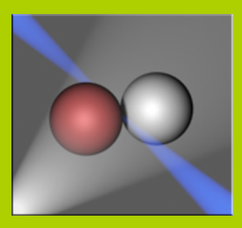
High-temperature pulsed source of Cd_2 and CdRg molecules in supersonic beam



Molecular Spectroscopy and Quantum Information

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Atomic Scale Science for Innovative Economy

Introduction

We present a prototype of all-metal pulsed supersonic source which operates at temperatures up to 1000K and carrier gas stagnation pressures up to 8 bars. Thanks to the operation temperature much above the cadmium melting point ($T_{Cd\ melt}$=594K), the source can be used to produce van der Waals dimers of cadmium Cd_2 and cadmium-rare gas complexes CdRG (RG= Ar, Kr, Ne). Our pulsed supersonic source (detailed description in [1]) is part of larger experiment [2] (based on [3]) dedicated to realisation of Bohm's spin 1/2 particle version of the Einstein-Podolsky-Rosen experiment [4] for entangled ^{111}Cd atoms.

Pulsed supersonic source

In molecular beam experiments supersonic pulsed sources are preferred over those operating in continuous mode because they reduce consumption of analyzing substance and carrier gas. Moreover, pulsed sources enable using of larger nozzle diameters, higher carrier gas pressure and provide excellent conditions to work with pulsed lasers (supersonic pulse can be correlated with pulse of light). The main disadvantage of pulsed sources is fact that commercially available pulsed valves can operate only up to 590K, which is insufficient for many purposes (particularly for production of supersonic beam of cadmium dimers). To overcome this limitation we use long plunger attached to water-cooled commercial solenoid valve (Parker-General Valve Series 9).The details of our construction are presented in Fig.1.

Principle of operation

In the experiment cadmium metal is heated in the lower reservoir (13) up to 1000K and mixed with carrier gas (Rg= Ar, Kr, Ne) delivered by lower pipe (12). Next, the cadmium vapour (partial pressure 0.2 bar) enter the upper source chamber (17) which ends with a nozzle (usually D=0.15mm orifice diameter) through which the mixture expands to the vacuum chamber forming supersonic beam containing Cd_2 and CdRg van der Waals molecules.

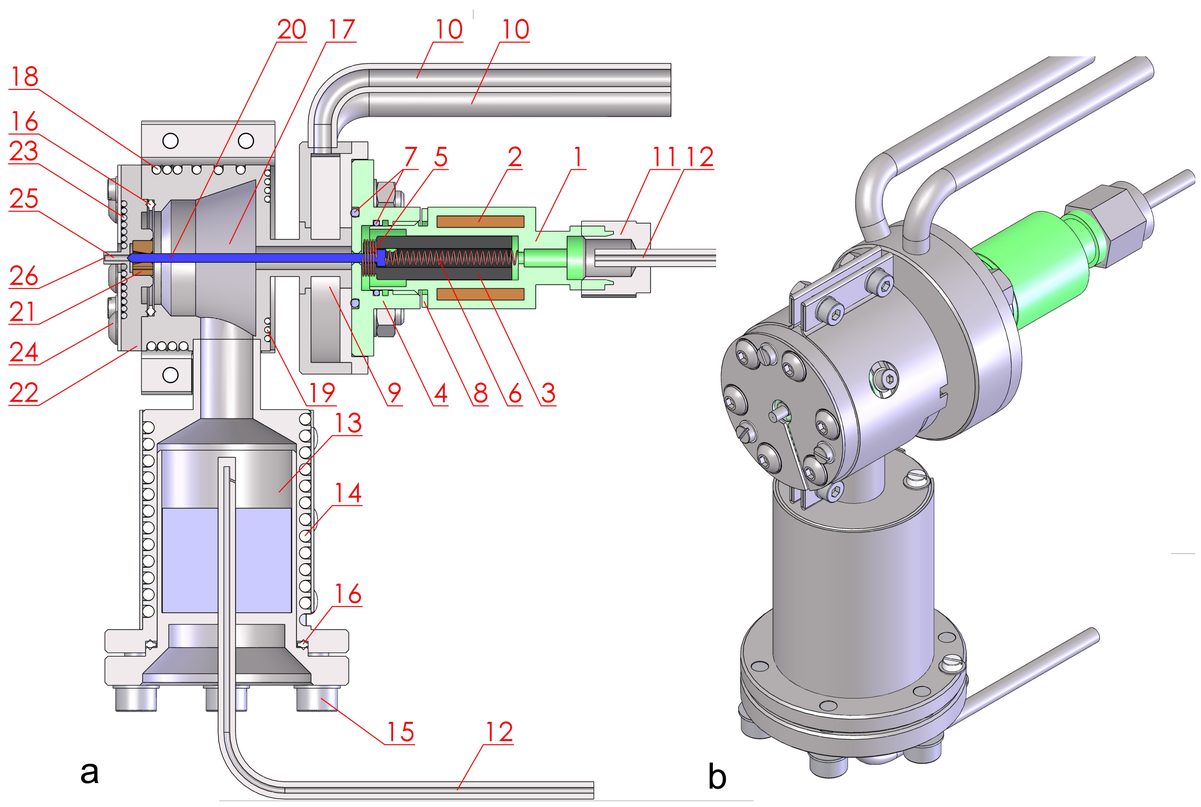

Fig.1. a) Cross section of the high-temperature high-pressure pulsed source of vdW dimers developed in our laboratory. Parker-General Valve Series 9 commercial solenoid valve (green): 1, coil assembly; 2, solenoid coil; 3, armature; 4, flange mount; 5, buffer spring; 6, main spring; 7, Kalrez orings of DuPont™; 8, shim. Parts of the pulsed source: 9, water shield; 10, water pipes; 11, Swagelok® connection; 12, carrier gas supplies; 13, Cd reservoir; 14, reservoir heater; 15, reservoir screw; 16, iron washer; 17, source chamber; 18, source body heater; 19, source body back heater; 20, titanium plunger; 21, brass slide bearing; 22, nozzle cartridge; 23, nozzle cartridge heater; 24 nozzle cartridge screw; 25, nozzle channel; 26, orifice. b) 3D view of the source.

References

[1] T. Urbańczyk, J. Koperski, *Rev. Sci. Instrum.* **83**, 083114 (2012).
[2] T. Urbańczyk, M. Strojecki, M. Krośnicki, J. Koperski, *Opt. Appl.* **42**, 433 (2012).
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Experiment

In our experiment molecules in supersonic beam were irradiated at distance of 11mm from the nozzle with a frequency-doubled dye laser beam (TDL90 system of Quantel with LDS(33%)-DCM(66%) mixture in ethanol, pumped with pulsed Nd-YAG laser). The excitation spectra were recorded in the 30670-30770 cm^{-1} spectral region by focusing the total LIF from the interaction region on the cathode of a photomultiplier (PM) tube (9893QB/350, Electron Tubes). During data acquisition phase, for each laser frequency (tuning realized in 0.06-cm^{-1}-step mode) the signal from PM was averaged in the oscilloscope (usually for 16 laser shots) and the resulting waveform was saved in a computer. The final spectrum was determined from collected waveforms after selecting proper size of time-integration window (the selection of time-gating window had an impact on which type of molecules from supersonic beam contributed to the final spectrum). It is important, that selection of time gating-window takes place in data analysis phase of the experiment, so different type of spectra can be obtained from one set of waveforms (see Fig.2 below)

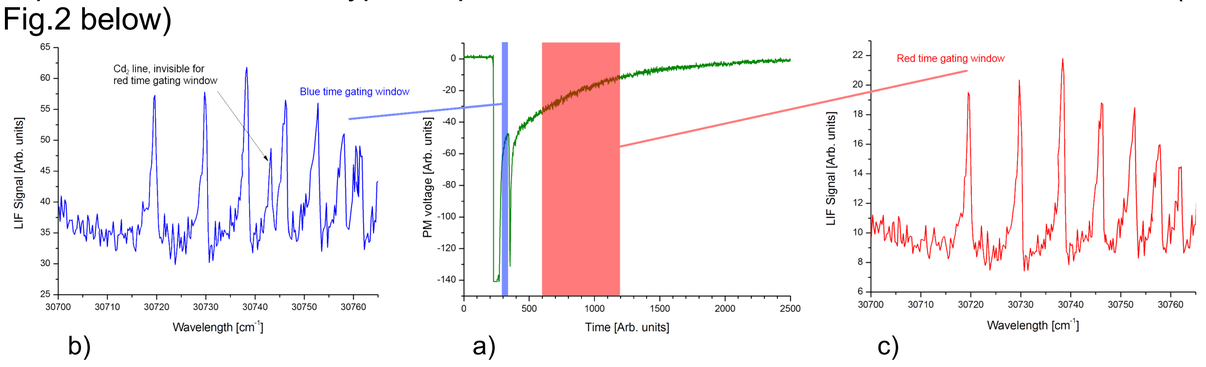

Fig.2 a) Sample of the waveform (averaged signal from PM for one laser frequency), red and blue rectangles illustrate the time gate interval applied for left and right spectra, respectively. b) The LIF spectrum with Cd_2 and CdAr vibrational components determined with blue time gate window. c) The LIF spectrum determined with red time gate window. The Cd_2 vibrational components are now invisible, as the fluorescence from Cd_2 lives shorter than that from CdAr (*i.e.*, Cd_2 fluoresce before opening of the integration window).

Tests of the pulsed supersonic source

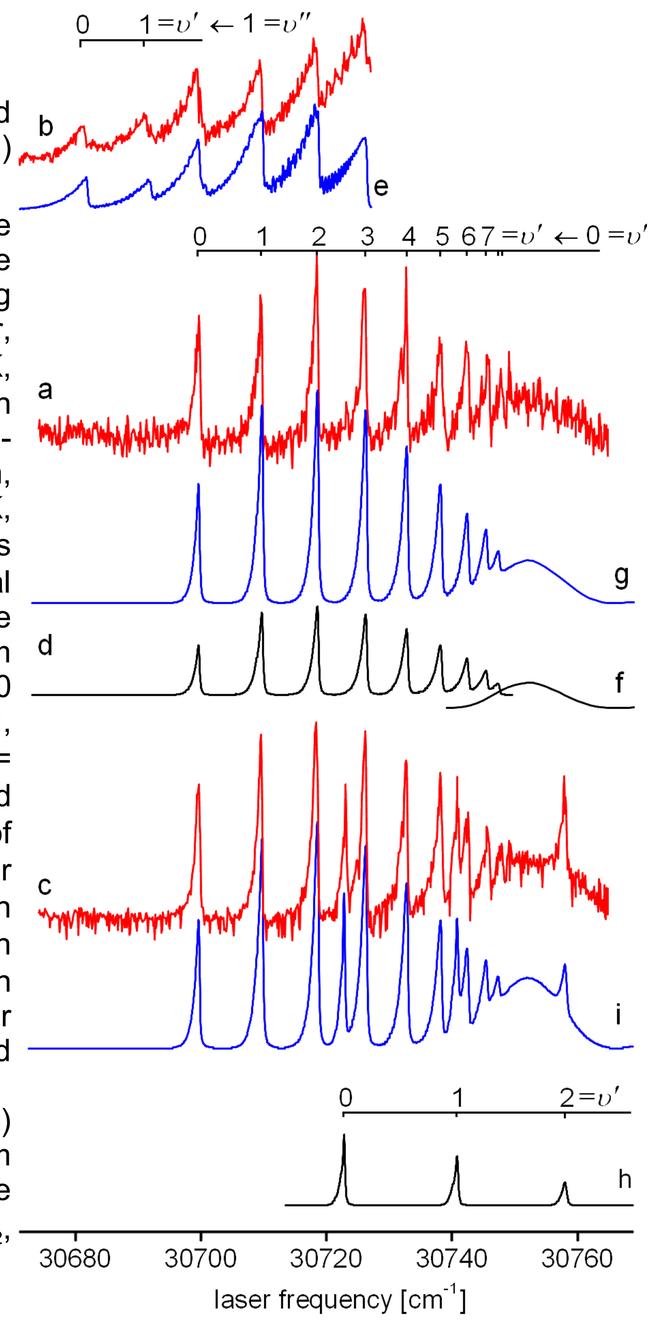

Fig.3 LIF excitation spectra of CdAr and Cd_2 recorded using the $B^31(5^3P_1) \leftarrow X^10^+(5^1S_0)$ and $b^30_u^+(5^3P_1) \leftarrow X^10_g^+(5^1S_0)$ transitions, respectively. The pulsed source from Fig. 1, was employed for the production of the molecules using following parameters: a) D=0.15mm, p_{Ar}=5.5bar, T_{res}=923K , T_{body}=943K and T_{nozzle}=943K, repetition rate f=10Hz, valve pulse width w=0.7ms, laser pulse delay τ=1ms, time-gating interval 3-5μs. b) D=0.25mm, p_{Ar}=1.5bar, T_{res}=903K, T_{body}=948K, T_{nozzle}=948K, the remaining parameters as in a). c) As in a) but with time-gating interval 0.2-0.5μs. d) Simulation of the bound←bound LIF excitation spectrum from a) *i.e.*, recorded using the $B^31 \leftarrow X^10^+$, υ'=0 transition in CdAr, assuming: ω_e'=11.3cm^{-1}, $\omega_e'x_e'$=0.59cm^{-1}, ω_e''=19.8cm^{-1}, $\omega_e''x_e''$= 0.93cm^{-1}, R_e'=5.01Å, R_e''=4.31Å, assumed rotational temperature T_{rot}=3K, bandwidth of the laser Δ_L=0.2cm^{-1} and Doppler broadening Δ_G=0.2cm^{-1}. e) Simulation as in d) but for υ''=0,1 and T_{rot}=19K. f) Simulation of the free←bound part of the excitation spectrum from (a) assuming Born-Mayer and Morse representations for the excited and ground-state potentials, respectively. g) Sum of simulations from d) and f). h) Simulation of the bound←bound spectrum from c) but recorded using the $b^30_u^+ \leftarrow X^10_g^+, \upsilon''$=0 transition in Cd_2, assuming : ω_e'=18.7cm^{-1}, $\omega_e'x_e'$=0.34cm^{-1} ω_e''=21.4cm^{-1}, $\omega_e''x_e''$=0.35cm^{-1}, R_e'= 4.02Å, R_e''=3.78Å from previous work, as well as calculated B_e'=0.01848cm^{-1} and B_e''=0.02090cm^{-1}, and assumed T_{rot}=3K, Δ_L=0.2cm^{-1} and Δ_G=0.2cm^{-1}. i) Sum of simulations d), f) and h) plotted to reconstruct the spectrum from c).

Acknowledgements

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Plans for the future

Currently, we are intensively working on developing new version of the source, which will eliminate some minor disadvantages of the current prototype such as condensation of cadmium on the plunger near the water shield or difficulties associated with disassembling of the prototype for cleaning. Moreover, a new tunable pulsed alexandrite ring laser with 30MHz spectral bandwidth will be employed in spectroscopy of Cd_2 and CdRg molecules with significantly better resolution.