-junction, respectively. Due to the projection technique based on this microscope, the patterns are capable to design conveniently using a basic computer program and interface to the transmission LCD plate. In this work, we created the patterns to be projected using the Microsoft PowerPoint. The first pattern was a linear line with a 0.11 mm width projected through this microscope to find the narrowest line on the substrate. The second pattern was a 3×3 droplets array with a 1.20 mm diameter of each circle and is useful for the fabrication of microfluidic platform for the detection of *E.coli* in the water (Golberg et al., 2014). The third pattern was a linear grating with a 0.25 mm width and gap used to enhance the sensitivity in the optical sensor (Suejit Pechprasarn et al., 2016). The last pattern was T-junction with a 0.20 mm width as a basic pattern of the microfluidic channel for mixing the chemical agents.

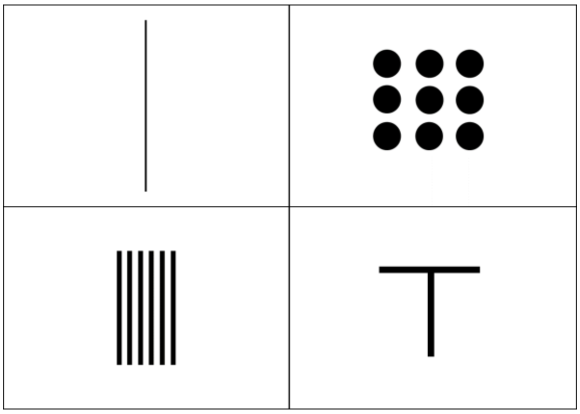

Figure 3 Pattern for projection on the substrate

4. Results and Discussion

The optical alignment of the conventional widefield microscope has been implemented showing in Figure 4. As seen, the components consisted of the high-power LED as a light source of the system as a reason of cost-effective and avoiding the heat problem from some types of the lamp (Albeanu, Soucy, Sato, Meister, & Murthy, 2008). The illumination system consisting of three convex lenses were the collector lens (50 mm), field lens (200 mm), and condenser lens (50 mm, 0.4472NA). The field diaphragm was placed between the field lens and condenser lens. The magnification system consisting of the 4x objective lens (0.1NA) and the 10x objective lens (0.25NA), was used herein. These lenses were matched with the NA of the condenser lens which was below 0.44. The tube lens with a 200 mm focal length was matched with the finite objective lens. The image acquisition system and monitoring were used CMOS sensor having size of 22.3mm x 14.9mm (4752 x 3168 pixel, Canon 50D). Other components, the aluminum mirror was sputtered aluminum with a 202 nm thickness used as the reflector where %transmission was less than 0.05% in a range of 200-1100 nm wavelength.

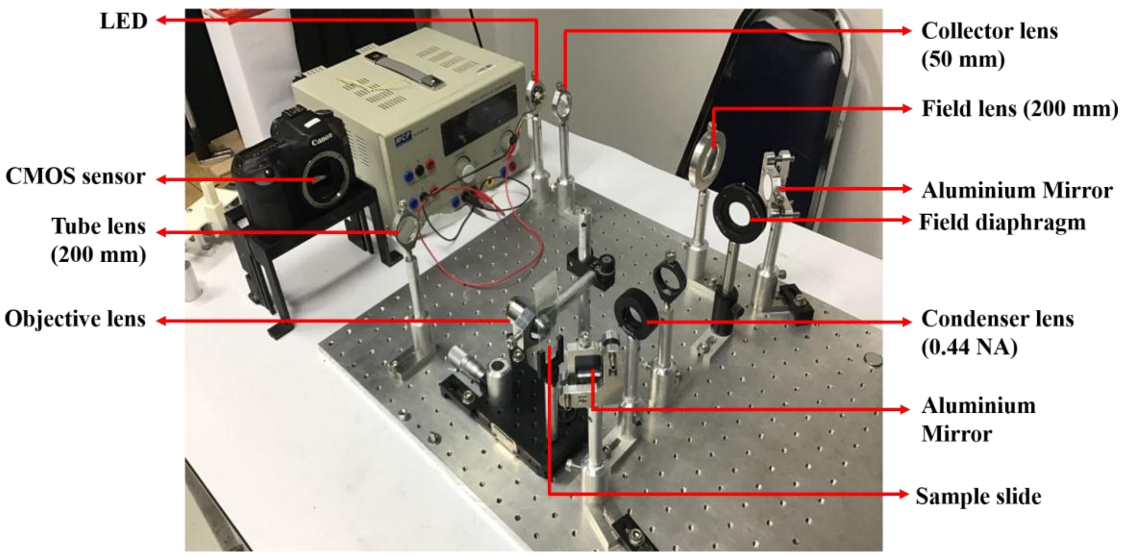

Figure 4 Implementation of the optical alignment of conventional widefield microscope

As a result, the grating target of USAF1951 (R1DS1N, Negative 1951 USAF Test Target, Thorlabs, Inc.) was used for testing the resolution of this widefield microscope. It was placed in the position of the sample slide as seen in the figure. The resolution of the image acquired from this system can obtain a measurement of approximately 8.7 µm which was the smallest details that are able to resolve the image.

Figure 5 shows the modified widefield microscope that has been implemented. We have transformed the system into a projection microscope for maskless patterning. As seen, the transmission LCD was inserted into the projector part. The convex lens with a 200 mm focal length was used for carrying out the pattern from the transmission LCD to the finite conjugated lens and the beam splitter which helped us to collect the image from the substrate. The objective lens was inversely used in order to minimize the pattern instead of magnification which was the result of the conventional method. Therefore, the image was projected on the substrate with micro-size and high-resolution image. In addition, the illumination part has to be covered with the aluminum sheet because the amount of noise from the circumstance affected the low intensity of imaging. The imaging results of the patterns in Figure 3 will be demonstrated in the next section.

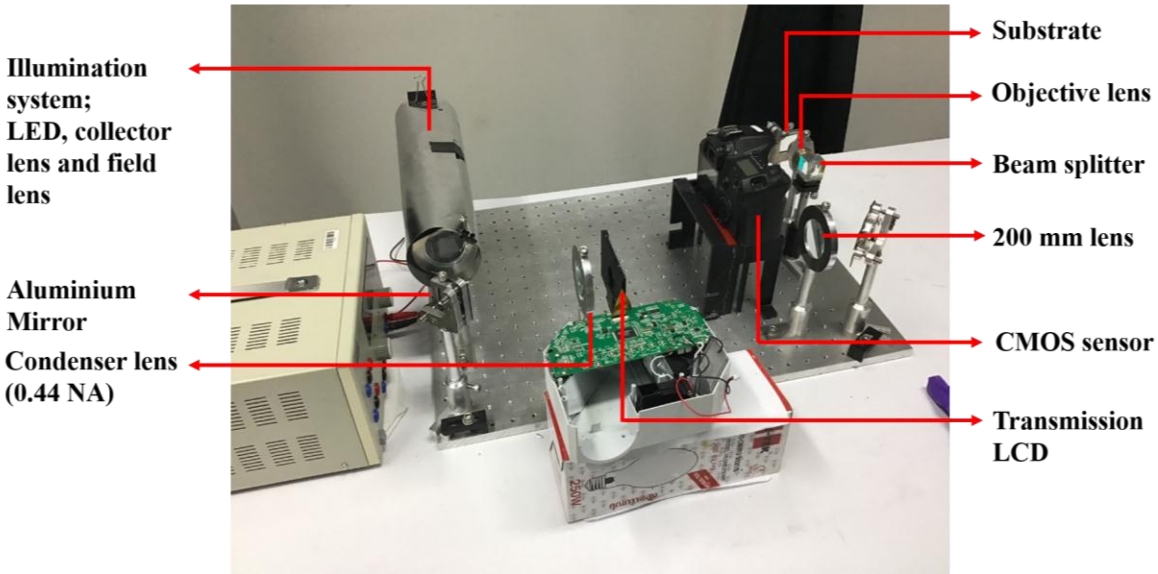

Figure 5 Implementation of the optical alignment of modified widefield microscope for projection maskless micropattern

The results of the system in the figure below show the four patterns projected on the substrate using 4x and 10x objective lens related to Figure 6a and Figure 6b, respectively. The results show that more magnification and more NA gave more resolution and contrast in accordance with the rules of resolution that were 0.61λ over NA in the xy-axis and 1.67λ over NA^2 in the z-axis (Mansfield et al., 1993).

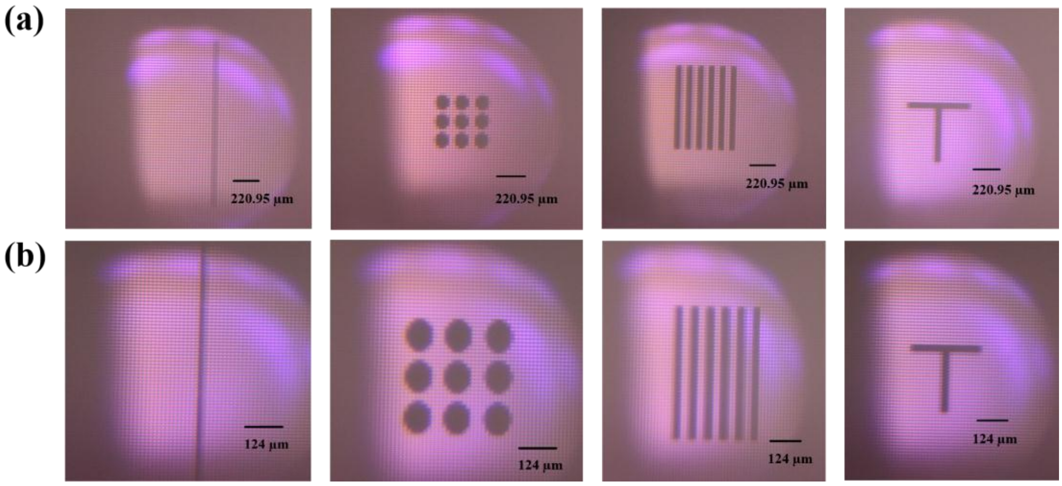

Figure 6 Patterns projected onto the substrate (a) using 4x objective lens and (b) using 10x objective lens. The patterns were linear lines, droplet array, grating and T-junction, respectively

As a result of pattern projection shown in Figure 6, we acquired these images from the monitoring part using CMOS sensor interfaced to the computer. All of the patterns can be obviously seen and resolved with the details. To evaluate the size of the patterns that was projected on the substrate, the demonstration was achieved to project the minimized patterns on the substrate and simultaneously reflect back to the CMOS sensor through an objective lens for monitoring. The CMOS sensor was connected to PC via USB cable so we can control the digital camera to capture and collect the image. Then, we can estimate the size of the patterns by comparing with a known object (width of line pair) of 1951 USAF image where we captured 1951 USAF with the same objective lens. The smallest micropattern size that can be projected on the substrate using this alignment was approximately 50 µm with 4x objective lens and 10 µm with 10x objective lens, respectively. However, the size was calculated theoretically related to the resolution of the CMOS sensor, which their real size could be observed under the electron microscope after the etching process for further work.

5. Conclusion

The modified alignment system of the widefield microscope for projecting a maskless micropatterning system has been implemented. The developed system consists of high-power LED as the light source of the system, the three-convex lens of Kohler illumination for uniformly illuminating the whole pattern, the 4x and 10x objective lens for reducing pattern images instead of magnifying, the beam splitter, and CMOS sensor for observation. As a system testing, we projected four patterns, namely the linear line, droplet array, grating, and T-junction on the substrate. Consequently, the pattern projected onto the substrate was measured at the size of approximately 50 µm with the 4x objective lens and 10 µm with the 10x objective lens. The projection pattern can be taken simultaneously by the CMOS camera in the backward reflection alignment which is very convenient for observing during the projection pattern incident on the substrate. The projection system will be integrated into the microfabrication of grating for further process. We expect that this system would reduce the cost of photomask fabrication, provide flexibility, and save production time.

6. Acknowledgements

This work was funded by the Research Institute of Rangsit University and STEM program of National Science and Technology Development Agency (NSTDA). CS and SS also would like thank Photonics Technology Laboratory (PTL) of National Electronics and Computer Technology Center

(NECTEC) and Biophysics and Medical Optic laboratory in College of Biomedical Engineering for supporting facilities during doing research.

7. References

Albeanu, D. F., Soucy, E., Sato, T. F., Meister, M., & Murthy, V. N. (2008). LED Arrays as Cost Effective and Efficient Light Sources for Widefield Microscopy. *PLoS ONE*, 3(5), e2146.

Ali, M. A., Srivastava, S., Solanki, P., Venu, R., Agrawal, V., Kim, C., John, R., & Malhotra, B. D. (2013). Highly Efficient Bienzyme Functionalized Nanocomposite-Based Microfluidics Biosensor Platform for Biomedical Application. *Scientific Reports*, 3, 2661.

Chen, X., Zheng, B., & Liu, H. (2011). Optical and digital microscopic imaging techniques and applications in pathology. *Analytical cellular pathology,* 34(1-2), 5-18.

Dawe, G. S., Schantz, J.-T., Abramowitz, M., Davidson, M. W., & Hutmacher, D. W. (2006). Light microscopy. *Techniques in Microscopy for Biomedical Applications,* 2, 9.

Mansfield, S., Studenmund, W., Kino, G. S., & Osato, K. (1993). High-numerical-aperture lens system for optical storage. *Optics Letters,* 18(4), 305-307.

Menon, R., Patel, A., Gil, D., & Smith, H. I. (2005). Maskless lithography. *Materials Today,* 8(2), 26-33.

Pechprasarn, S., Learkthanakhachon, S., Zheng, G., Shen, H., Lei, D. Y., & Somekh, M. G. (2016). Grating-coupled Otto configuration for hybridized surface phonon polariton excitation for local refractive index sensitivity enhancement. *Optics Express*, *24*(17), 19517-19530.

Pechprasarn, S., Sukkasem, C., Suvarnaphaet, P., Thongchoom, R., Chuwittaya, S., & Janyasupab, M. (2018, November). Low-cost instrumentation of Automated Whole–slide Microscope for Biomedical Imaging. In *2018 11th Biomedical Engineering International Conference (BMEiCON)* (pp. 1-4). IEEE.

Seok Park, E., Jang, D., Lee, J., Jeong Kim, Y., Na, J., Ji, H., Choi, J. W., & Kim, G.-T. (2009). Maskless optical microscope lithography system. *Review of Scientific Instruments*, *80*(12), 126101.