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 potential to applications of optoelectronics.

The group comprises an intensive collaboration network of researchers at the Optoelectronics and Measurements Laboratory, 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. This includes co-operation projects related to long term research but most development projects are omitted.

Close collaboration partners include the Circuits and Systems group (University of Oulu, Professor J. Kostamovaara), the Optical Measurements group (VTT Electronics, J. Tornberg), the Optics and Optical Communication group (VTT Electronics, P. Karioja) and the Manufacturing group (VTT Electronics, J. Lenkkeri). 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. In addition, new materials, manufacturing technologies and integration of the systems are developed by combining customized micro-optical devices, optoelectronic devices and novel packaging technologies. The findings are used in applications in medicine, the paper, pulp and mechanical wood industry, as well as optical communication and instrumentation.

Scientific Progress

Instrumentation within the mechanical wood, pulp and paper industry, and non-invasive methods of monitoring human health are the main application areas targeted by the optoelectronics and 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 (Micro Opto Electro Mechanical Systems) in sensor and telecommunication applications has been initiated.

Pulp and paper measurement research

The Optoelectronics and Measurements group members have carried out research work on pulp and paper measurement applications in pulp characterization and paper surface structure and moisture measurement.
areas. Techniques applied in these topics included TOF (Time Of Flight), PAS (PhotoAcoustic Spectroscopy), UV (UltraViolet), NIR (Near InfraRed) and MIR (Middle InfraRed) spectroscopies.

Pulp characterization research was focused on the fines content measurement of pulp slurries using TOF techniques. IR-spectroscopy was used to analyse pulping liquors and to evaluate strength potential of chemical pulps. The lignin content of fiber walls was measured using a self-made intelligent microscope based on UV-absorption and light polarisation.

Use of TOF, PAS and mathematical modelling to evaluate paper porosity was studied in co-operation with the Helsinki University of Technology.

Paper coating porosity and coat weight measurement research were also performed using NIR and MIR techniques as was moisture measurement research.

**Mechanical wood processing**

Image processing, microwave and IR technology were developed for the needs of mechanical wood processing.

In development programs of the Kainuu province and the city of Kajaani the development of mechanical wood processing has been emphasized. In 1998, a program called Woodpolis was established for the incrementation and diversification of wood production, as well as for the development of operational environments. Woodpolis included also academic research activities and support for a product development. One of the goals was to start a mechanical wood research (Puumi) project at the Measurement and Sensor Laboratory.

The objective of the Puumi project is to establish research facilities for the study of mechanical wood processing. Activities will be focused on the evaluation and development of measurement methods such as optical, microwave and ultrasound technologies. Applications include the determination of the size, shape and structure (inner as well as outer) of wood logs and planks. In addition, changes within the microstructure of wood material will be examined during the various drying/heat treatment processes.

Up to now a test bench for wood logs and planks has been designed and engineered. The construction allows the examination of wood material using camera, ultrasound and microwave measurements. Heat treated wood can be produced using a small oven (0.5 x 0.5 x 2.0 m$^3$). In addition, wood can be ‘traditionally’ processed in a workshop.

**Demonstration of polymer display devices and novel micro-cavity OLEDs**

The processing equipment modification for the fabrication of micro-cavity OLEDs was carried out. Preliminary feasibility data on the processing and operating parameters of the micro-cavity OLEDs was accomplished. Concepts for the integration of diffractive optical elements with the micro-cavity OLEDs, as well as micro-structuring (e.g. pixels) of such devices were demonstrated. Integration studies of the micro-cavity OLEDs on MOT (Micro Optical Table) components is ongoing. Novel packaging constructions for OLED displays and backlights were developed. The figure shows the effect of the thicknesses of luminescence/electron transporter material on the external quantum efficiency of OLED devices.
Optical signal processing and data storage

A general overview of the optical data storage technologies was obtained for the purpose of state-of-the-art reporting; a miniaturized optical pick-up head was modeled, and a novel pick-up head arrangement was envisioned resulting an invention disclosure in collaboration with the University of Arizona. Experimental characterization of the miniaturized ESEC (extremely-short-external-cavity) optical head in a static tester bench was started. In addition, a universal tool for modeling small optical components using finite difference time domain, FDTD, calculation was made. A 4M (multi modal micro-optical microscope) microscope and a chemical sensor (figure), based on the use of the MOT concept, were designed and modeled. Stray light characteristics of MOT materials and devices were studied. UV lithographic process compatible glasses for 3D-MOT systems with negative and positive tone and high aspect ratio properties was studied.

Optical transmission and interconnects

Transmitter and receiver modules for the verification of a free space modeling system were built and experiments were started.

The realization of a future high-speed free-space optical LAN, is depicted in Figure 4. The system is based on the use of a multi-beam transmitter equipped with a diffractive element capable of modifying the beams of each emitter element. In fact, to demonstrate the multi-beam transmitter, a single element providing a 50-degree illumination angle was fabricated and characterized. The advantages of free-space optical interconnects are large bandwidth, lightweight, small size, low cost and high-level security. The disadvantages, however, are bandwidth degradation due to multipath dispersion, sensitivity to ambient light and limited transmission distance due to the limited optical power budget. Based on the study, novel Monte Carlo ray-tracing software can be used for the analysis of the multipath dispersion and optical path loss of free-space optical links. Potential applications for these free-space systems are high-bit rate wireless LANs.

Medical instrumental methods and devices

Blood pressure and electrocardiogram (ECG) are traditional indicators of the condition of the human body. A new non-invasive blood pressure monitoring method based on electronic palpation has been developed in the unit. The monitoring method has been tested in measurements, which were made in collaboration with the Oulu University Hospital. The electronic palpation method was found to be reliable and its blood pressure measurement results correlate well with those of the intra-arterial method. Thus, it provides valuable clinical information during the diagnosis of blood pressure diseases.

The electrical action of the heart has been also studied in the medical unit. The aim was to produce new information about ECG-signals and their measurement techniques. The main research in this field was to study different signal processing algorithms to detect different arrhythmias in an ECG-signal.
A non-invasive laser Doppler method has been studied for blood flow monitoring in different media, for example in tissue and teeth. The method has also been superimposed to cardiovascular pulse detection and its applications in this sector. The method has been demonstrated to evaluate the elastic properties of the arterial wall. A close correlation between the theory and measurement results of the elastic modulus of the radial artery was found. In addition, it has been used to measure baroreflex regulation, which is one part of the autonomic nervous system and thereby it is possible explore the action of the autonomic nervous system. Both the elastic properties and the baroreflex regulation are important indicators of different cardiovascular diseases, for example arteriosclerosis and hypertension. The block diagram of the developed laser Doppler measurement system is presented in the figure.

![Block diagram of the laser Doppler measurement system developed in the unit.](image)

Photoacoustic effects (PAS) in human tissue and liquids after illumination with a short laser pulse were examined. The current photoacoustic apparatus has been used to study scattering media during the last year. The first studies were concerned with how the scattering and absorption compositions affected the photoacoustic signals. Then, adding glucose in scattering solutions and mixtures, the sensitivity of glucose concentration was found to be larger than with distilled water. Finally, the glucose concentration in whole human blood sample was measured, and the minimal detectable concentration was about 200 mg/dl, which is in the upper part of physiological glucose concentration. Compared with optical techniques, the photoacoustic method has higher sensitivity in compositions detection but it easily affected by temperature and the contact pressure of a piezoelectric transducer.

**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 job-order 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 own 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 the pore structure of paper, and non-invasive measurements of human tissue and blood,
3) studying the correlation between the elastic properties of the arterial wall and blood pressure pulse wave velocity (PWV). Carrying out test and application measurements of a laser Doppler system.
4) studying the applications of optical coherence tomography (OCT) in different scattering media, for example tissue, paper etc.,
5) developing optoacoustic methods for measuring human blood and tissue, and the properties of pulp and paper,
6) 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,
7) studying advanced MOEMS modeling and designs, releasing devices through micro processing and packaging, and applying them to MOEMS such as micro-optical table constructs, and
8) developing high-speed free-space LAN and implementing critical parts of the system.

### Personnel

| professors & doctors | 8 |
| graduate students    | 25 |
| others               | 16 |
| total                | 49 |
| person years (university: Oulu 34%, Kajaani 39%; VTT 27%) | 37 |

### External Funding

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### Doctoral Thesis


### Selected Publications


