Contribution ID: **65** Type: **Poster**

A compact interferometric sensor for precise sensing of displacement below 1kHz based on novel glass technologies

The Einstein Telescope, as a third-generation gravitational wave detector, aims to improve the sensitivity of the detection band in the low-frequency region over existing gravitational wave detectors. For this, displacement sensors that provide high sensitivity between 100 mHz and 200 Hz are required for seismic isolation, and the scientific community is striving to increase their sensitivity by investigating novel sensing techniques. We demonstrate a heterodyne interferometric displacement sensor design that aims to be compact while achieving a sensitivity in the sub-picometer region in the mentioned frequency range. Our sensor receives its compact nature by decoupling the interferometric readout and sensing units using a polarisation-maintaining optical fibre. By sending both the reference and the test beam through the same fibre, we can reduce the optical components in the sensing unit to a polarising beam splitter and a mirror. At the same time, no electronics are required in the sensing unit at all. We present measurements from our tabletop sensor setup achieving a sensitivity better than $1pm/\sqrt{Hz}$ between 3 Hz and 600 Hz and better than $30pm/\sqrt{Hz}$ down to 100 mHz. In addition, we show our sensor's nonlinear phase contributions are smaller than $\pm 5nm$ when the test mass is moved over more than 5.4 µm. Using novel glass technologies, we aim to make our sensing unit even more compact. With the development of a meta-structured sensor head that provides the properties of a polarising beamsplitter, a high reflective mirror and a fibre collimator at the same time, parts of the classical optics can be replaced with just a single glass element. By splicing the fibre directly on the glass body, we would get an ultra-stable monolithic fibre sensor head assembly. We show a first prototype of the metastructure, which is spliced directly onto a fibre and acts like a flat lens without yet offering the properties of a polarising beam splitter. Based on our data, we are convinced that our current design already represents a compact displacement sensor that can be used to increase the sensitivity of a third-generation gravitational wave detector in the low-frequency regime. The meta-structure currently under development aims to make the sensor head even more compact while representing a unique fibre-coupled assembly to split light depending on the polarisation state into a reference and sensing beam within a monolithic glass body.

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Session Classification: Poster Session

Track Classification: Instrument Science (ISB): Suspensions