Background and Mission

The component technology of optoelectronics has shown rapid progress after the discovery of the laser. Nowadays the development of components is led by telecommunications. Reliable light source and detector components, together with optical fibers and new manufacturing technologies, give new potential to applications of optoelectronics.

The group comprises an intensive collaboration network of researchers at the Optoelectronics and Measurements Laboratory of the University of Oulu, the Measurement and Sensor Laboratory in Kajaani and VTT Electronics. In accordance with the principles of Infotech Oulu, the group engages in basic research, drawing on the resources of the three organizations, as well as their extensive industrial connections and wide experience in technology transfer. Close collaboration partners include the high-speed electronics team of Infotech Oulu along with the analyzer, production technology and microsystems teams of VTT Electronics. At the international level, the Optical Sciences Centre of the University of Arizona (USA) and the Technical University of Gdansk (Poland) are among the primary co-operation partners of the group. In addition, the group participates in several European research and exchange programs.

The group performs basic research in optoelectronic measuring techniques with particular emphasis on the practical application of these techniques. In this undertaking, the group focuses on measuring and modelling the propagation of light in turbulent and scattering media such as atmosphere, human tissue, pulp, paper and optical fibres. Interesting properties are for example scattering, reflection, absorption, time-of-flight and the so-called photoacoustic phenomenon. The findings are used in novel applications in medicine, and the pulp and paper industry, as well as in smart structures and instrument technology.

Scientific Progress

Instrumentation within the pulp and paper industry and non-invasive methods of monitoring human health are the main application areas targeted by the optoelectronic measurements unit. In addition, distributed fibre-optic sensors enable the development and construction of new, challenging quality control and monitoring systems for large composite, concrete and metal structures. Recently, research on MOEMs in sensor and telecommunication applications has been initiated.

Pulp and paper measurement research

Optoelectronic Measurement group members have carried out research work on pulp and paper measurement applications in pulp characterization, paper surface structure and moisture measurement areas. Techniques applied in these topics included TOF (Time of Flight), PAS (Photoacoustic spectroscopy), NIR (Near Infrared) and MIR (Middle Infrared) spectroscopies.

Pulp characterization research was focused in the fines contents research using TOF techniques. This work was performed in the Measurement and Sensor Laboratory in cooperation with Optoelectronics and Measurement Laboratory in the University of Oulu.
Paper surface porosity and structure were studied in the PORO (Optical properties of Porous Materials) project using PAS techniques in the VTT Electronics and Measurement and Sensor Laboratory in cooperation with several universities.

Paper coating porosity and coat weight measurement research was also performed by NIR and MIR techniques in VTT Electronics, in addition to the moisture measurement research at VTT for several process industry fields.

**Reflectometer for determining the optical constants of industrial liquids**

One of the research areas in the Measurement and Sensor Laboratory (MSL) is related to the analysis of process liquids found, for example, in the pulp and paper industry. Knowledge of the optical constants of such liquids plays an important role in the industry, where they have been used for various purposes, such as measurements of concentration, determination of dissolved solids in liquids, density measurements, identification of species, purity testing of liquids and even temperature measurements.

A variety of optical techniques has been developed for the determination of optical constants. Reflection techniques offer an advantageous means of studying optically dense liquids (including a wide range of organic liquids); experiments can be carried out with minimum sample preparation. In transmission measurements, such liquids have to be diluted or, alternatively, the optical path length has to be limited to a relatively narrow range. Reflection measurements typically provide information about thin layers of the material in question. The importance of this technique for the study of surface phenomenon such as adsorption and contamination has therefore been acknowledged.

To this end, a novel spectroscopic reflectometer has been designed and constructed. Specular as well as diffuse reflectance may be determined as a function either of angle of incidence or of the wavelength of incident light. In addition, the polarization of incident light can be varied. As the device in question allows for a number of measurement modes, so there is a choice of data analysis methods available. Analysis techniques compatible with the use of the reflectometer, such as phase retrieval procedures, were introduced and tested. Information concerning the wavelength-dependent complex refractive indices of both transparent and opaque liquids was gathered across the UV-visible spectral range.

![Image of the measuring unit of the reflectometer.](image-url)
Wavelength tuning of a laser diode

The wavelength tuning properties of an edge emitting extended cavity laser diode with a micromechanical Fabry-Perot interferometer as an external reflector were studied at VTT. It was seen that this arrangement provides an essentially similar tuning range (few nanometers) to the traditional system with one external mirror only, but with much smaller mirror movement.

The operation of the tunable laser is based on the change of the effective reflectance of the external cavity system of the laser. The calculated reflectance characteristics of the external cavity system is shown in the figure; the effective reflectance of the system is plotted as the function of both etalon length and wavelength for ~10-µm external reflector distance. When increasing the control voltage applied between the electrodes of the FPI, the FPI resonance dips move towards shorter wavelengths and the smaller-period modulations move towards longer wavelengths. The phase behavior of the FPI reflectance causes fast changes to the small-period reflectance structure near the resonance dips. This will play an important role in the explanation of the experimentally observed laser tuning characteristics.

Alignment techniques for multimode laser pigtailling

When packaging multimode lasers into low-cost modules, passive fiber alignment would be extremely advantageous especially if the fiber alignment structures could be manufactured by using an injection-molding technique. Injection molding as a large-volume manufacturing technique allows for the reduction of the unit price of molded parts, provided that the number of parts molded by using a single molding tool is large. In this research active and passive fiber alignment techniques are compared. The constructions and packaging procedures of two modules packaged by using active and passive alignment techniques are studied. Using a sleeve construction, a multimode laser with a 230 µm x 2 µm emitting area was actively pigtailed with a 100/140-µm multimode fiber. In the other example, a multimode laser with a 300 µm x ~1 µm emitting area was passively pigtailed with a 200/230-µm multimode fiber through the use of an alignment structure which was precision-machined using LIGA technique. The study results in the applicability analysis of the passive alignment technique for low-cost fiber pigtailling.
Fiber optic sensors

Fiber optic sensing technologies have been developed for the determination of residual stresses of composites in cooperation with the Engineering Mechanics Laboratory and the Department of Chemistry at the University of Oulu. The Finite Element Method has been used to calculate residual stresses building up in the microstructure of composite materials during the manufacturing process. The results obtained have been evaluated and verified by commercial Fabry-Perot optical fibre sensors and a time-of-flight method for measuring fibre strain developed at the University of Oulu. Fastening methods of the optical fibres to the surrounding material have been investigated, and promising chemical procedures have been developed. Classification of distributed optical fibre sensing methods and their main properties for measuring quantity information continuously from a long sensor fibre have been reported. Good results were obtained in monitoring the integrity of a chemical container by using an attenuation method based on PCS optical fibres and a commercial OTDR. Also a prototype readout device for interrogation of wavelength multiplexed Bragg grating sensors have been developed.

Medical instrumentalational methods and devices

In the medical field, a new non-invasive blood pressure measurement method has been developed in the unit. Another aim was to produce new information about EKG-signals and measurement techniques. Optical blood flow monitoring methods and photoacoustic effects (PAS) in the human tissue and liquids after illumination of a short laser pulse were also examined.

Exploitation of Results

Active interaction with industry ensures the rapid application of research results. The work of the group paves the way for the introduction of a new generation of optoelectronic sensors and instruments based on micro-optics, micromechanics and microelectronics.

The research results of the group have been presented at conferences and published in professional journals. In projects funded by TEKES, the acquired knowledge has been directly transferred to the participating enterprises. Also commissioned research has been directly reported to the enterprises concerned, and several senior and junior researchers have taken up employment with them.

Future Goals

Reaching an acknowledged position as a top European research unit in its research area forms a key objective for the group. Another important goal involves becoming a central cooperation partner for Finnish industry in the development and application of measuring techniques and instrument technology. In addition, the group advances the scientific understanding of optoelectronics and measurement applications and produces high-quality dissertations and publications. Finally, the highly applicable, in-depth, information produced by the group also makes a contribution to product development and the creation of new business opportunities.
In the short term, the research activities of the group will be focused on:

1) promoting current theoretical understanding of multi-scattering in terms of the propagation of light in media such as paper, pulp, process suspensions and human tissue,
2) studying the applicability of time-domain spectroscopy in the characterization of pulp, the analysis of pore structure, and non-invasive measurements of human tissue and blood,
3) developing optoacoustic methods for measuring human blood and tissue, and properties of pulp and paper,
4) developing distributed fibre-optic sensors for both quantity and location measurements and applying these sensor systems to such tasks as the monitoring of large composite structures,
5) studying the applicability of ellipsometry for measuring pulp, process suspensions and human tissue, and
6) studying advanced MOEMS modeling and designs, releasing devices through micro processing and packaging, and applying them for MOEMS such as micro-optical table constructs.

### Personnel

| professors & doctors | 7 |
| graduate students    | 26 |
| others               | 7 |
| total                | 40 |

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| University (Oulu) | 28% |
| University (Kajaani) | 32% |
| VTT               | 40% |

### Doctoral Theses


### Selected Publications


