RADIATION BEHIND THE STRONG SHOCK WAVES: EXPERIMENT AND MODELING

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Introduction

Emission contribution to space vehicle heat transfer can be significant under reentry conditions. Under the situation of high velocities and low densities the main area of emission is a non-equilibrium region. Consequently chemical reactions carry against the background of incomplete vibrational relaxation processes.

Martian atmosphere consists mainly of CO_2 and small-scale impurities, such as N_2, Ar, H_2 and so on. Experimental data can help us to evaluate the emission contribution to heat transfer. At the same time, with the experimental data obtaining it is necessary to work out the kinetic scheme of reactions behind the shock wave front.

For the experimental data obtaining in mixtures similar to Martian atmosphere the emission behind the shock wave front was observed. The results allow us to analyze emission spectra in vacuum ultraviolet, visible and near infra-red regions.

As it was said, the distinctive feature of processes after the shock wave front at a high speed was chemical reactions passing with incomplete vibrational relaxation. So, state-to-state kinetics must be used to sufficiently describe the processes pattern after the shock wave front. Such a type of the scheme was elaborated during our work. Using this scheme the emission influence of different electron-excited states on gas mixture temperature was analyzed. Also, the translational and vibrational temperatures and kinetic curves of the mixture components were calculated at different temperatures and initial mixture components. The numerical results of the mixture emission were compared with our experiments.

Experimental setup

For investigation of radiative heat transfer for hypersonic flow the shock tubes are the typical implement. We use stainless two-diaphragm circular section shock tube with inner diameter 75mm. It consists of high pressure chamber, low pressure chamber and suppression chamber.

The pump-down of low pressure section before the experiment was carried out to 10^{-2} torr. Low pressure section was filled with investigated gas. Different gas mixtures: one close to the Mars atmosphere and CO_2:N_2 mixture diluted in Ar, were used. The emission spectra after incident shock wave were studied. In order to avoid reflected shock wave suppression chamber was used. It was divided by diaphragm against low pressure section.

High pressure section can be used with pneumatic and explosive regimes to obtain wide velocity range (1.5-8 km/s). In case of explosive regime stoichiometric H_2:O_2 mixture diluted with He was used. The pressure in high pressure section at the beginning of the experiment was equal to 10 atmosphere. Due to a such regime high shock wave velocities were achieved. These velocities corresponded to the real reentry vehicles velocities during the entrance to upper layers of atmosphere.
The shock wave front velocity measurements were carried out using two schlieren gauges, with the distance of 890 mm between them. The signals of these gauges were registered by a Tektronix TDS 2014 digital oscilloscope.

The diagnostic system consisted of a modified spectrometer with a low resolution grating (22 G/mm) that allowed us to investigate an entire visible spectral range, a vacuum spectrometer and a streak camera C5680 Hamamatsu.

The C5680 streak camera has a high-sensitivity streak tube with a very high detection capability. This camera photocathode allows us to get the radiation spectral distribution over the 120-850 nm range and the spatial (temporal) distribution at once. In our experiments we used a camera time resolution of 2-200 μs, it is sufficient to observe the entire radiative region behind the shock wave.

The camera sweep was chosen so that the radiating zone between the shock wave front and the contact surface was kept within the measuring time of the streak-camera.

Streak camera measurements

The experiments were carried out in the CO_2:N_2 (97:3) and CO_2:N_2 diluted in Ar (in different proportions) mixtures. The shock wave velocities in the mixture were in the range of 3.5-6 km/s.

The experiments helped us to investigate emission spectra of the mixture behind the incident shock wave in a visible range of a spectrum to separate the most bright and informative bands for diagnostics of gas emission. It was necessary to make the series of experiments at different relations between investigated gases for the checkout of the kinetic model of processes after the shock wave front in the CO_2:N_2 and CO_2:N_2:Ar mixtures. The experimental data could help us to confirm the values of chemical reaction constants and monitor the trend of kinetic curves.

For the refinement of spectral bands the measurements with a high resolution grating were performed. The most interesting area was the high velocity experiments, because they could render the pattern of a vehicle entering into the upper atmosphere layers. CO_2:N_2 and CO_2:N_2:Ar mixtures were used. But the significant discrepancy was revealed between different mixtures results under such conditions.

Vacuum ultraviolet emission of the Ar:CO_2:N_2 mixture behind a strong shock wave

Experimental measurements in the VUV spectral range were performed with the help of a shock tube. The explosive regime of the shock tube was exploited to obtain a wide velocity range (3.3-6.6 km/s), with the shock wave front velocity measured by two schlieren gauges. We investigated the CO_2:N_2 mixture diluted with Ar. The emission spectra after the incident shock wave were studied.

The emission diagnostic system consisted of a vacuum spectrometer and a vacuum monochromator McPherson 234/302 with a photomultiplier FEU-181. With the help of the vacuum spectrometer we could analyze the entire radiation spectrum (from 120 up to 800 nm). Thevacuum monochromator was used to make an appropriate relative spectrometer calibration in the vacuum ultraviolet spectral range. The spectrometer was connected to the Hamamatsu streak camera and a streak signal was captured by PC for further processing. The PM signal was reproduced by the digital oscilloscope Tektronix TDS 2014. So the temporal distribution of an emission signal could be observed. A turbomolecular pump and a forvacuum pump supported required conditions for diagnostics. MgF_2 diagnostic windows permitted one to observe the 12-830 nm spectral area. The intensity dependence on the shock wave front velocity and on the wavelength was investigated.

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