HORIBA Scientific

Application Note

Chemistry

Raman

RA25

Raman Analysis in Microreactor Channels with an Inverted Microscope

Raman microscopy is a technique with a wide variety of applications from semiconductors and mineralogy, to pharmaceuticals and forensics. It provides a non-invasive technique for obtaining full spectral information on the microscopic scale. The LabRAM INV, with its inverted microscope, presents a unique new configuration for Raman microscopy, which has proven vital for microreactor technology research.

Figure 1: The LabRAM INV

Miniaturization in Chemistry

Interest in developing microfluidic systems has grown considerably, as the reality of achieving a faster and cheaper means of performing chemical analysis has been demonstrated. The principles demonstrated by miniaturised total analysis systems can readily be exploited to develop reactors on the micron scale for the synthesis of organic compounds. In this field, a strong research base is now developing, and has established the need for monitoring and characterisation of these microreactor systems.

The LabRAM INV with its inverted geometry enables microreactors to be easily monitored (Figure 2). The reactor fits into the normal INV sampling position, with all the dosing and electrical connections for the reactor mounted on the usual top face. The microchannels can be monitored precisely from beneath, with mixing and kinetic information defined and interrogated at various points along its length.

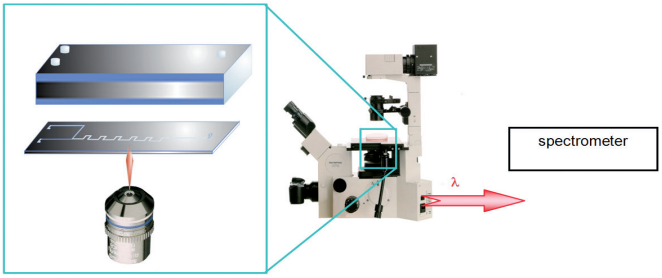

Figure 2: The unique inverted sampling configuration of the LabRAM INV opens up new possibilities for analysis

Ethyl Acetate Synthesis

Preliminary data has been obtained for the acid catalysed reaction of acetic acid and ethanol to synthesise ethyl acetate. The industrial applications of this reagent are numerous, but in this case, the system was chosen for more fundamental reasons, namely strong Raman scattering by reactants and products, allowing the reaction to be monitored with ease.

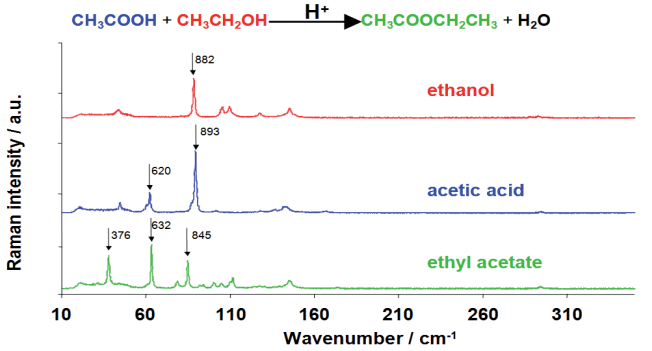

Figure 3: The ethyl acetate synthesis reaction, with the Raman spectra of the individual components shown beneath.

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Spatial Imaging of Mixtures

Preliminary studies were undertaken to investigate the spatial distribution of components across the T-junction. No acid catalyst was included, ensuring that ethyl acetate would be not formed, and thus allowing the distribution of ethanol and acetic acid to be fully characterised.

The flow within the microchannels is laminar (ie, no turbulence), and so the two liquids meet at the T-junction and then flow side by side down the channel. Any mixing that occurs does so only by interdiffusion across the interface between the two laminar streams.

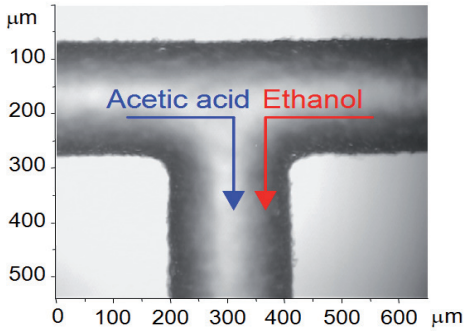

Figure 4: Optical micrograph of T-junction with flow directions shown.

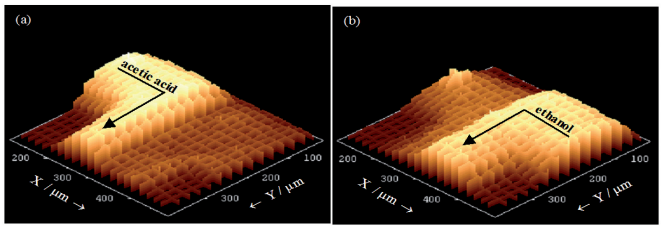

Figure 5: 3D plots of Raman intensity (without background subtraction) in the T-junction region for specific bands. (a) 893 cm^{-1} from acetic acid. (b) 882 cm^{-1} from ethanol.

Low resolution Raman mapping over a 375 µm x 375 µm area (step size ≈ 18 µm and 25 µm in X and Y dimensions) clearly illustrates this (see Figure 5). The two distinct streams can be identified, flowing down the channel towards an end reservoir. The 'spike' apparent in the left hand side of the cell in Figure 5b is caused by a defect in the glass structure, resulting in an unusually strong fluorescence signal at that point.

Monitoring the Chemical Reaction

With the acid catalyst included, the chemical reaction to synthesise ethyl acetate within the microreactor can now be monitored.

Analysis at five discrete sampling points across the centre of the channel (see Figure 6) results in identification of the ethyl acetate product at the centre of the cell. The band at 845 cm^{-1} is clearly visible at position 3, corresponding to the join between the two streams. At the edges (positions 1 and 5) the spectra correspond to those obtained for pure acetic acid and ethanol, respectively.

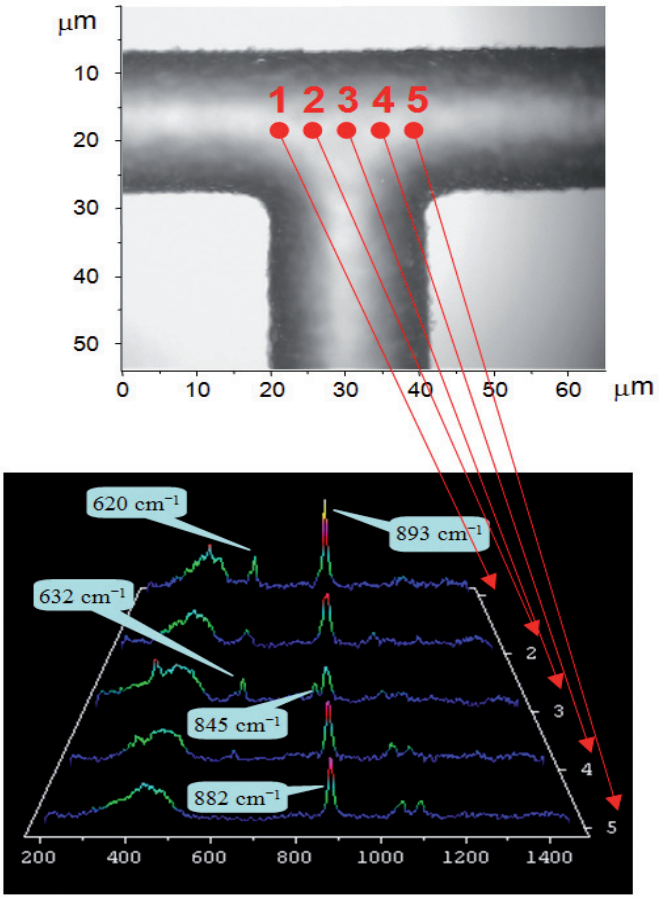

Figure 6: Raman spectra (left) acquired from different positions within the T-junction (shown above)

Concentration Profiles

In order to profile the concentrations of the reactants and product, the relationship between concentration and Raman intensity must first be identified.

Figure 7 shows the expected linear relation between concentration and Raman intensity for the acetic acid, ethanol and ethyl acetate.

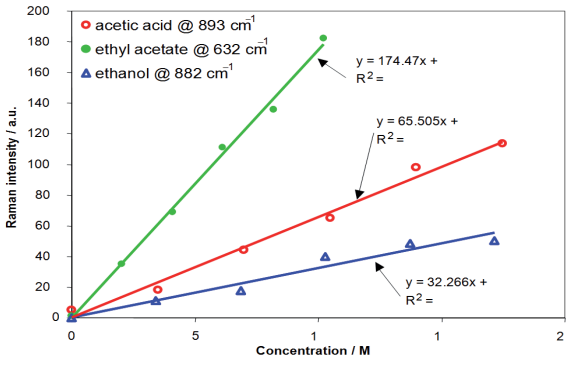

Figure 7: Calibration results of Raman Intensity vs concentration

The calibration plots obtained allow concentrations to be deduced from Raman spectra acquired from various positions within the T-channel. Figure 8 (below) shows the concentration profiles of the reactants and product across the downstream microchannel at two Y positions (Y = 750 µm and Y = 3150 µm) corresponding to times after contact of the reactants of 2.3 s and 9.8 s respectively.

It can be seen that the concentrations of reactants and product depend both upon X position (giving an indication of the diffusional mixing of the reactants) and Y position (corresponding to increasing time for reaction). The asymmetric nature of the product concentration profile is attributed to slight differences in diffusion speeds and viscosities of the species in the mixture region.

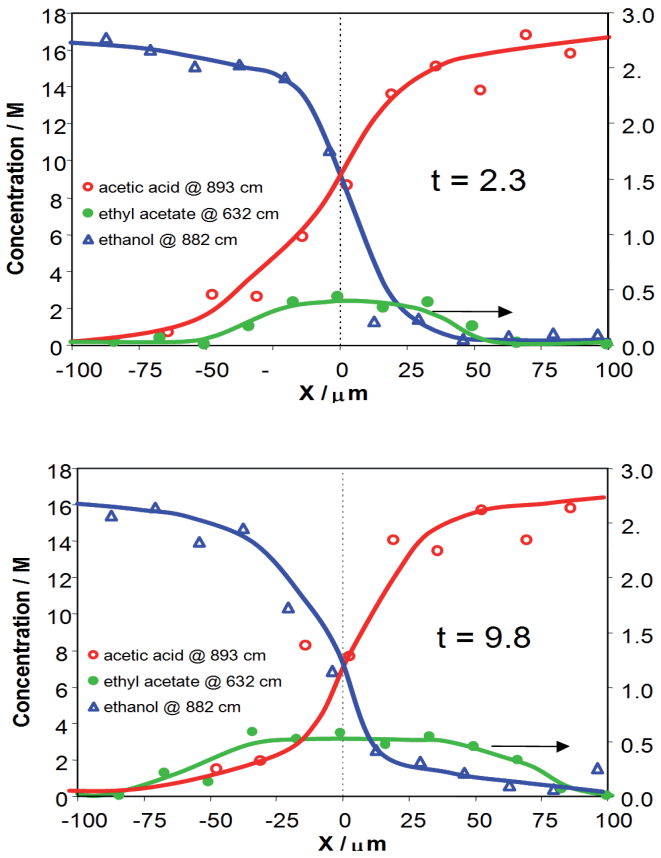

Figure 8: Concentration profiles for acetic acid, ethanol and ethyl acetate across the downstream channel at different Y positions, corresponding to 2.3s and 9.8s after initialisation of reaction.

Conclusions

The flexibility provided by the inverted microscope configuration of the LabRAM INV is ideally suited to *in situ* Raman measurements within microreactor channels.

Information on flow properties, mixing and reactions within channel networks can be obtained, allowing reactions to be fully optimised. In particular, the Raman concentration imaging method described in this application note provides a valuable tool for testing and validating mathematical models of organic reactions in these microchannel systems.

The true confocal performance of the LabRAM systems ensures that the best possible spatial resolution can be achieved so that the Raman signal can be analysed with minimal interference from background effects, such as fluorescence from the glass substrate. In addition, the capability for multiple laser wavelengths allows a wide range of reactions to be studied with the one instrument.

Acknowledgements

Paul Fletcher, Stephen Haswell (Department of Chemistry, University of Hull) and Xunli Zhang (Micro Chemical Systems, Ltd., Hull) are kindly thanked for providing the data for this application note.

Key Reference

Paul D. I. Fletcher, Stephen J. Haswell and Xunli Zhang, Monitoring of chemical reactions within microreactors using an inverted Raman microscopic spectrometer, Electrophoresis, 2003, 24, 3239

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