Supplementary Materials

In the supplementary materials of this paper we discuss some practical consideration for alignment of optical components to help unexperienced users to achieve a high performance optical setup.

Scan and tube lens mechanisms. The scan and tube lens mechanisms in our design are two identical Plössl compounds. We suggest first putting the compounds together. Then assembling them to from a relay mechanism. The two Plössl lenses should be placed at the approximate distance by connecting them using lens tubes and proper tube adapters. For fine alignment, the relay mechanism should be illuminated with a collimated infrared light at $\lambda \approx 1300nm$. The out going beam should remain collimated at a distance more than a meter. If beam convergence/divergence was observed, use the tube adapter to decrease/increase the distance between the scan and tube lenses. The beam diameter can be investigated visually using a near infrared (NIR) detector card. Once the optimal distance is achieved lock the adapters using retro rings. Two identical relay lens mechanisms are needed in this design, one for the sample arm and one for the reference arm.

Aligning the scan head. The scan head consists of a light collimator, a translational mount, and two galvanometric mirrors that should be aligned properly. At the first step install a collimator package on a xy translational mount (CXY1, Thorlabs) and attach it to a head cube (Fig. 2). Then the galvanometric mirrors can be installed. We use a small beam diameter galvanometric system package from Thorlabs. The package includes the necessary drivers, heat sinks, and power sources for proper function of the galvanometric mirrors. The galvanometric mirrors should be clamped using the custom made brackets, while the brackets can be mounted on a holder using cap screws. It is helpful to first attach the brackets loosely, and then to insert the first scanning mirror. Once in place, turn the drivers on and command the mirror to go to angle 0. The body of the mirror should turn to approximately 45 degrees with respect to optical beam path and then locked at that position before placement of the second scanning mirror. The same procedure can be used to install the second mirror. At this stage the galvanometric mirrors should be connected to power supply and commanded to go to the origin. For an OCT system in the infrared region, the alignment procedure can be started using a visible laser. The laser should be incident on the center of the mirrors. This can be done by adjusting the position of the collimator which is installed on the translational mount. If beam truncation is detected after the scanning mirrors adjust the translational mount properly. Once the beam location on the mirrors are adjusted, the angle of the mirror should be fine tuned such that the beam exits the scanning head and hits the center of the scan lens and is parallel to its optical axis. This process can be facilitated by first connecting an empty lens tube instead of the relay lens to the scanning head. This tube uses two adjustable iris at its ends. Attempt to angle the mirrors such that is incident at center of the first iris while monitoring the location of the beam at the other end of the tube. At the beginning the irises are opened at their maximum diameter. As the alignment process moves forward the iris diameters can be reduced to achieve a reasonable alignment. This is when the beam is almost parallel to the optical axis and passes both irises when their open diameters are less than $1mm$. If the beam is almost parallel to the tube axis but is off-centered more than $1mm$ then the galvanometric mirrors and the collimator locations should be relocated. The can be done by loosening the mirrors and translating them slightly in the desired direction. After each translation, the process should start over until satisfactory result is achieved. Once the alignment is done using the visible light, it should be confirmed by the OCT light as well. If the OCT light beam is not centered or there is beam cut then the same process can be repeated for the OCT beam. The pre-alignment with a visible light, reduces the alignment time of the infrared light. We do not recommend using translation mounts for the galvanometric mirrors as they can increase the vibration in the scan head as the mirrors move.

Installing the relay lens. After the scan head alignment, the relay lens mechanism (scan lens + tube lens) can be installed in place. The back focal plane of the scan lens should be located at the center of the two scan mirrors. The distance of the lens tube and the mirror can be adjusted by using a proper tube adapter to connect the lens tube to the scanning head (Fig. 2). The ideal position for the tube lens is such that the conjugate image of the mirrors locate at the back focal plane of the objective. The conjugate image of each mirror can be located by commanding that mirror to scan at its maximum angle. Using the infrared detector find the location that the beam has the least motion. If the location of the conjugate image of the mirrors are far from the designated locations by more than a few millimeters ($\sim 3 - 5mm$) tune the tube lens location by adjusting top tube adapter. The objective then can be attached to the end of sample arm by use of lens tube adapters and an adjustable collar. The length of collar should be adjusted to place the objective lens at the nominal location that is recommended by the manufacturer. The final step is locating the focal plane of the sample arm. It can be done by placing a mirror in front of objective in sample arm. The distance between mirror and objective should be adjusted until the maximum back coupling is detected in the return path from the sample arm. Then the mirror surface approximately collocates with the focal plane of the sample arm.

Reference arm. The reference beam should illuminate the reference mirror perpendicularly such that it travels travels back to the collimator and couple into the optical fiber. For this reason the reference mirror is mounted on a kinematic mount which can adjust the angle of the mirror. The coarse alignment can be done using the visible light and placing a pinhole ($< 1mm$ in diameter) at the center of the beam. The mirror angle should be adjusted until the reflected beam travels back through the pinhole. At this point the pinhole can be removed and the fine tuning can be done by maximizing the power of light that is re-coupled to the fiber. An optical circulator is necessary to guide the re-coupled light toward the detector.

In our design, there is an adjustable iris in the reference arm that controls the strength of the reference beam at the time of experiments. This iris can be used as a pinhole during the coarse alignment. The reference arm can incorporate paths for different objectives by adding a removable folding mirror in its pat. The mirror can be inserted to the arm to redirect the light beam to a path which is designed for the desired objective.

Typically the location of the zero path difference (the conjugate location of the reference mirror in the sample arm) should be above the imaging focal plane. for most applications a depth of $\sim 200 - 500\mu m$ is desirable. This way the whole depth of focus is withing the sample. However, in some applications, the location of the zero path difference with respect to the imaging focal plane needs to be adjusted according to the sample configuration and depth of interest. The fine positioning of reference mirror can be done by mounting it on a high resolution translational stage. When a mirror is placed at the focal plane of the sample arm, then move the adjust the reference mirror until the desired distance between the focal plane and zero path difference is achieved. It is important to note that this step requires a data acquisition and post-processing software to obtain OCT images. The OCT image of a mirror appears as a line. By moving the reference mirror this line moves up/down in the OCT image. To set the zero path difference $\sim 200 - 500\mu m$ above the focal plane, one should first move the reference mirror so that the mirror image is at the top of the image. It means the zero path difference is almost located at the focal plane. Then by using fine tune nub in the translational stage slowly move the mirror toward the collimator (reduce the length of reference arm) until the mirror image appears at the desired depth.

Troubleshooting. When there is no such line in the OCT images, first check that the light is delivered to the sample and reference arms. Then, block each of sample and reference arms one by one and confirm that for each arm a noticeable light power is recorded by the line camera. This assures that the back reflected light from the sample and reference mirrors are reaching to the detector. The block should occur close to each of the mirrors for example by placing a paper in front of the each mirror. When blocking one of the mirrors does not cause change in the detected signal check the fiber connections, and the alignment of that arm. After confirming that the detector is receiving sufficient power from each arm if no line is detected in OCT image, check the length of the reference arm. In the presence of a large (more than several millimeters) mismatch between the length of sample and reference arms, the interference signal might not be detectable by the spectrometer. Then, it is necessary to adjust the length of the reference arm by using the translational stage. If the mismatch is outside the range of the translational stage it should be relocated until the horizontal line appears in OCT images. When displacing the reference mirror it is important to frequently check the reference power by blocking the reference power.

Spectrometer alignment. After placing the collimator and grating at their designated positions, one should confirm that the OCT beam incident on and diffracted by the grating is not partially blocked by the rotary mount. If the beam is truncated, the collimator should move accordingly. Use the fine tuning nub on the rotatory mount (PRM1, Thorlabs) to adjust the roll angle of the grating so that the diffracted OCT beam forms a horizontal line. When possible change the light source to a monochromatic light source at $\lambda = 1300nm$ and fine tune the yaw angle of the grating. This can be done by rotating the bottom rotatory mount (PR01, Thorlabs) until the outgoing beam follows the desired angle ($180 - 2 \times 48.6 \approx 83^o$) with respect to the incident beam. If a monochromatic light source is not available, the OCT beam can still be used to coarsely adjust the yaw angle. Then place the achromatic lenses at the designated locations. The diffracted beam should be incident as close as possible to the center line of the lensing system, otherwise lens aperture may truncate the diverging beam, or optical aberrations may degrade the quality of OCT images. By using a NIR detector card confirm the location of image plane. The diffracted OCT beam that is focused by the lens mechanism forms a horizontal line. The focal plane of the spectrometer system is the location that this horizontal line is the sharpest and brightest. If it does not match the expected image plane, check the alignment of the lensing mechanism. If it is accurate, then check the alignment and angle of the grating. After locating the focal plane, use the fine tuning screw of the rotary mount (PRM1) one more time to align the focal line as horizontal as possible.

The line-CCD detector array should be aligned properly with this line. After confirming the focal location of the diffracted beam, place the detector at the desired locations. By reading the detected spectrum ensure that there are no significant artifact in the recorded spectrum. Under an imperfect alignment the recorded spectrum is contaminated with artifacts, which may appears as a strong high frequency pattern in the recorded interference pattern or some sharp changes in the intensity of camera pixels. If there are such artifacts, continue fine tuning PRM1 until an artifact-free spectrum is obtained. This means the recorded spectrum does not include sharp changes and resembles the spectrum that is provided by the light source manufacturer. After initial alignment of the hight and angle of the camera, find the proper axial location of the detector. For that purpose place a mirror in the sample arm so there is a strong sinusoidal interference pattern. Adjust the location of the mirror in the sample arm until a high frequency interference pattern is formed on the camera detector. Adjust the position of the detector along the lensing optical axis until the interference is at its maximum amplitude. Due to a long depth of focus of the beam it is possible to find a range of displacement which causes no significant amplitude change. Then the best positioning is around the middle point of that range. Typically it is necessary to do this alignment in an iterative fashion in which periodically the grating angle and camera horizontal are aligned until it approaches the best performance. Placing the camera on a horizontal axis translational stage might be helpful; however, we did not find it necessary. After this step a fine tuning of the PRM1 rotary mount might be necessary to obtain an artifact free spectral reading. This alignment process might take about 1 hour.