

# Improved versatile piezoelectric pulsed molecular beam source for gaseous compounds and organic molecules with femtomole accuracy for UHV and surface science applications

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This note describes the construction of a piezoelectric pulsed molecular beam source based upon a design presented in an earlier work [*Proch et al.*, *Rev. Sci. Instrum.* **60**, 713 (1988)]. The new design features significant modifications that allow the determination of the number of molecules in a beam pulse with an accuracy of  $\pm 5 \cdot 10^{10}$  molecules per pulse. The 21 cm long plunger-nozzle setup allows the molecules to be brought to any point of the UHV chamber with very high intensity. Furthermore besides typical gaseous compounds, also smaller organic molecules with a vapor pressure higher than 0.1 mbar at room temperature may serve as feed material. This makes the new design suitable for various applications in chemical and surface science studies.

PACS numbers: 07.77.Gx sources and detectors of molecular beams

Chopped supersonic beams are frequently used in surface science to increase the coverage step by step, thereby studying adsorption heats, reactions or turn over frequencies. But there is always the problem to determine the number of molecules per pulse in the beam.

Either a stagnation gauge (a known conductance glass tube combined with a calibrated ion gauge [1] or a spinning rotor gauge [2]) has to be employed, or the pumping speed of the vacuum system has to be known with high accuracy [3]. Especially the latter method might be problematic, as the pumping speed may vary locally and modifying the setup inside the ultra high vacuum (UHV) chamber can affect the pumping speed seriously. If the molecular beam consists of organic molecules, liquid-nitrogen cooled quartz crystal microbalances were used to determine the number of molecules in the pulse.[3] All the methods have in common, that they are quite demanding. Thus a simple determination of the number of molecules per pulse is desirable.

Due to enormous flexibility regarding pulse width and repetition rate, as well as the simplicity of construction, the design of Proch *et. al.*[4] found its way into various molecular beam experiments. Even though the design, based on a piezoelectric driven plunger opening and closing a nozzle, is very attractive, since less technical equipment is needed in contrast to chopped molecular beam sources, it has found only little applications in surface science until now, which is possibly due to some disadvantages.

For instance with the old design, the pulsed valve can not be mounted close to the target, if the target itself

e.g. is positioned in the middle of an UHV chamber. Solving this problem by adding a simple tube at the end of the nozzle flange increases the temporal pulse width by a factor of five due to the limited conductance of the tube.[5] With regard to our purpose of dosing also organic molecules, the question of saturation effects, adsorption and desorption effects or different flow properties for varying pulse intensities within such a tube becomes additionally crucial.

We approached this problem by redesigning the beam source, more precisely by applying two major modifications. A cross section of the new design is shown in Fig. 2. Firstly we minimized the plungers' diameter and elongated it. The new plunger (4), which opens and closes the nozzle, is a M4 aluminum threaded rod (the diameter is thinned to about 3.8 mm) and has a length of 25 cm. Secondly, instead of a simple nozzle plate, we inserted a CF 16 flange (3a) with a 21 cm long tube (3b), which is closed by a cap (3c). The cap contains the 0.2 mm diameter nozzle hole (3d).

In addition also the high backing pressure of the old design of up to 4 bar is unfavorable, because it takes 24 hours to determine the number of molecules per pulse from its decrease with the needed accuracy for surface science experiments.[5] Moreover running the pulsed source over such a long period has the disadvantage that the UHV system might be contaminated by the gaseous or even organic compounds.

Therefore additionally to the prolonged plunger and the tube-nozzle modification we used Conflat sealings wherever it was applicable and kept the whole reservoir volume as small as possible. Top cover (1) and the base plate (2) are joint by CF63. On the opposite side of the base plate a CF40 connection to the UHV chamber, and a CF16 for connecting the elongated nozzle flange can be found. The gas inlet (1b) is closed by a valve, and

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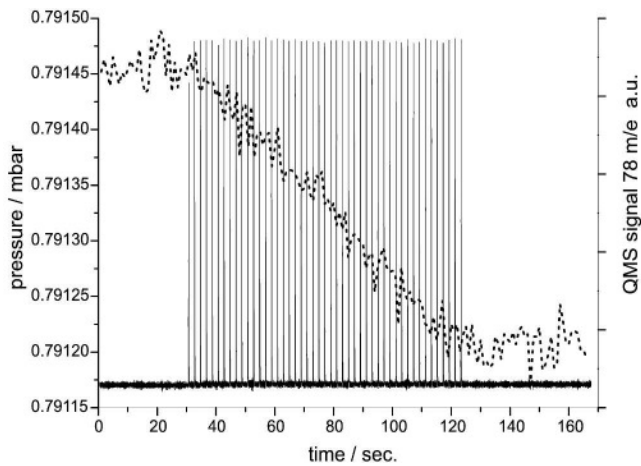


FIG. 1: Observed decrease of the backing pressure (dotted line), when the gas doser is switched on at  $t = 30$  sec. Recorded quadrupole mass spectrometer (QMS) signal (solid line) of  $1.35(\pm 0.01) \cdot 10^{13}$  benzene molecules per pulse with a repetition rate of 0.5 Hz.

the flange (1a) is connected to the pressure gauge.

This construction allows to reduce the backing pressure in the reservoir drastically without any observable leaking. The pressure is measured by a capacitive pressure gauge (0-10 Torr Baratron, Type 122A, 0.5% accuracy). Its voltage output is acquired by a low priced USB6008 from National Instruments with 4 kS/sec. A simple self written LabView program averages the signal, determines the slope, and calculates the number of molecules per pulse by applying the ideal gas equation,

$$n_{pulse} = \frac{|\dot{p}| V_{Res}}{f R T_{Res}} \quad (1)$$

By connecting a vessel of known volume (over a interim piece that is joint to a pressure gauge and a vacuum pump) with the piezoelectric valve, the reservoir volume  $V_{Res}$  could be estimated to be  $99(\pm 0.5)$  ccm. For the run shown in Figure 1 the slope  $\dot{p}$  was determined to be  $-2.8(\pm 0.01) \cdot 10^{-6}$  mbar/sec. Together with the temperature  $T_{Res} = 298(\pm 1)$  K and taking a repetition rate of  $f = 0.5$  Hz into account, one obtains  $1.35(\pm 0.01) \cdot 10^{13}$  molecules per pulse.

Astonishingly the new design with a nearly ten times longer piezo driven plunger still produces pulses with a high stability and reliability (see also Fig 1) like it is known from chopped molecular sources or even better, but with a higher flexibility. Since there is a higher risk of electric breakdown in this pressure range, precaution concerning the isolation (e.g. teflon tape) is advisable. A pressure of  $5 \cdot 10^{-10}$  mbar in the UHV chamber, to which the pulsed piezoelectric valve is mounted, can be reached without any problem. Additionally, the valve should work in any position.

Accuracies of  $1 \cdot 10^{12}$  molecules per pulse are reported by others for chopped molecular beam sources.[2] The

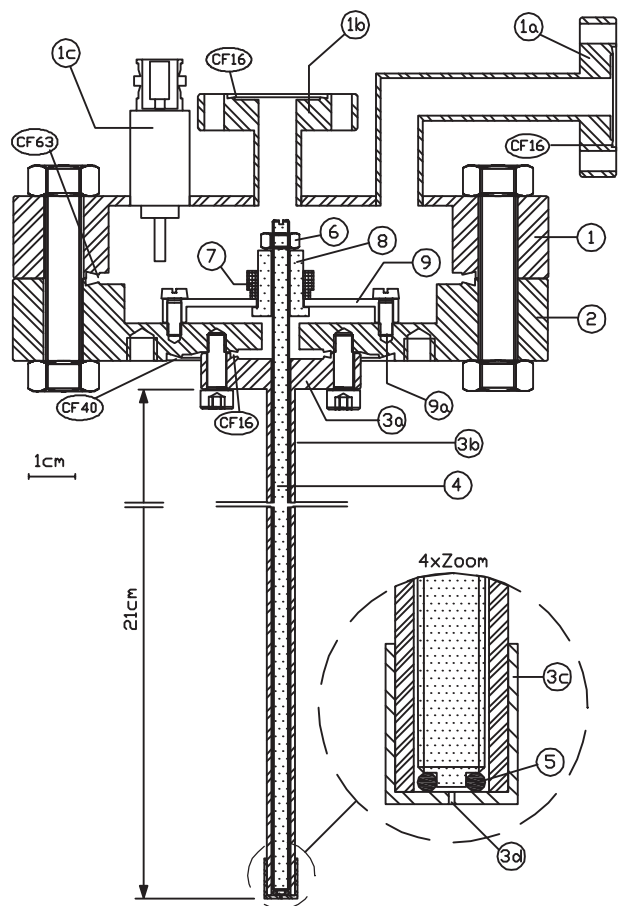


FIG. 2: Cross section drawing of the piezoelectric valve: 1: top cover; 1a,b: flanges for pressure gauge and gas inlet; 1c: coaxial feed through with MHV connector; 2: base plate; 3a: flange with a hole ( $\varnothing_i: 4\text{mm}$ ); 3b: tube (22cm,  $\varnothing: 6\text{mm}$ ,  $\varnothing_i: 4\text{mm}$ ); 3c: cap; The parts 3a, 3b and 3c are welded together; 3d: nozzle ( $\varnothing: 0.2\text{mm}$ ); 4: plunger (26cm, threaded rod  $\varnothing: 3.8\text{mm}$ ), with slit for screwdriver on top; 5: sealing O-ring ( $\varnothing_i: 1.5\text{mm}$ , width:  $3.5\text{mm}$ ); 6: M4 hex nut; 7: teflon nut (M10 fine thread); 8: vertical adjustment for plunger (M10 fine thread, M4 thread); 9: piezo disk translator (Physik-Instrumente P286.27); 9a: mounting holes for the disk translator. For clarity, half of the length of the plunger and tubing is not shown. Channels in the base plate, which provide mass flow between the upper and lower part are not drawn. Parts made of stainless steel are hatched, aluminum parts are dotted.

accuracy reachable with this setup is about  $\pm 5 \cdot 10^{10}$  molecules per pulse, and could be even improved with a more accurate pressure gauge, smaller reservoir volume and better temperature control of the system.

Thus the system described above represents a pulsed molecular source, that can be employed in surface science or other applications, which need exact dosing of a wide variety of gaseous compounds and organic molecules.

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