A MINIATURIZED SPECTROMETER FOR ISRU MATERIAL CHARACTERIZATION M. Grott[1], J. Knollenberg[1], L. Miller[1], D. Wolter[1], C. Althaus[1], T. Großmann[2], J. Wecker[2], J. Martin[2], A. Ihring[3], B. Jung[1], K. Vasiliou[1], A. Maturilli[1], [1]German Aerospace Center, Institute of Planetary Research, Berlin, Germany, [2]Fraunhofer Institute for Electronic Nano Systems, Chemnitz, Germany, [3]Leibniz Institute of Photonic Technology, Jena, Germany

Introduction: In-situ resource utilization or ISRU describes the techniques and processes involved in the harnessing of local natural resources as an alternative to bringing all needed material to the respective mission destinations. To locate and identify viable feedstock for, e.g., in-situ concrete production [1], oxygen production [2][3], or fibre production for additive manufacturing [4], in-situ prospecting and characterization of materials is necessary.

The lunar regolith is the most abundant locally available resource and consists of rocks and fine-grained particles composed of a number of minerals, the most abundant of which being plagioclase, pyroxene, olivine, ilmenite and spinel, with minor constituents being apatite and sulphides [5][6]. While volatiles are present in only trace amounts in nominally anhydrous minerals, they are more abundant in minerals like apatite [7].

Many of these minerals show distinguished spectral features in the mid to long thermal infrared wavelength range [8]. These include the Christiansen feature between 7.5 and 9 µm as well as Reststrahlen bands and Transparency features between 10 and 13 µm. In addition, sulphates and phosphates show features between 8 and 10 µm. Thus, the wavelength range between 7 and 13 µm is well suited for characterizing these materials using remote sensing techniques [9][8].

Amongst the resources most needed for building and supporting a lunar outpost are feedstock for concrete production, feedstock for fibre production, as well as feedstock for oxygen and water extraction [6]. Concrete production using geopolymers [1][10], i.e., synthetic amorphous aluminosilicates that can be used as inorganic binders, is generally viewed superior to using classical techniques like mixing Ordinary Portland Cement (OPC) for building materials [1]. The plagioclase feldspars albite and anorthite are particularly important for geopolymer production. Concerning oxygen production, most oxides can be thermally reduced at high temperature to release O_2 [5], but ilmenite reduction through electrolysis is the more favourable process [2][3][5] as it requires the lowest temperature and has the highest Technology Readiness Level (TRL). Pyroxenes like diopside can be used for fibre production and additive manufacturing. Apatite glasses are amongst the few lunar materials that contain significant amounts of hydrogen, although they are present at the wt% level only.

Example spectra of ISRU relevant materials as measured at DLR's Planetary Spectroscopy Lab (PSL) in the mid to long wavelength infrared range are shown in Fig. 1. Diagnositic spectral features of anorthite, diopside, ilmenite, and apatite, like the Christiansen feature and Reststrahlen bands, are readily identified.

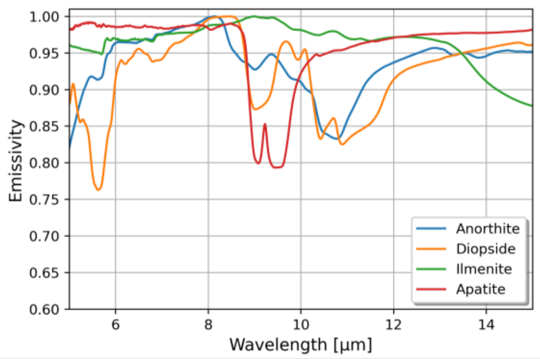

Figure 1: Emissivity as a function of wavelength for selected minerals relevant for ISRU. The Christiansen emissivity maximum is located between 7.5 and 8.5 µm while Reststrahlen bands are located at wavelengths beyond 8.5 µm.

Spectrometer Design: The spectrometer design for in-situ resource characterization and prospecting shown in Fig. 2 is based on electrically tuneable micro-electromechanical Fabry-Perot filters [11] and thermopile detectors [12]. The instrument design heavily relies on heritage from the radiometers built for the Hayabusa2 MASCOT [13] and MMX missions. These used six individual infrared channels to determine surface brightness temperatures and emissivity in the thermal infrared wavelength band.

The new technology element that enables the acquisition of resolved spectral information is a micro-electromechanical system (MEMS) based Fabry-Perot filter, which is integrated into the thermopile sensor housing. The filter works in the first interference order and the free spectral range of the instrument is half the central wavelength. For the current application, the central wavelength was chosen to be 9 µm, resulting in a useable wavelength range from 7.5 µm to 10.5 µm. Theoretically achievable spectral resolution is better than 50, i.e., about 180 nm.

Thermopile sensors and FPI filters have been integrated into standard transistor outline (TO) hermetic packages with a diameter of 15 mm and a height of 5 mm and cut views of the stack consisting of thermopile, space, and Fabry-Perot filter are shown in Fig. 2. The control voltages for tuning the central wavelength of the FPI lies between 0 and 70 V.

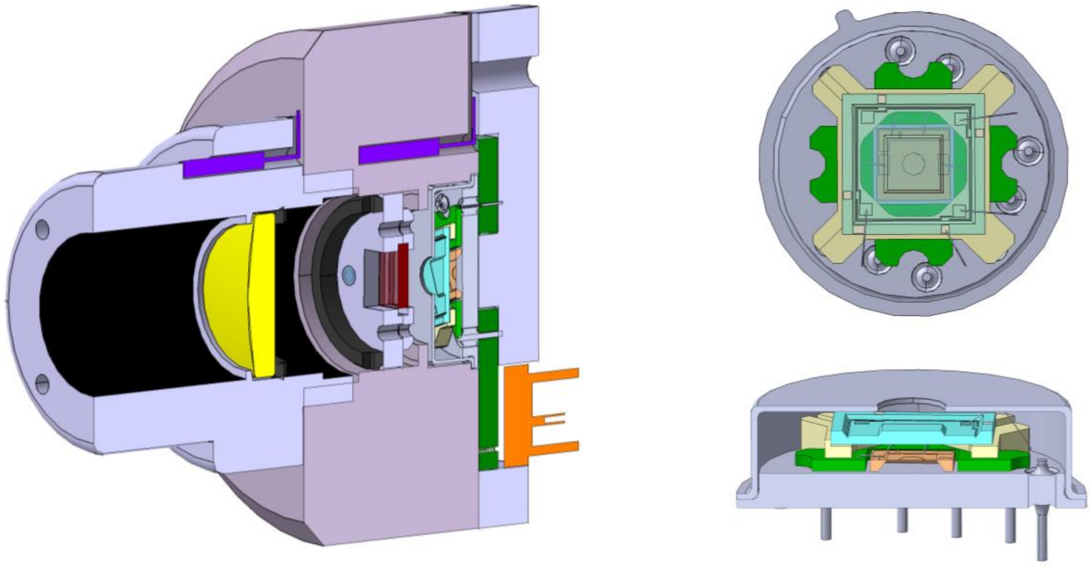

Figure 2: Left: Cut view of the spectrometer sensor head showing the baffle (black), lense (yellow), order blocking filter (red), FPI filter (cyan) and thermopile (orange). Top Right: Top view of the FPI Sensor and Filter Assembly. Bottom Right: Cut view of the Sensor including the Fabry-Perot filter (cyan) and thermopile sensor (orange).

The instrument optics have been designed to satisfy the scientific measurement requirements of the Lunar Leaper Mission [14] and allow for a meter-scale ground sampling distance at a distance to target of around 50 m. This translates into an instantaneous field of view of 24.5 mrad. The optical tube assembly uses commercially available germanium plano-convex anti-reflection coated lenses with a diameter of 12.7 mm and a focal length of 20 mm. A germanium based order selection filter (bandpass filter) is used to block higher interference orders at short wavelengths and prevents leakage radiation to reach the sensor at longer wavelengths. The sensor head has a diameter of 40 mm, a length of 45 mm, and a total mass of 105 g.

Instrument electronics consist of an analogue part for thermopile signal conversion and housekeepings, a digital part for instrument commanding and control, and a high voltage part to generate the 70 V needed to operate the FPI filter. Electronics will be housed on two PC/104 printed circuit boards and the total mass of the boards is estimated to be 200 g if space grade components are to be used. If instrument commanding and control could also be performed in the lander / rover central onboard computer, the space and mass requirements of the spectrometer would be reduced to one PC/104 board and 100 g, respectively.

Summary and Conclusions: The current instrument design has been implemented on breadboard level and the current TRL of the sensors including FPI filters is TRL 4. A functional verification has been performed under ambient conditions and the next steps for instrument development consist in a characterization of the instrument performance in terms of spectral resolution, signal to noise ratio, and noise-equivalent emissivity difference. Tests under vacuum conditions will follow to increase the readiness level of the instrument to TRL 6.

The application of the MEMS based Fabry-Perot spectrometer concept is not limited to in-situ applications and depending on ground speed, applications on orbiters and cube-sats would be feasible. Furthermore, using 2D imaging sensors, compact hyperspectral imagers for moderate spectral resolution applications can be realized.

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