Examination in Laser-based Combustion Diagnostics (FBR024)

Friday, March 10 2006, 8:00 – 12:00 (E421)

Calculator and a physics handbook (TEFYMA or equivalent) allowed. Answer concisely, with neat handwriting, in Swedish or English. Good luck!

1. Laser-based techniques have a number of significant advantages compared to conventional probe techniques for diagnostics of combustion processes. Unfortunately there are some disadvantages too. Give four examples of advantages and disadvantages/limitations (four of each). (4 points)

2. Which laser-diagnostic technique is most suitable for these tasks?
   a) Simultaneous measurements of several major species concentrations in a H2/air flame
   b) Visualization of OH concentration in a turbulent flame
   c) Point measurement of temperature in a sooty flame
   (3 points)

3. The Nd:YAG laser cluster (multi-YAG laser) available at the department is a world unique laser system, able to provide a pulse train consisting of eight pulses of 10 ns duration with arbitrary time separation between consecutive pulses (typically a time separation of 80 μs is used since it corresponds to maximum pulse energy). The overall repetition frequency of the laser system is 10 Hz. Discuss why such a laser system is very useful for combustion diagnostics. (3 points)

4. Laser-induced fluorescence (LIF) is one of the most widely used techniques for species concentration measurements in combustion processes.
   a) As a simplified model for the LIF process a two-level energy diagram may be used. Outline such a two-energy level diagram with all relevant transitions/processes indicated with arrows and corresponding names of the respective process.
   b) Explain what is meant by quenching and why this process often possesses so much difficulty in terms of extracting quantitative data from LIF measurements.
   c) Explain what is meant by LIF measurements in the linear and saturated regime, respectively? What are the advantages of saturated LIF measurements? Are there any disadvantages/limitations with saturated LIF measurements? Motivate your answer. (6 points)

5. This question deals with coherent anti-Stokes Raman scattering (CARS)
   a) Draw an energy level diagram for a vibrational CARS and a rotational CARS process, respectively.
   b) Make a comparison between vibrational and rotational CARS in terms of merits and limitations for both methods (both as thermometers and species detectors).
   c) The vibrational CARS signal from methane (CH4) is very strong whereas the rotational CARS signal is zero. Why is that? (5 points)
6. A laser-diagnostic measurement is performed in a flame. The laser system used is a tunable dye laser, pumped by a Nd:YAG laser. The laser beam generated by the dye laser is frequency-doubled before it is directed and focused into the flame. You tune the laser wavelength to 283 nm and collect the signal perpendicular to the incident laser beam direction. The collected signal is focused into a spectrograph and detected with a CCD camera. There are no optical filters in the signal collection path. The spectrum recorded is shown below.

You are quite convinced that the peak at 309 nm is due to a LIF process. Your research colleague, however, says that it might be a peak due to Raman scattering. Your task here is to prove that it is a LIF spectrum (and not a Raman spectrum) by performing various experimental studies. You have a really well-equipped laboratory with all possible equipment you may want to use available, e.g. the equipment described above, lenses, optical filters, polarizers, fast photomultipliers, fast oscilloscopes, high-resolution spectrographs, CCD-detectors, and a tunable pico-second laser system, etc. Even if a single experiment is enough to prove that it is a LIF spectrum you should try to find as many experimental ways as possible. Which species does the LIF signal come from? (6 points)
7. An experiment with laser-induced incandescence (LII) was performed using the laser wavelength 532 nm. The detection wavelength is below 450 nm. The graph below has been obtained from imaging measurements using a laser sheet (with Gaussian beam profile orthogonal to the sheet).

a) Study the LII-signal in the graph below. Describe the processes leading to the shown LII-signal dependence on laser fluence when it is increased from zero to 1.4 J/cm².

b) Motivate why it can be beneficial to use such a short detection wavelength as below 450 nm.

(3 points)