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# From Molecular Raman Fingerprints to AI-Driven Precision Medicine

Raman spectroscopy has evolved from a highly specialized analytical technique into a versatile platform technology for biomedical diagnostics. By providing label-free molecular fingerprints of cells, tissues, and biofluids, Raman-based methods enable direct access to biochemical composition and functional molecular states without labeling procedures.

This lecture highlights recent progress in translational Raman biophotonics with a focus on artificial intelligence, and clinically compatible instrumentation. Advances in laser technology, fiber-optic probe design, and data-driven analysis strategies have enabled Raman spectroscopy to move increasingly from laboratory environments toward real clinical applications.

A first focus will be placed on Raman-based infection diagnostics, where molecular fingerprints from blood and blood-derived samples are combined with machine learning approaches to support rapid therapeutic decision making. These approaches enable molecular phenotyping of host responses and pathogen-associated biochemical changes under clinically relevant conditions.

Clinical translation will further be illustrated using fiber-based Raman systems for endoscopic tissue assessment. In particular, the MDR-conform Raman-InvaScope platform demonstrates how Raman spectroscopy can already be implemented in clinically compatible instrumentation for in vivo diagnostics and intraoperative decision support. However, such fiber-based Raman probes typically provide pointwise molecular information only. This limitation motivates the transition from point spectroscopy toward multimodal optical imaging approaches capable of delivering both biochemical and morphological information over larger tissue areas.

A second focus will therefore address multimodal nonlinear imaging strategies combining coherent Raman scattering with complementary contrasts such as two-photon excited fluorescence and second harmonic generation. These approaches enable rapid morphochemical imaging by simultaneously visualizing tissue architecture and molecular composition at subcellular resolution. Implemented in miniaturized and fiber-based platforms, such technologies open new opportunities for real-time intraoperative imaging, molecularly guided surgery, and emerging “see-and-treat” concepts integrating diagnosis and therapy directly within the surgical workflow.

Beyond current diagnostic applications, the convergence of Raman spectroscopy and artificial intelligence opens the door to personalized optical digital twins, where longitudinal molecular fingerprints are integrated with clinical and physiological data streams to enable predictive diagnostics and individualized therapy guidance.

Together, these developments demonstrate how Raman spectroscopy is bridging molecular analytics, multimodal photonics, and clinical translation to establish next-generation tools for precision medicine.

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