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META-INSTRUMENT: AN OPTO-MECHANICAL PLATFORM FOR IMAGING NEAR-FIELD OPTICAL INSTRUMENTS

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In 1947, Chuck Yeager flew a Bell X-1 to break the long upheld belief of the Mach barrier: no one could fly faster than the speed of sound. Physicist today are working to break another such barrier: the diffraction limit. In 1873, Ernst Abbe postulated that the fundamental limit of optical microscopy was limited by the wavelength and the numerical aperture of the optics to approximately half the wavelength [1]. In the visual spectrum, this equates to a resolution limit of approximately 100 nm.

By tapping into the optical near-field, the region where non-propagating fields can still be detected, the diffraction limit can be broken. For new technologies such as hyperlenses and nano-antennas, theoretical resolutions of 10 nm have been reported [3][4].

Industrial application of these imaging artifacts, however, is limited by the lack of an instrumentation platform that is capable of positioning the artifact in extreme proximity to the sample. For the visual spectrum of light, the optical near-field can be detected at distances from the sample measured in tens of nanometers. The two main challenges that are imposed by this are (1) measuring the distance to the sample [2] and (2) positioning it at the required distance.

The meta-instrument is an opto-mechanical instrumentation platform that is designed to meet the requirements imposed by imaging near-field technologies. These concern the positioning accuracy and speed, distance measurement, high bandwidth actuation, optical read-out and instrument dimensions.

The instrument sports a three stage design of coarse approach stage, fine positioning stage and high speed MEMS stage, which are used for engaging to the sample, following the surface topography and maintaining the optical artifact in focus. A topographical sketch can be found in Fig.1.

Fiber interferometers are utilized to close the control loop of the fine positioning stage and realize sub-nanometer control of distance and micro radian control of tip- and tilt of the optical element with a 470 Hz bandwidth.

This paper reports on the ongoing efforts and advances made in realizing the meta-instrument and open challenges for the next iteration.

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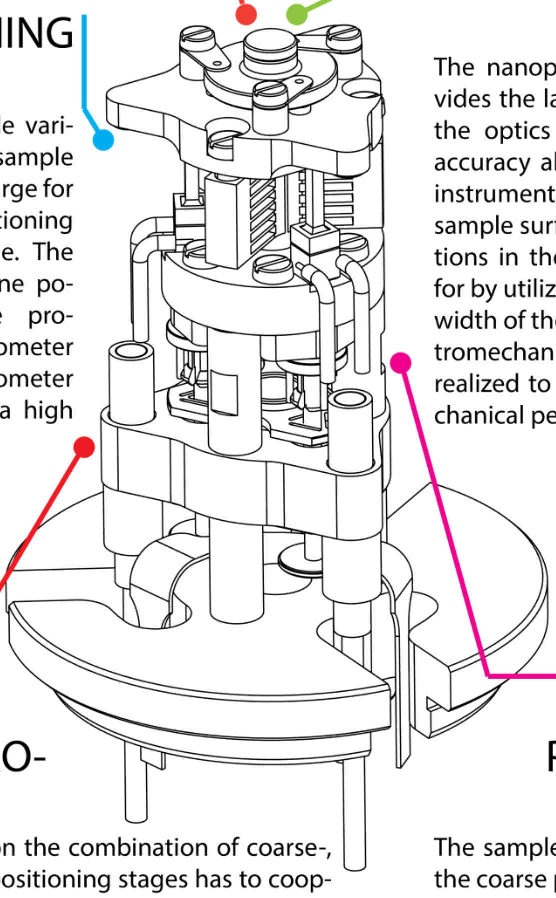

OPTICS

The meta-instrument provides an optomechatronic platform for novel lens concepts. Currently hyperlenses, solid immersion lenses and superoscillatory lenses are considered.

FINE POSITIONING STAGE

Micrometer scale variations in the sample height are too large for the nanopositioning stage to handle. The piezo-electric fine positioning stage provides micrometer stroke at nanometer resolution and a high bandwidth of ~10 kHz.

NANOPOSITIONING STAGE

The nanopositioning stage provides the last step in positioning the optics with sub-nanometer accuracy above the sample. The instrument is scanned over the sample surface. Small scale variations in the height are adjusted for by utilizing the 600 kHz bandwidth of the system. A microelectromechanical (MEMS) dummy is realized to demonstrate the mechanical performance.

FIBER INTERFEROMETERS

During operation the combination of coarse-, fine- and nanopositioning stages has to cooperate to keep the lens at the right distance, while scanning the instrument over the sample. Fiber interferometers are used to close the loop and provide sub-nanometer accuracy displacement measurements.

COARSE POSITIONING STAGE

The sample is approached using the coarse positioning stage. This stage provides sub-micron accuracy and a few millimeters of stroke. Using a stick-slip system, the stage can engage the sample in mere seconds.

Fig.1: Sketch of the first realization of the meta-instrument.