Development of Data Acquisition and Analysis System for HF/DF Chemical Lasers

Vidya Sagar[1], Chhaya Ravikant[2], Mainuddin[3], Manish Borkar[4], Alok P Mittal[5]

[1,3,4]Laser Science & Technology Centre, Metcalfe House, Delhi -110054, India
[2]Department of Applied Sciences, GGS IP University, Kashmere Gate, Delhi-6, India
[5]Instrumentation & Control Engineering, NSIT, Dwarka, New Delhi, India
[2]Corresponding author: chhaya_rkant@yahoo.co.in

Abstract: *The paper reports the development of data acquisition and analysis system (DAS) for a noisy and hostile environment for arc operated hydrogen fluoride/ deuterium fluoride (HF/ DF) chemical lasers. HF/ DF is a high power chemical laser based on vibrational transition. The typical lasing wavelength of HF is 2.7 μm and that of DF is 3.8 μm. The plasma arc discharge in an arc heater/ generator is essentially employed for inducing thermal dissociation of SF_6 for production of fluorine atoms. The dissociation of SF_6 is a much safer alternative than other options of combustion of F_2/ NF_3 in an environment of H_2/D_2. Another accrued advantage is that the composition of the lasing mixture to an extent may be varied independently of the pressure and temperature of its constituents. But the arc load is complex load and involved high voltage transients and electromagnetic noise. The development of suitable DAS for monitoring and performance evaluation of parameters for 50 kW arc tunnel is implemented with proper protection devices. Since each designed plasma arc tunnel is unique in itself and specific to the application, DAS would enable altering arc discharge for optimization of the intended laser.*

Keywords: *HF/DF Laser, Arc tunnel, DAS, Optical fibre*

1. INTRODUCTION

Gas lasers have wide range of applications in various defense and industrial scenarios [1]. HF/DF gas lasers fall in class of high power chemical lasers based on vibrational transition. These lasers have proved their mettle in various defense applications. However, one of their limitations is the toxicity of its constituent elements. Hence, production of lasing species through combustion forms a safety concern. In this context, the use of arc plasma generator [2, 3, 4] is beneficial as it offers safe decomposition of SF_6 for generation of fluorine atoms to be used subsequently for lasing action.

Arc plasma heater or generator is a versatile tool for optimizing lasers parameters [5] such as gas flow rate, pressure, temperature and Mach no. etc. These parameters are to be acquired and monitored in real time. So a compatible Data Acquisition and analysis System (DAS) is essential for monitoring and control the operation of arc driven HF/ DF tunnel. A DAS consists of individual sensors with necessary signal conditioning, multiplexing, data conversion, data processing, data handling & associated transmission storage & display systems. Any DAS can be divided into two types on the basis of environment in which the system works. These are defined as a system which is suitable for less noisy environment or for the favorable conditions and the other one which is working in hostile environment like arc tunnel [6, 7]. The precise control of flow of gases (i.e. Nitrogen, Sulphur Hexafluoride, Hydrogen & Oxygen) with proper time sequencing, need to change the flow parameters during operation and handling of various sub systems are some of the important features of arc driven HF/ DF tunnel. Also safety considerations demand operation from remote control console. Keeping these features in mind, it is important that arc driven HF/ DF tunnel should be operated with a dedicated DAS, where all the controls are in the hands of a single operator. We have operated arc driven HF/ DF laser system that was developed in-house. Using DAS, the basic arc behavior is studied and lasing experiments are reported on 50 kW arc tunnel.

2. SYSTEM DESCRIPSTION

The goal of all chemical lasers is efficient conversion of chemical energy into coherent radiations of high power beam. Most of the recent developments in high power HF/ DF chemical lasers are based on combustion of Fluorine/ NF_3 gas with Helium and H_2 / D_2 to have lasing compositions. These types of lasers are difficult to use in normal laboratory environment because of toxic & hazardous gases. In order to overcome this drawback and to have laboratory useable HF/ DF Laser, arc tunnel is used for optimization of various laser parameters. The arc heater is used to create fluorine atoms by thermal dissociation of SF_6, which is very safe gas as compared to other fluorine based gases in laboratory environment. The arc heater has the advantage that it allows independent variation of gas composition with respect to temperature & pressure and thereby permitting ideal gas mixture ratio at required temperature & pressure conditions for longer run times. Arc heater is neat & clean and best laboratory apparatus for optimizing laser parameters. The presented work in this paper discusses the development of DAS for a kW level HF chemical Laser facility using arc discharge method.

The Data Acquisition and Analysis System (DAS) for arc driven hydrogen fluoride chemical laser system was realized with ADAM 5000 series cards of Advantech make (schematics shown in fig 1). This system consists of system Kernel with plug in modules. The system Kernel handles all software functions between the field devices and the host computer, including signal conditioning, data conversion, calibration, alarm monitoring, internal diagnosis and communication. As the arc plasma is a complex load involving high voltage transients and electromagnetic interference (EMI), so the system has been developed to cater for EMI induced environment with fiber optic cable as the communication link between the DAS and the PC. The DAS initiates the operation of various subsystems such as power, gas, water etc. It also switches 'off ' these subsystems after the defined run time. Various experimental parameters such as gas flow, pressure, temperature, voltage, current, power etc. are being acquired, displayed on the screen & stored in the PC. In case of any parameter going out of set range or in case of gas leakage an alarm is sounded and the system is switched off. The DAS has been designed for 24 analog inputs channels, 16 digital outputs, sampling rate of 10samples/sec with distributed I/ O features and RS 485 as serial communication interface with PC. It is capable of communicating up to 1200 metres with a speed of 9.6KBPS. Thus the cards for arc heater driven system are chosen for 2.5kV dc opto-isolation in communication lines and 3kV dc isolation in the power lines & I/O lines. Also to reduce EMI optical fiber communication link has been used. The 820nm wavelength is used as a carrier wave with fiber core/clad diameter 62.5/125µm and typical attenuation at this wavelength is 12.5 dB.

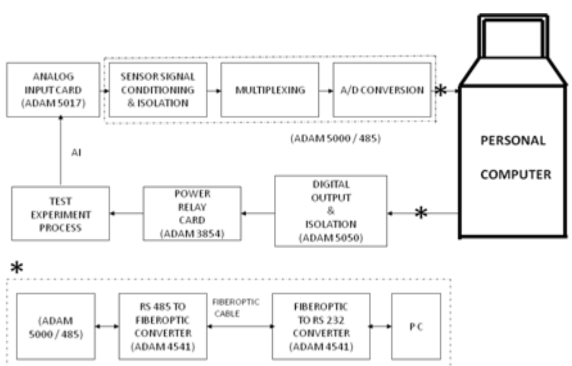

Fig 1:BLOCK DIAGRAM OF DACS FOR ARC DRIVEN HF CHEMICAL LASER

The dedicated DAS is utilized to control and monitor the safe functioning of arc test bed facility (schematics shown in fig 2) comprising of arc heater, cooling water system, gas supply system and power supply system along with smooth operation of arc tunnel for lasing experiments. The details of various sub systems developed for safe operation of 50 kW arc tunnel are as:

A. Arc Heater: The arc heater was designed to provide a highly energized, continuous plasma source, composed of free electrons, positively charged ions and neutral atoms [8, 9, 10]. The system is capable of operating with gases such as argon, nitrogen, helium, and mixture of such gases. The plasma is formed in a direct current electric arc and discharged in to a plenum chamber for mixing of other gases (such as N_2, SF_6) for achieving desired lasing composition temperature close to 2000 K. The DAS ensures the safe operation at such a high temperatures by incorporating the proper sequence of operation and interlocks.

B. Direct Current Power Source: The power for the arc heater is obtained from combination of industrial welding machines (i.e. rectifiers and generators) of Miraj Electronics make rectifiers for dc Output: open circuit voltage (OCV) of 80V, 600 Amp, input: 45KVA, 415V, 3Ph, 50 Hz and Advani Orlikon make generators for OCV 60V, 450 Amp dc max, Input: 26kW, 3ph, Induction motor, 2850rpm, with a total rating of 780 V OCV and 600 Amp current capacities for operating arc heaters up to 200kW ratings. These are connected to the arc heater with cables of 1000 A rating through a control panel and monitored from DAS.

C. Cooling system: De-ionized water supplied by a de-ionized water plant is utilized for arc heater cooling. The water is supplied from a storage tank filled with ionized water, which is pumped employing a 20 HP multistage centrifugal pump at a pressure of 10 Kg/cm^2 with a flow rate of 300 lpm. The flow through the arc heater system, mainly the manifold and the electrodes, is monitored online by the DAS through thermal flow meter. The coolant stream from arc heater system is then supplied back to a second manifold and to another tank for water disposal.

D. Gas Supply System: The gas supply systems for arc heater and plenum comprise of a cylinder bank to feed the high pressure gas manifolds and dome regulators for the desired high mass flow rates and pressures. Dome regulators are employed for flow regulation and strain gauge (IRA make with accuracy ±0.5 torr) and peizo-resistive (Yokogawa make with accuracy of ±0.25 torr) type pressure transducers are used for pressure measurements and control by the DAS in cavity and plenum respectively. Thermal mass flow meter (Bronkhorst make with accuracy of ±1%) for SF_6 and coriolis mass flow meters (with accuracy of ±0.5%) for N_2 & H_2 are placed for mass flow measurements through DAS.

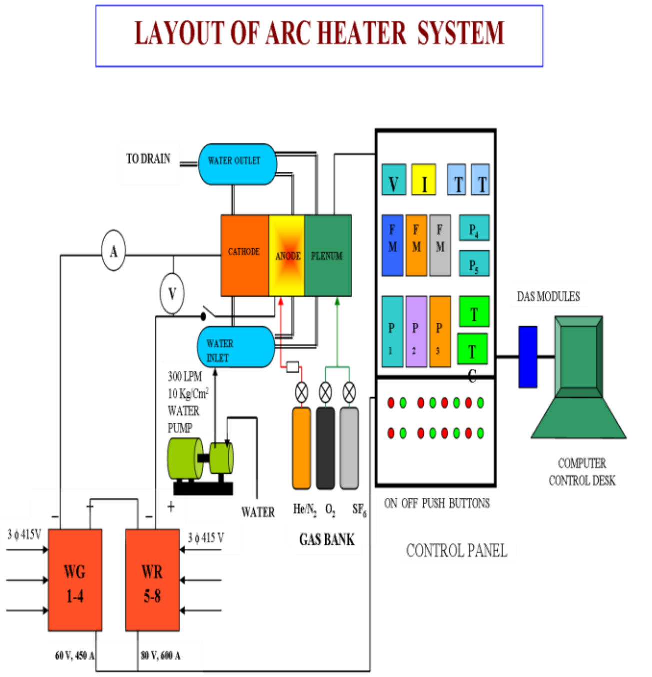

Fig. 2: Arrangement of various sub systems of arc plasma generator

E. D.M. Plant: A de-mineralized water plant was installed for this purpose supplying 600 liters per hour of water with less than 1 siemens conductivity.

F. Control Panels: Control panels were designed & developed for measurement and control of different arc related parameters such as voltage, current, flow, pressure & temperature etc from single control console at DAS station. The control panels were made operational for safe working of 50 kW arc tunnel. Instrumentation was directed towards the two-fold purpose of arc operation and performance evaluation. Primary instrumentation is directed towards the determination of arc performance and is basically necessary for an energy analysis to evaluate performance of arc heater. Pt-100 RTDs (with accuracy of ±1%) and R-type thermocouple (with accuracy of ±0.5%) were used for water and plenum temperature measurements respectively.

G. Development of 50 kW arc tunnel: The 50 kW arc tunnel consisting of arc heater, plenum, supersonic nozzle, cavity, diffuser and dump was integrated for lasing experiments (schematics shown in fig 3). In a chemical Laser, the population inversion is by the chemical reaction, where reaction mostly involves free atoms since the fuels involved do not react rapidly in their molecular form [11, 12, 13].

Basic Chemical reaction is given by:

$$F + H_2 \rightarrow HF^* + H + 32\text{kcal/ mole}$$

$$HF^* \rightarrow HF + H + \text{Laser}$$

The arc plasma generator or arc heater is an attractive tool for obtaining the high temperature necessary for dissociation of SF_6 (>2000K). The energy from N_2 arc plasma is utilized to dissociate SF_6 in plenum so as desired number of fluorine atoms are generated for initiating the subsequent lasing reaction in the cavity [14]. For a kW level HF arc-driven chemical Laser system, $1gs^{-1}$ flow rate of SF_6 is required in plenum to generate desired quantity of fluorine atoms and subsequently $1gs^{-1}$ of H_2 is added at the nozzle exit plane to initiate the chemical reaction essential for lasing action. A 50 kW arc heater (input power) is sufficient to create N_2 plasma and to carry out the parametric variations of different gases (viz. SF_6, N_2, O_2 etc) in plenum to have desired lasing composition for kW laser output.

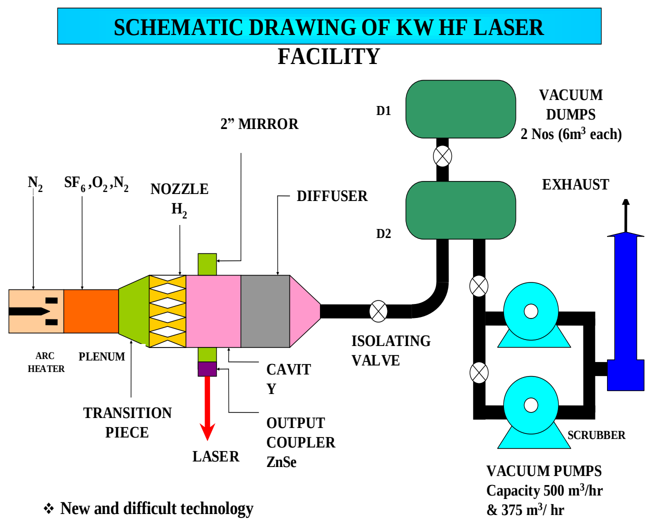

Fig. 3: Arrangement of key components of the laser tunnel

3. PERFORMANCE EVALUATION OF ARC HEATER

An ordinary electric arc without forced convection has definite intrinsic properties. However, mass flow of gas through the arc chamber represents a new, independent parameter not present in ordinary arcs with natural convection. Typical voltage-current characteristics for a cylindrical configuration with thoriated tungsten cathode are shown in fig 4 for Nitrogen in 50kW Arc Heater. The arc is negative resistance load, so special power source with drooping characteristics is needed for stable operation. Also it has been observed that at fixed mass flow rate, the arc voltage is relatively insensitive to arc currents. However, with increasing mass flow rates the voltage demand and input power increases proportionally.

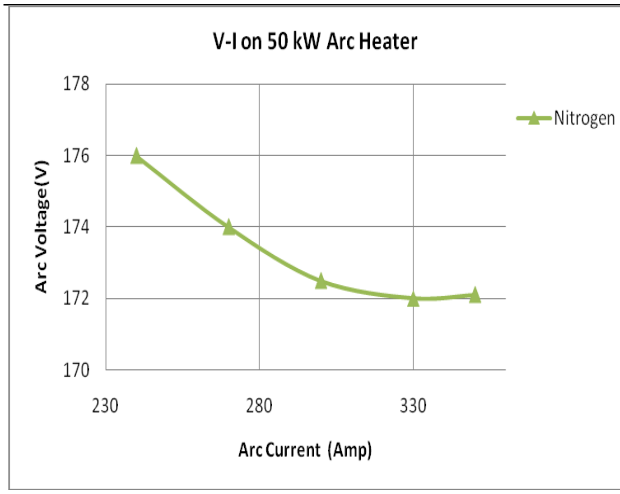

Fig 4: Variation of arc voltage with arc current

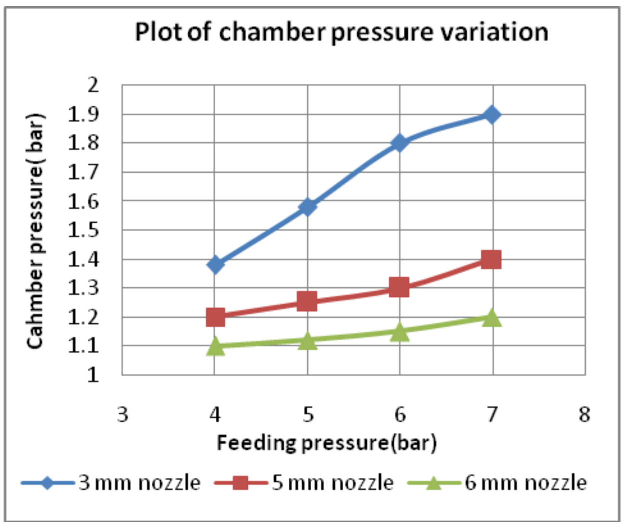

Fig. 5: Variation of chamber pressure for various nozzle combinations

The chamber pressure variations [refer fig (5)] were studied with three different nozzles i.e. 3mm, 5mm and 6mm. It is apparent that the smallest nozzle shows the highest chamber pressure.

Arc heater efficiency is defined as ratio of the power to the gas divided by the gross arc power fed into the arc heater;

$$\eta = 100\left(1 - \frac{PC + PA}{PG}\right)\%$$

PC = Cathode losses in kW
PA = Anode losses in kW
PG = Gross power in kW

The results [refer fig (6)] show that thermal efficiency of the arc heater ranges from 42 to 45 in 50kW arc heater, which means that more than half of the total power input taken away by the cathode and anode cooling water.

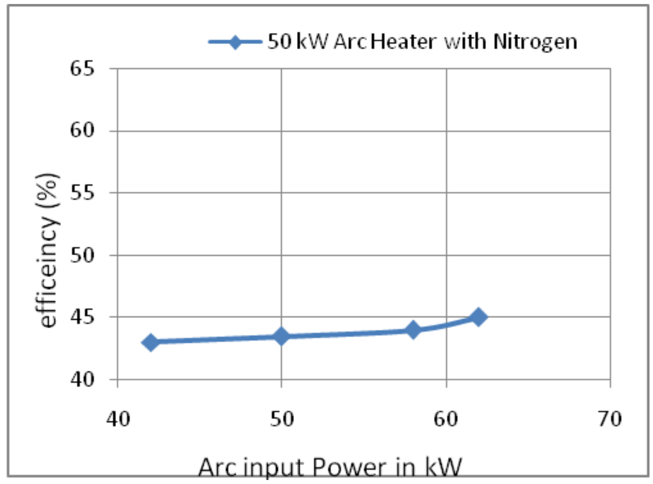

Fig. 6: Efficiency as a function of arc input power

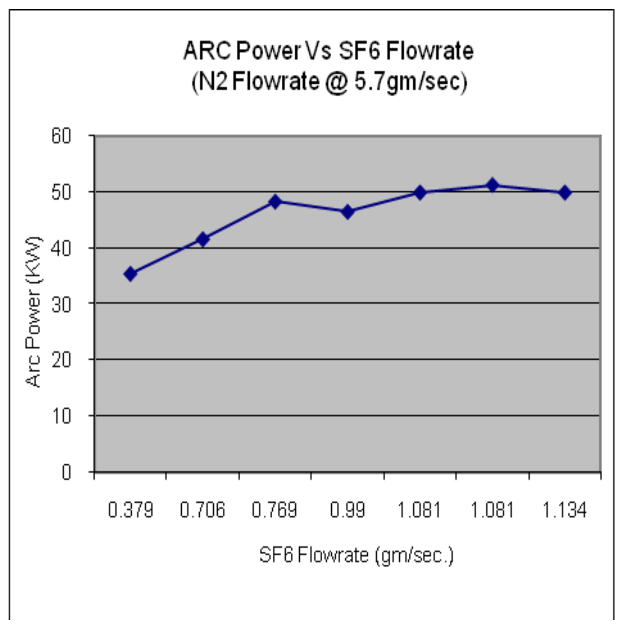

Fig. 7: Variation of arc power with SF_6 flow

4. EXPERIMENTAL RESULTS ON 50KW ARC TUNNEL

The experimental parametric analysis for the developed arc plasma tunnel is highly time intensive where the final aim is to employ it for laser applications. Experiments were carried out to establish the lasing parameters in 50 kW arc tunnel. The results achieved are in compliance with the theoretical values for lasing gas mixture in 50 kW arc tunnel [14]. The desired Mach No in gas mixture is achieved with special supersonic converging/ diverging nozzle attached to plenum of the tunnel. The variation of arc power with variation in SF_6 and H_2 flows is shown in fig (7) and (8) respectively.

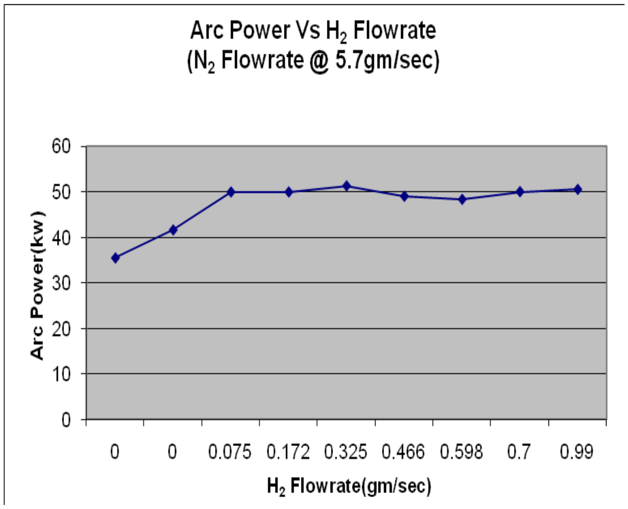

Fig. 8: Variation of arc power with H_2 flow

Fig 9: Developed hardware and arc heater in operation

5. CONCLUSION

In this paper an attempt has been made to present the developmental work on DAS using commercially available data cards of Adventech make for hostile arc environment. Experiments were conducted on 50 kW arc heater tunnel for basic arc behavior and for optimizing lasing parameters. The quantitative variation is attributed to the different geometry being employed specific to intended laser application. The experimental results of effect of variation of arc parameters on laser performance are also reported here. The calculated results for different operating conditions show that with an increasing mass flow rates in arc heater, there is increase in the arc voltage demand and result in better thermal efficiencies. Also with increases of arc current, we get the results in shorter arc & lower thermal efficiency. From the analysis of power input distribution it can be concluded that a major part of the electrical power input is consumed by anode cooling water (more than 50% of total power input) and only a small part of total energy is lost due to cathode cooling.

6. ACKNOWLEDGMENT

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7. REFERENCES

[1] DL Carroll, "Overview of high-energy lasers: Past, Present and Future", presented at 42nd AIAA Plasma Dynamics Lasers conference, Honolulu, Hi, *AIAA*- 2011-3102, (2011).

[2] B Selvan, K Ramachandran, KP Sreekumar, TK Thiyagarajan and PV Ananthapadmanabhan, "Numerical and experimental studies on DC plasma spray torch" Journal of Vacuum, **84**, 444-452 (2010).

[3] E Gomez, D Amutha Rani, CR. Cheeseman, D Deegan, M Wise, AR Boccaccini, "Thermal plasma technology for the treatment of wastes: A critical review ", Journal of Hazardous Materials, **161**,614-626 (2009).

[4] Andreas Schutze, James Y. Jeong, Steven E. Babayan et al, "The Atmospheric- Plasma Jet: A Review and Comparison to other Plasma Sources", IEEE transactions on plasma science; **Vol.26**, No.6, December, (1998).

[5] D.J.Spencer, H.Mirels et al "Preliminary Performance of a CW Chemical Laser", *Applied Physics Letters*, **16** (6); 235, (1970).

[6] W. Bolton, "Measurement & Instrumentation Systems", Neuunes, Butterworth Heinemann publisher, (1996)

[7] Mainuddin, RK Tyagi, R Rajesh, Gaurav Singhal and AL Dawar, "Real-time data acquisition and control system for a chemical Oxygen-Iodine laser", J of Measurement Science & Technology, Instt. Of Phys publishing, **14** (2003).

[8] H.Edels, "Properties and theory of Electric Arc", IEE Paper No**. 3498**; 55, (1961).

[9] Finkelburg and Maecker, "Electric Arcs and Thermal Plasma", Handbook of physics (German); 254, (1956).

[10] S Ghorui, SN Sahasrabudhe, AK Das, "Current transfer in dc non-transferred arc plasma torches", Journal of Applied Physics D, **43**; 245201 (18pp), (2010).

[11] S.J. Davis, D.B. Oakes, M.J. Read, A.H. Gelb,"Atomic Fluorine Source for Chemical Lasers", SPIE paper 4631-29, (2002).

[12] V.D Bulaev et al., "High power repetitively pulsed electric-discharge HF chemical Laser", Russian Journal of Quantum Electronics, volume **40**, No. 7, 40615 (2010).

[13] Evgenii A et al., "Electric-discharge pulsed F_2 + H_2 (D_2) chain reaction HF/ DF Laser with 4.2-L active volume" Russian Journal of Quantum Electronics, volume **40**, No. 2, 40103 (2010).

[14] Andre Sontag, Rene Joeckl, "Arc driven supersonic CW HF chemical Laser", SPIE-**1810**, (1992).