sample, aligning the positions with respect to the laser light, providing an output control signal related to the signal output from the photosensitive device from a feedback algorithm/process to a precision positioner to stably maintain the positions over a time interval, replacing the first region of interest of a sample with a second region of interest of a sample, projecting laser light onto this second region of interest of a sample to produce back-scattered light and repeating the steps of receiving the back-scattered light by a photosensitive device, aligning the positions with respect to the laser light, providing an output control signal related to the signal output from the photosensitive device from a feedback algorithm/process to a precision positioner to stably maintain the positions over a time interval with respect to the tip region and the second region of interest of a sample, and returning the tip region to the identified dimensional positions of the tip region and the first region of interest with the precision positioner. This method may be repeated as desired with additional regions of interest of a sample.

## ADVANTAGEOUS EFFECT OF THE INVENTION

**[0013]** The present invention includes several advantages, not all of which are incorporated in a single embodiment. The present invention actively decreases drift and can be used to generate nanometer-scale registration between the tip and sample even after exchanging tips. The present invention is expected to expedite atomic force microscope (AFM) images of biological samples and also enables atomic force microscopy with the ability to swap tips for different functionality akin to a nanoscale milling machine. Finally, the present invention allows the return to specific features after long times, as in incubations (hours to days), which may be necessary in chemical or biological processing.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0014]** FIG. **1** (A) illustrates a representative microscopic device for use with the present invention comprising two focused lasers measuring tip and sample position by separately scattering off the tip and a fiducial mark engineered into the sample. FIG. **1**(B) illustrates a representative device for use with opaque samples.

**[0015]** FIG. **2** illustrates one possible optical layout for use with the present invention.

**[0016]** FIG. **3** illustrates the alignment of the tip: quadrant photodiode (QPD) signals as a tip was scanned along the x-axis through a detection laser.

**[0017]** FIG. **4** illustrates centering the tip on the laser focus.

**[0018]** FIG. **5** illustrates atomic force microscope (AFM) images of a feature taken over the course of a day with the different tips, utilizing the present invention.

**[0019]** FIG. **6** illustrates registered tip exchange with the present laser-based coordinate system and an array of fiducial marks.

## DETAILED DESCRIPTION OF THE INVENTION

**[0020]** The present invention introduces a technique which allows sharp objects to be rapidly brought into close proximity to a particular region of interest of a surface with high precision and accuracy in one, two or three dimensions. The method has potential applications in a broad array of tip-based research instrumentation and manufacturing techniques, including scanning probe microscopy, atomic force microscopy, proximal probe lithography, dip-pen lithography, tip-indent lithography, molecule array manufacturing, and single atom manipulation, as well as optical microscopy, local probe lithography, semiconductor patterning including semiconductor wafer and mask alignment, and operating optical tweezers. The region of interest according to the present invention contains a fiducial mark, object, structure or feature to be imaged or studied. The region of interest of the sample may also be the fiducial mark, object, structure or feature itself. The region of interest may also be located at a lateral offset from a fiducial mark.

**[0021]** The method disclosed herein utilizes at least one, but preferably two, laser beams to detect tip and sample dimensional position in real time and with atomic scale precision. One beam is used to localize the surface via light scattering off a fiducial mark in or on the surface, as described in Carter, A. R., King, G. M. & Perkins, T. T. *Back-scattered detection provides atomic-scale localization precision, stability, and registration in* 3*D*. Opt Express 15, 13434-13445 (2007), incorporated herein by reference. Another laser is used to localize the tip in a similar manner, as described in King, G. M., Carter, A. R., Churnside, A. B., Eberle, L. S. & Perkins, T. T. *Ultrastable atomic force microscopy: atomic-scale lateral stability and registration in ambient condition*. Nano Lett. 9, 1451-1456 (2009), incorporated herein by reference. Automated centering of the beams to their respective objects (i.e. tip, surface) is possible. Either the tip or the sample (or both) are affixed to a precision positioner, such as a piezoelectric transducer (PZT) stage, which generates rapid, precise displacements. Optical signals from both beams guide the tip-surface registration at the nanometer-scale level. The tip exchange process can begin with the tip safely oriented approximately 1 micron above the surface and can terminate with the tip localized to a particular distance above the surface (e.g. 5 nm) and to a particular lateral position with respect to the surface. Automated motion of the lasers, via, for example, lenses or mirrors, could be used to independently move the foci of the beams and increase the range of the controlled approach.

**[0022]** The method allows for rapid tip replacement and surface registered re-engagement during a manufacturing process or an experiment. Additionally multiple tips could be toggled into and out of engagement with the surface at a well defined surface location to enable complex manufacturing processes requiring multiple tips, for example, one tip for fine feature manufacturing, one for coarse manufacturing, one for device/feature evaluation. The exchange of multiple tips to measure or modify the same atomic-scale feature is enabled by the detection lasers. This "laser guided approach" is possible because the tip dimensional position will be fully and accurately defined with respect to the sample through the laser-based reference frame. After replacing a tip, the user can re-align the new tip to the laser and be assured that its alignment on the sample is the same. This ability is particularly useful in the field of nanomanufacturing, where a process may require two tips with different functions. Further, one tip may be required to manipulate a sample and another to image the final product for quality assurance.

**[0023]** Specifically, the process starts with a scanning probe microscope having a tip, an electronically controllable stage with subnanometer capability, and a pair of lasers. One of the lasers is focused on the tip or a fiducial mark engineered near the tip, rather than the back side of the cantilever. A sample on a substrate is provided, which either includes a fiducial or can itself function as the fiducial. The second laser