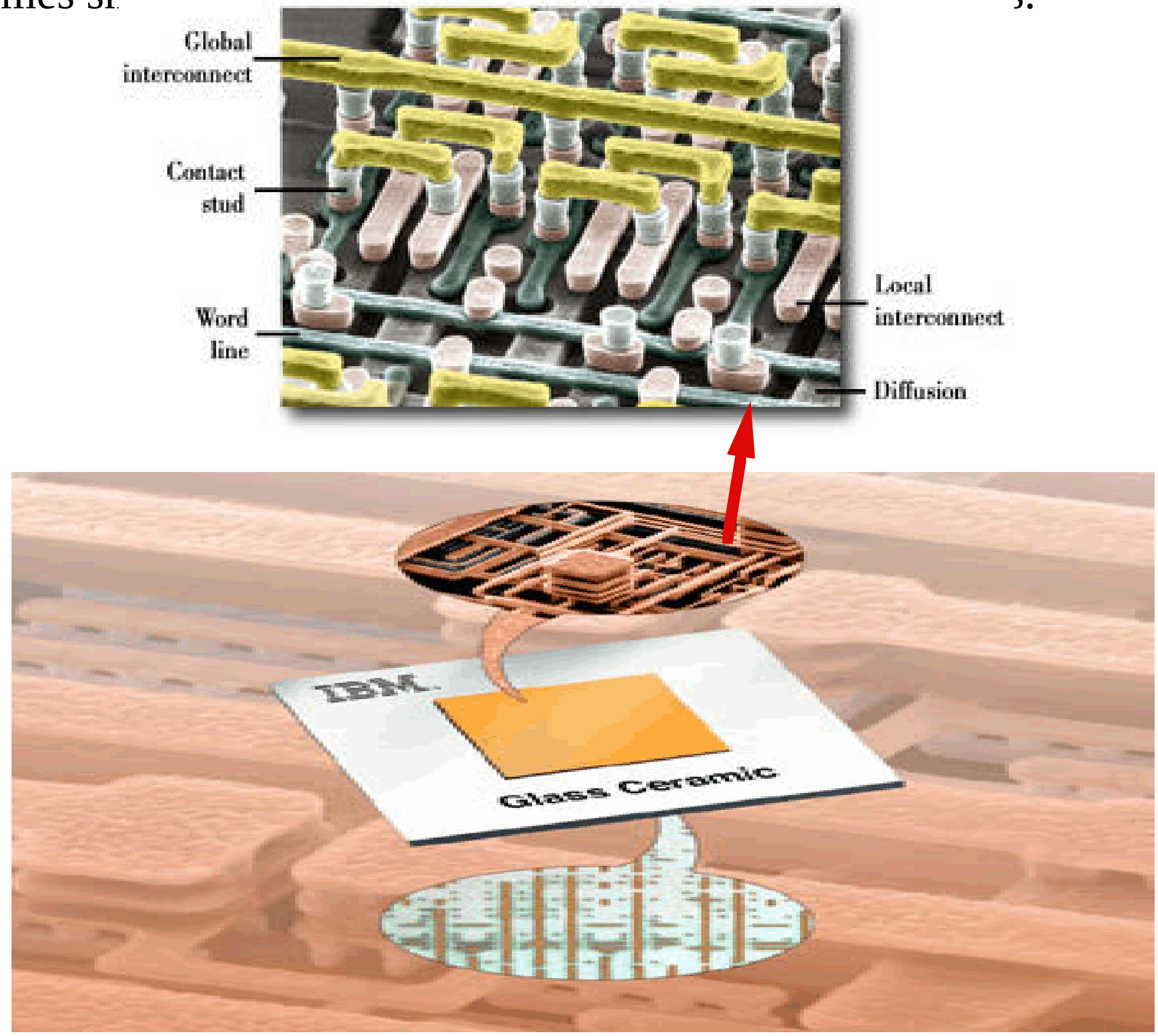
Introduction:

How to make a microchip ?

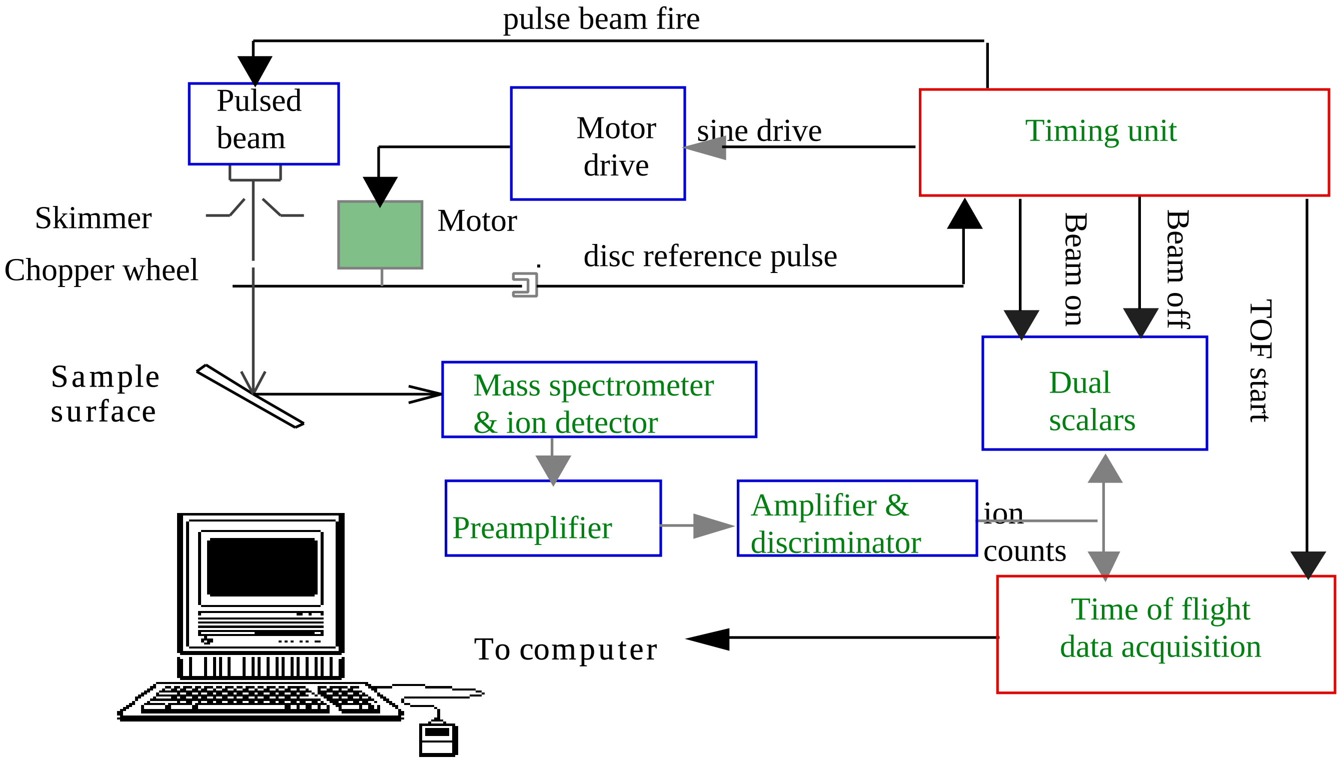
The modern structure of a chip is complex, both on its surface and in its internal three-dimensional composition. The chip is made up of many layers, each of which is detailed pattern. The manufacturing process consists of forming this sequence of layers very precisely. Microscopically small circuits, some 250 times smaller than a human hair, are built on these layers.



Experiments

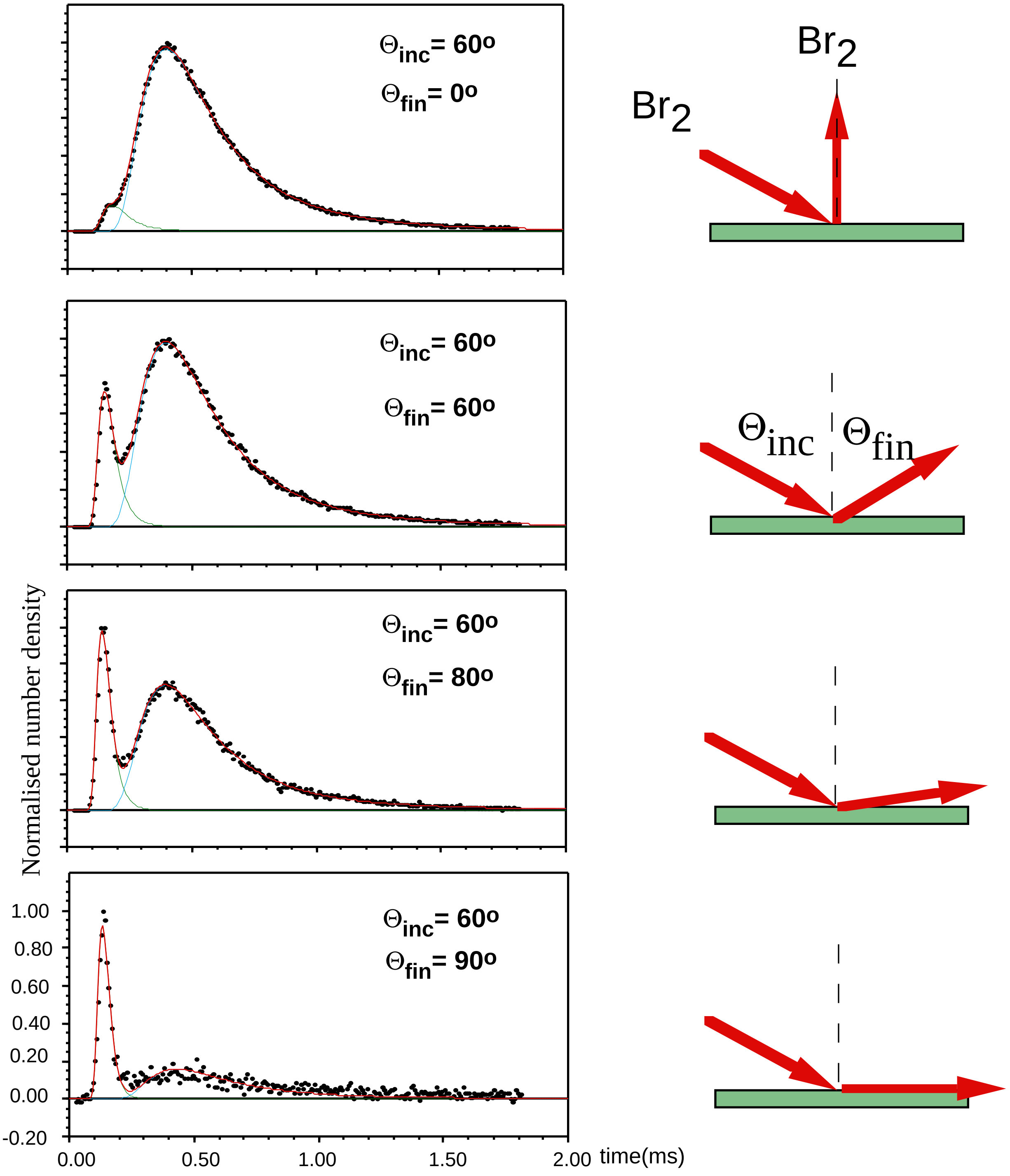
How do we do our experiments?

The experimental overview is shown below. A short pulsed supersonic molecular beam of a halogen gas(35 μs fwhm) is directed onto a GaAs(100) surface. Gas molecules hit the surface and are scattered towards the detector consisting two collinear floating-potential Brink type ionisers followed by a quadruple mass spectrometer and a fast pulse-counting channeltron. All the reaction products are identified by their mass spectroscopy. GaAs(100) wafer samples (9 mm x 9 mm) are indium mounted on a molybdenum block provided with a Rh/Pt resistive heating element for temperature control over 300-900 K. The base pressures during the experiments are ~ 3×10^{-10} torrs and rise to ~3×10^{-8} torrs during scattering.

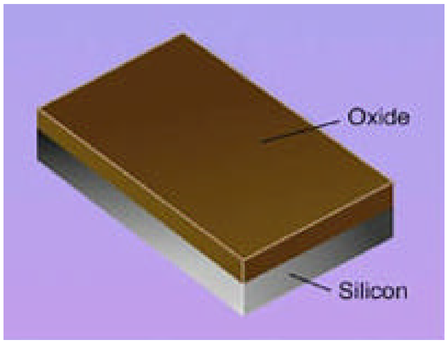


3) Inelastic scattering: molecules rebound off the surface, losing some of their energy to the surface. Inelastically scattered molecules have very short residence time on the surface. Investigation of inelastic scattering of molecules from a surface will give details of the energy desposals of the incoming molecules. We can do following experiments:

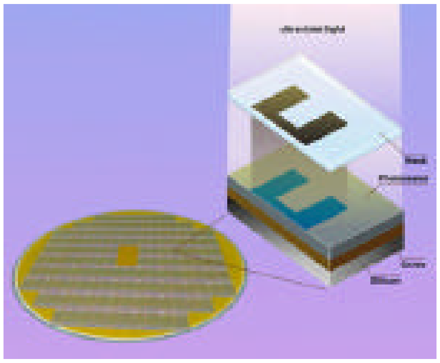
a) TOF distributions of scattered molecules from a surface as a function of reflected angle at a fixed incident angle and surface temperature.(e.g. Time-of-flight of Br_2 from GaAs(100) surface as a function of a reflected angle at an 60° incident angle and a surface temperature of 30°C.



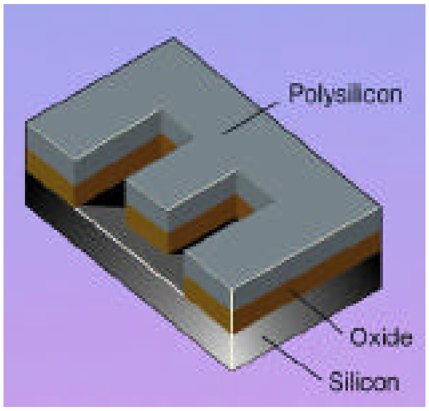
The production of these chips requires the following processes:



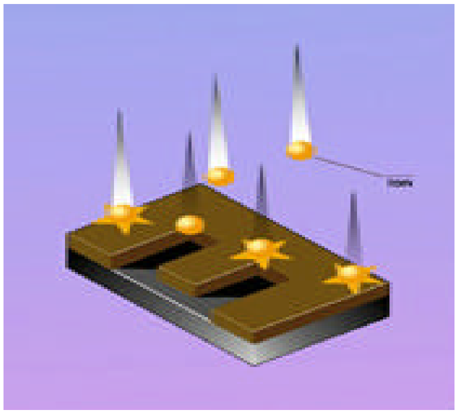
1) Oxidation
(making insulating material layer)



2) Photolithography
(making circuit pattern)



3) Etching (making circuits)



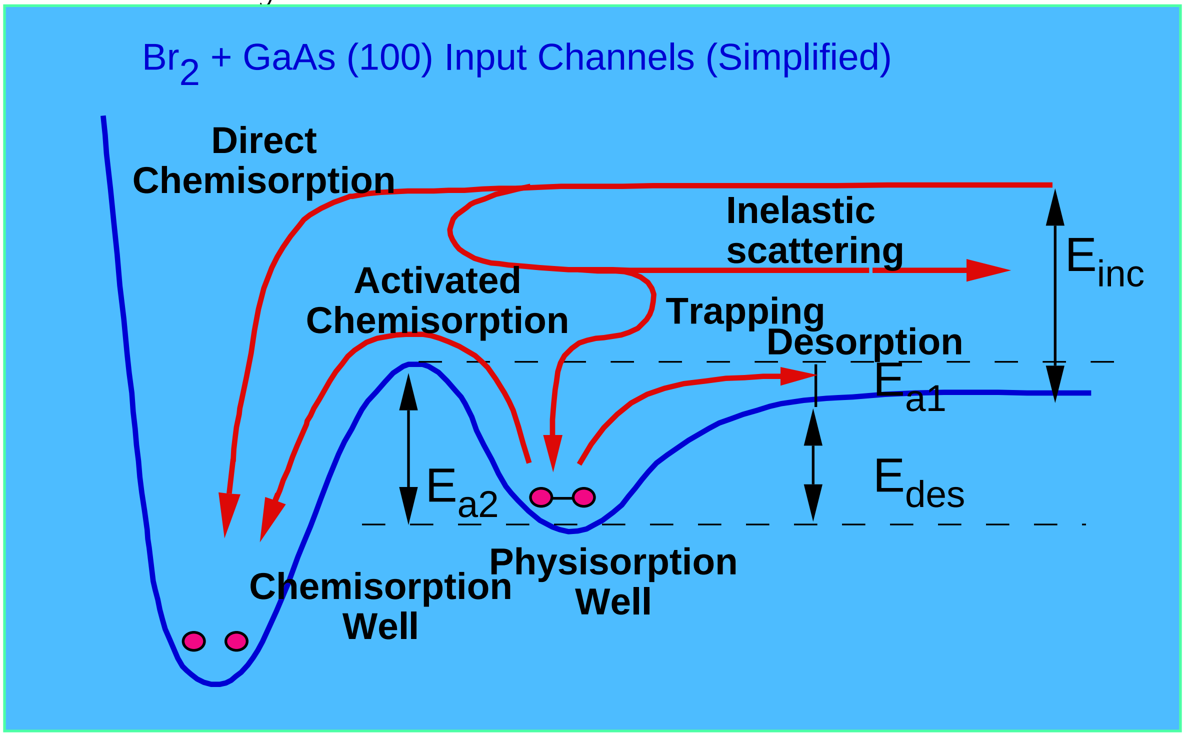
4) Ion implantation
(making positive and negative
conducting regions)

These processes are repeated many times to build the transistors and other electronic circuitry that make up each chip on a wafer.

Results:

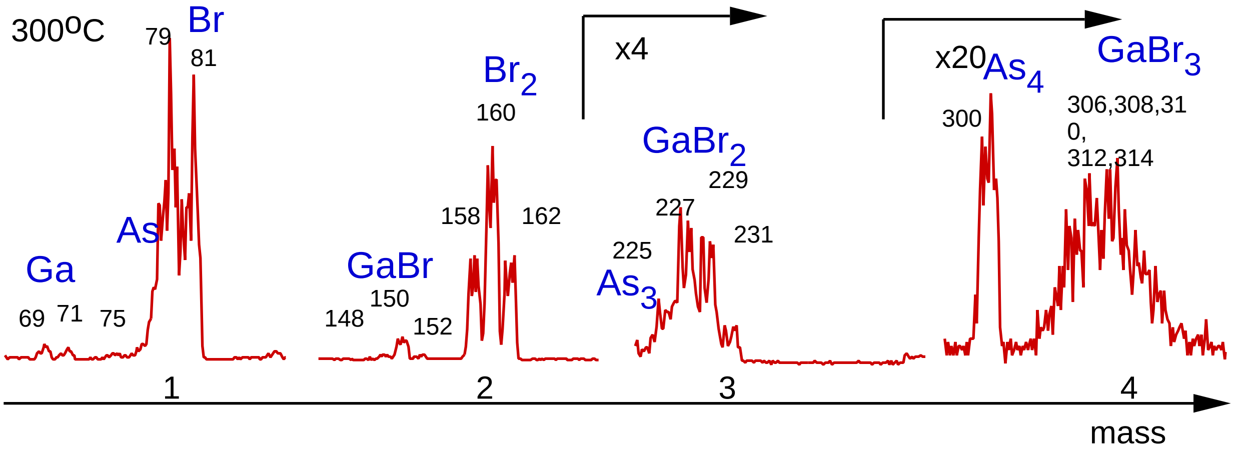
What can we learn from these experiments?

A halogen molecule coming into contact with a GaAs(100) surface usually has three interactions:

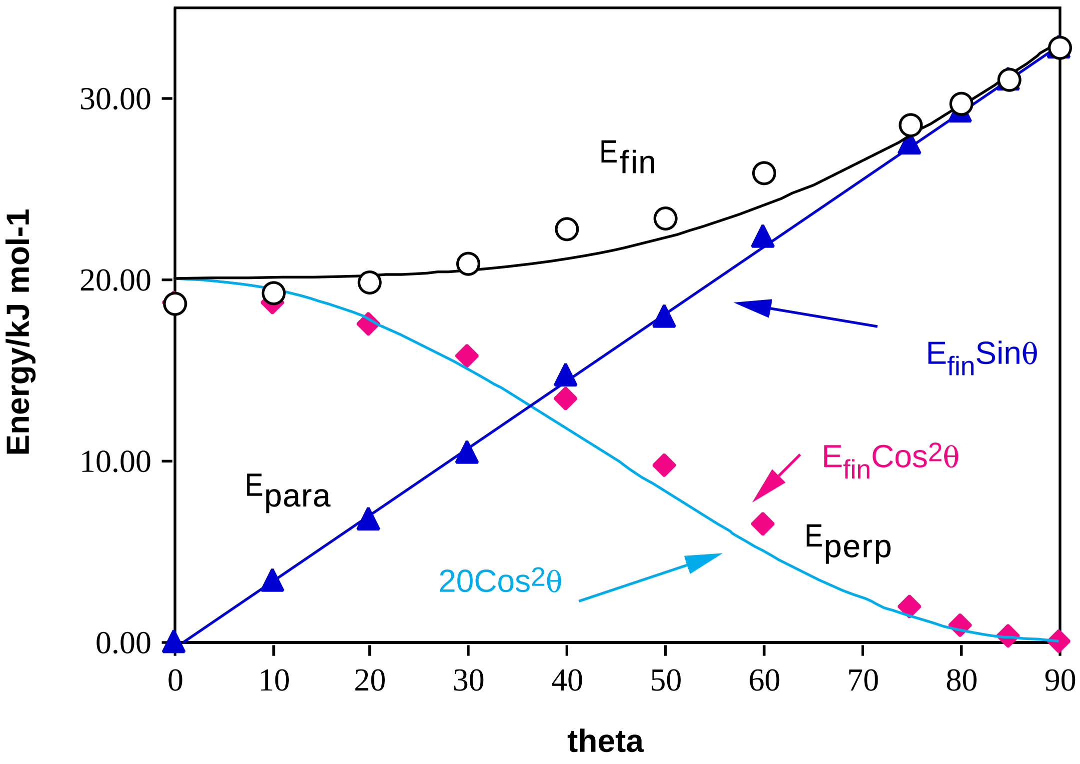


1) Chemisorption and thermal reactions: molecules adsorb onto the surface and form chemical bonds with atoms on the surface. Chemisorbed molecules can dissociate to accommodate the bonds with the surface. The dissociated molecules can undergo thermal reactions with neighbouring surface atoms or with other adsorbates. The following experiments can be done:

a) Identify all the reaction products from the surface using a mass spectrometry. (e.g. the reactions of Br_2 with GaAs(100) surface)



From measured TOF distributions of Br_2 at various detection angles, the energy disposals of Br_2 into the surface can be analysed: (e.g. angular distributions of outcoming molecular energy)



Angular dependence of E . From here we can understand the energy distribution(total outcoming energy E_{fin}, energy parallel(E_{para}) and perpendicular the surface(E_{perp})) at various scattering angles

b) Study State resolved study of dynamics of Br_2 scattered from GaAs(100) surface using Laser-Induced Fluorescence(LIF) technique. Such experiments have provided detailed information on elastic, inelastic and reactive collisions. The study of the most complex of these reactive collisions, has been a major force in changing the way chemists have looked at chemical reactions. These experimental data in turn have been a major spur to our theoretical understanding of the dynamics of chemical processes.

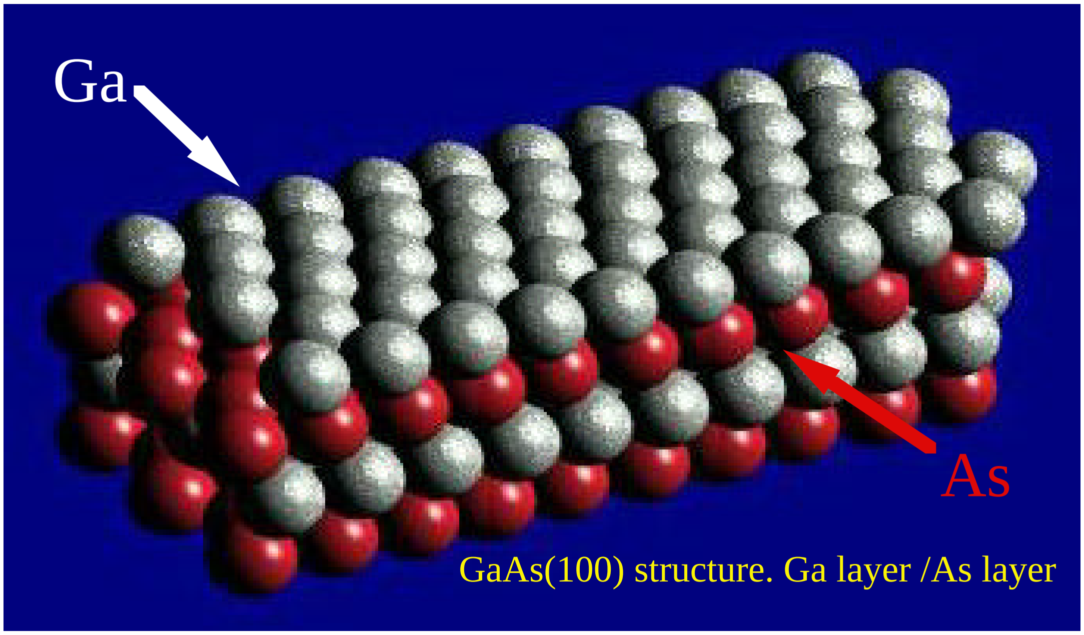
One of the least understood areas is that of collisions with solid surfaces, yet these are often at the heart of industrial processes ranging from catalysis of gas phase reactions to semiconductor fabrication. The following schematic diagram of our new LIF experimantal apparatus for study of scattering of a molecular beam from a surface is shown right:

What is object of our research?

The production of a integrated circuit requires etching of a surface followed by deposition of the other materials. Dry etching has been widely used in modern microchip factories. The main methods of etching are reactive ion, chemical or plasma etching, where the substrate is selectively reacted to form species which easily desorb from the surface. The etching process is still not well understood chemically. However the technology is well developed and works very well, although the production of these microchips is very expensive and prone to more errors as the level of complexity increases. Plasma etching and chemical etching are subtle and precise compared to other techniques, but as the integrated circuit become smaller, approaching the atomic scale, a great understanding will be required for the technology to meet these demands.

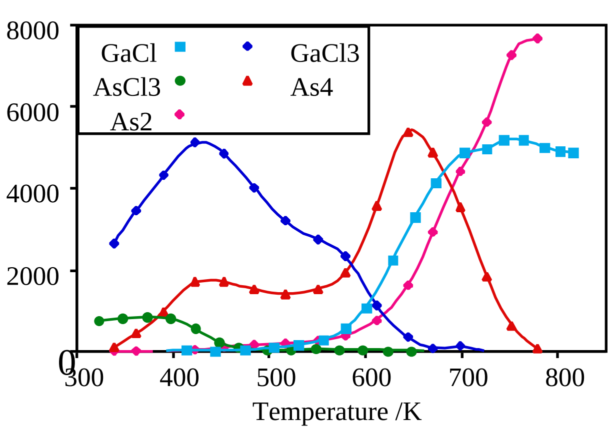
The goal of Manchester molecular beam group is to understand the fundamental etching processes through the experiments.

Why do we study halogen and GaAs reaction?

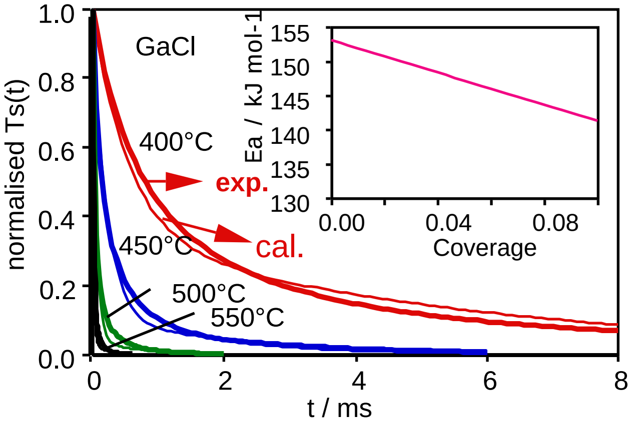


GaAs(100) structure. Ga layer /As layer

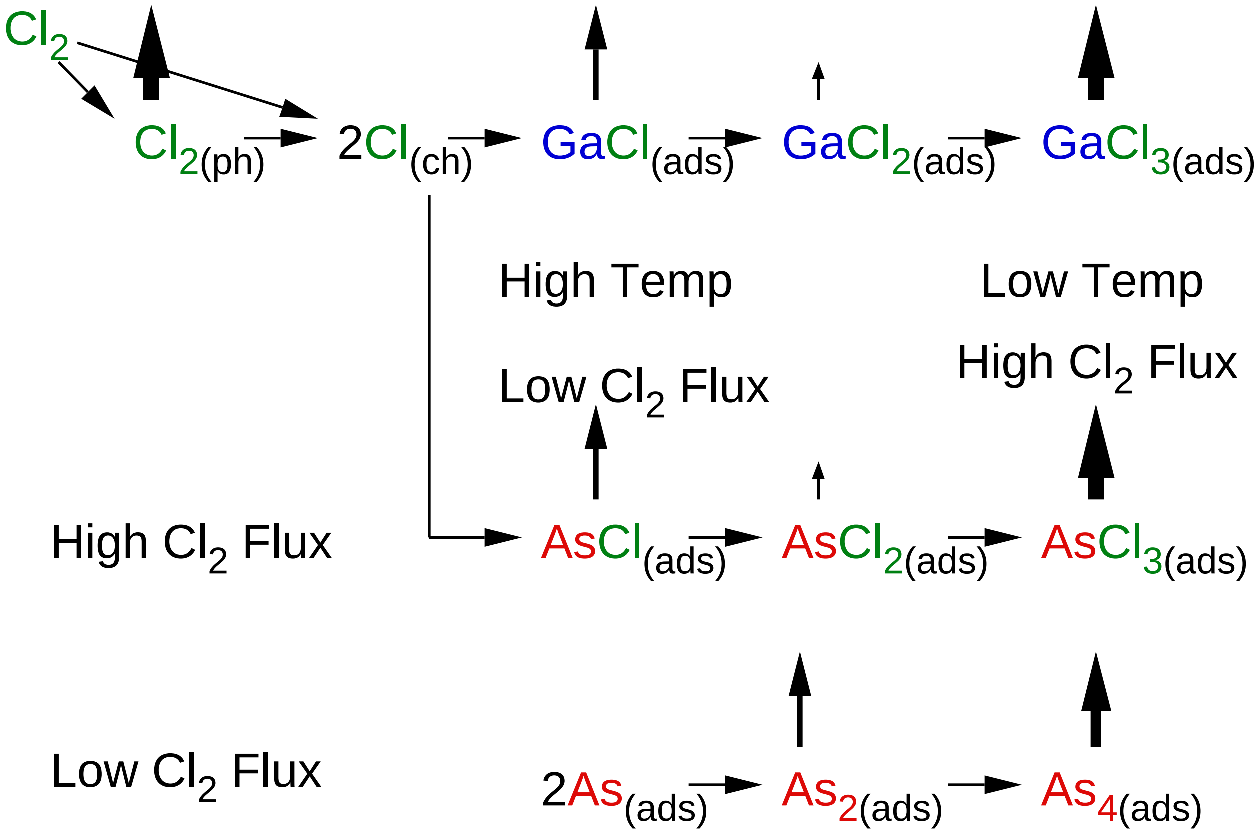
b) Measure surface temperature dependence of the reaction products from the surface (e.g. the temperature profiles of the reaction products of $GaAs(100)+Cl_2$)



c) Measure residence times of reaction species on a GaAs(100) surface at various temperatures. (e.g. the experimental and calculated residence times of GaCl from the etching reaction of HCl+GaAs(100) at various temperatures)

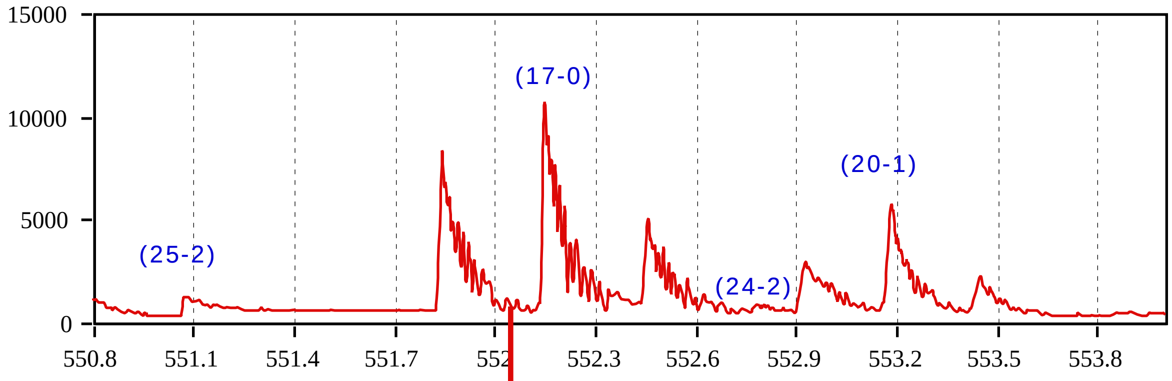


d) Find out the reaction scheme according to the experimental results.(e.g. The reaction of $GaAs(100) + Cl_2$)

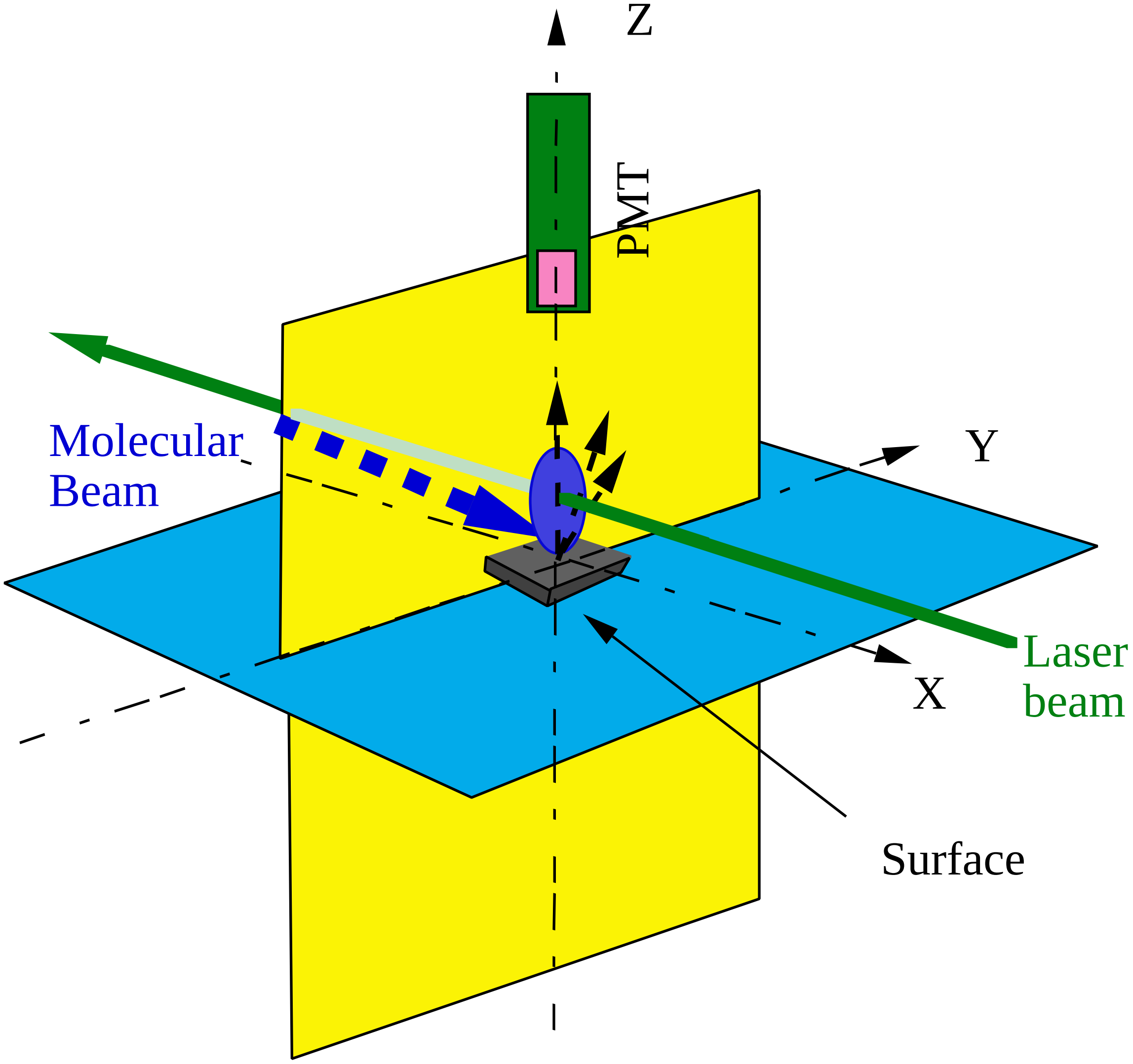


2) Trapping + desorption: molecules adsorb onto the surface, then desorb again. The outcoming molecules have the same temperature of the surface. They are trapped in a physisorption potential energy well by Van der Waals forces. Their surface residence time depends on surface temperature. Their time-of-flight (TOF) distributions can be well fitted with Maxwell- Boltzmann distributions.

The LIF spectrum of a Br_2 beam(11% V/V in He) are shown here:

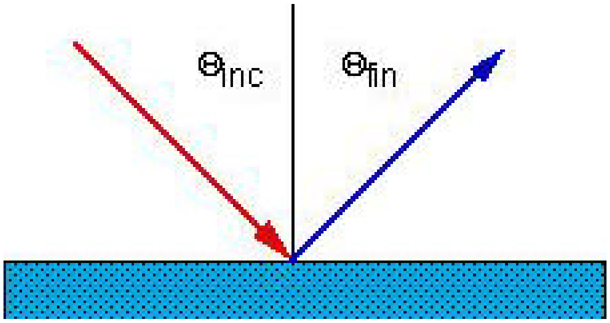


Schematic layout for LIF measurements



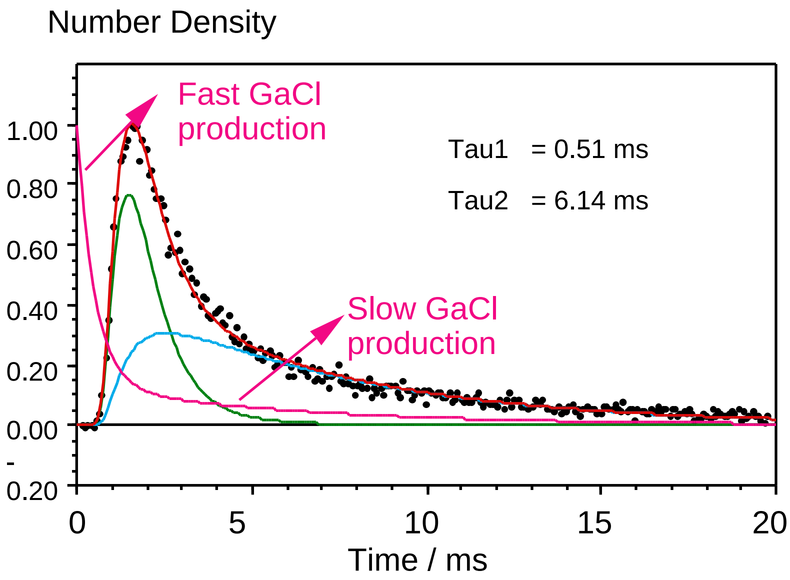
Halogen and some halogen molecules(Cl_2, Br_2, HCl,HBr) are very reactive molecules. They can react with semiconductor materials to produce volatile species (such as $GaCl_3$, GaCl). Gallium arsenide (GaAs) is a semiconducting material with many applications in the electronics industry. GaAs can be used as an alternative to silicon in the manufacture of microchips as the base layer, or as part of the individual components within the microchip. In comparisons with these two materials, it is found that GaAs is the superior, with a faster voltage drift, and higher resistance to temperature and electromagnetic radiation. GaAs is thus more desirable for use in extreme environments, such as in communication satellites or in military applications.

What can affect the outcome of the collision between a beam and surface?



* Crystal face and surface morphology
* Surface temperature
* Incident translational energy
* Incident angle
* Incident flux/dosage
* Temperature of incoming molecules
* Surface coverage
* Residence time and surface mobility
* Surface adsorption energies : physisorption and chemisorption
* Reaction probabilities / rate constants

a) Measure time-of-flight(TOF) mass spectroscopies of species from a surface at various temperatures to determine surface residence times and reaction activation energy. (e.g. TOF GaCl from the etching reaction of Cl_2+GaAs(100))



$$T(t) = \int_0^t F(t_d)\ T_{MB}(t - t_d)\ dt_d$$

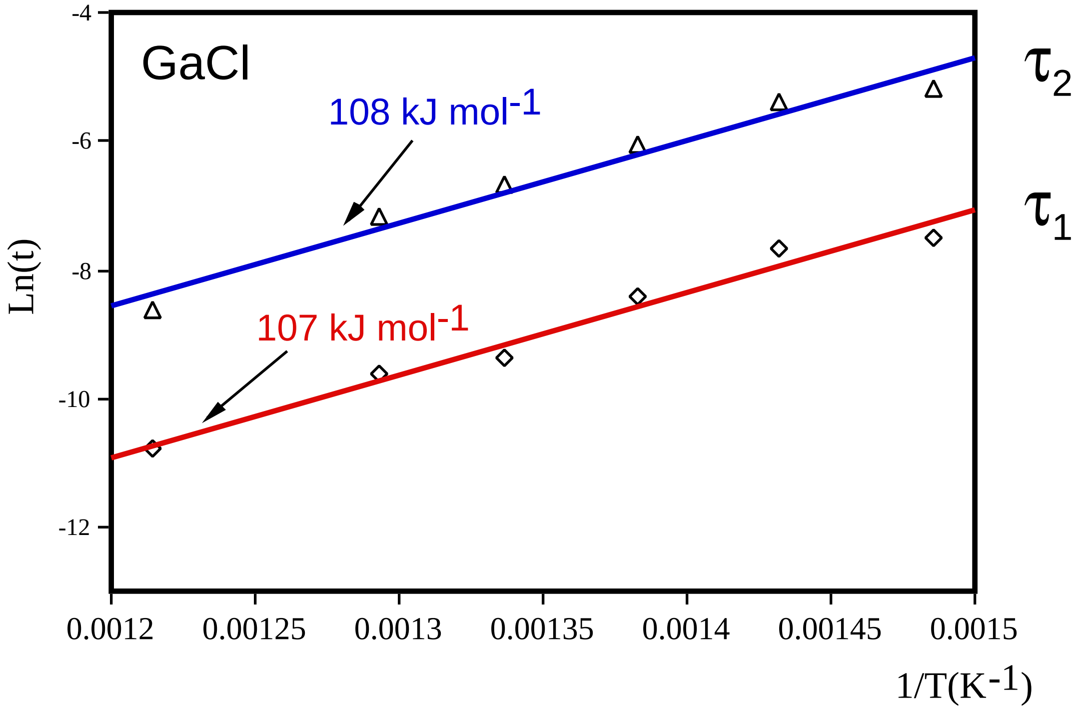
Fit T(t) with a given F(t) function, adjust parameters via non-linear least-squares

$$F(t) = A\ e^{-t/\tau_1} + B\ e^{-t/\tau_2}$$

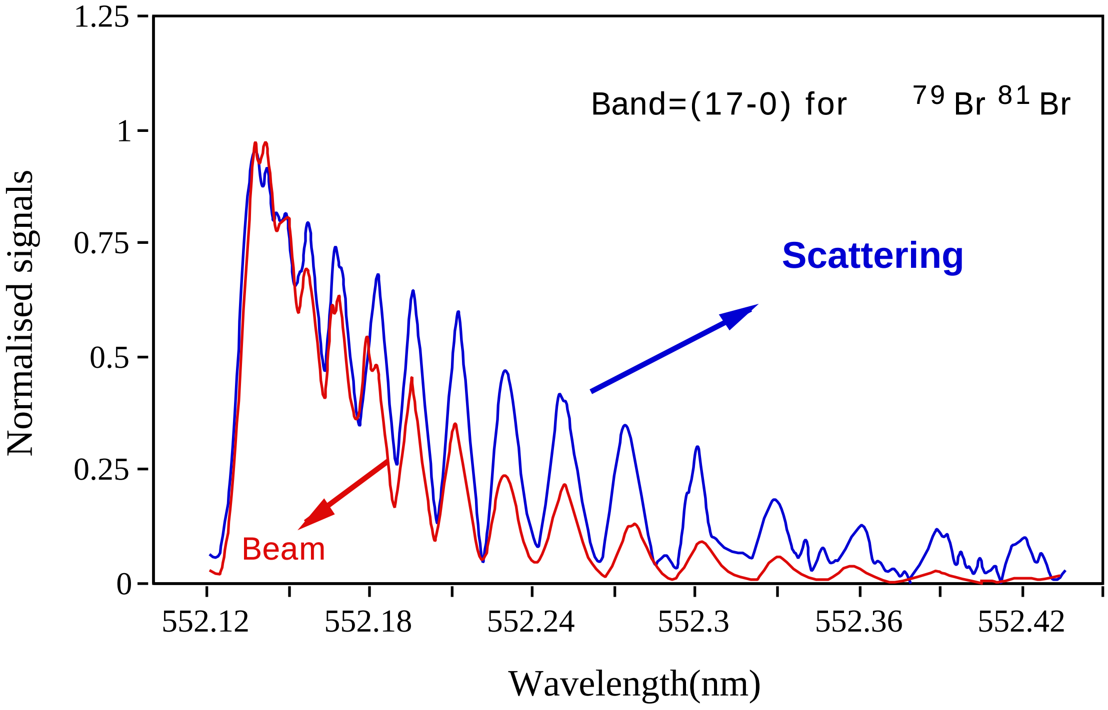
$T_{MB}(t)$ the Maxwell-BoltzmannTOF distributions of species at a given surface temperature

From measured surface residence time at various temperatures, the reaction activation energy can be obtained:

Ahrrenius plots for τ_1 and τ_2 of Cl_2 + GaAs (100)



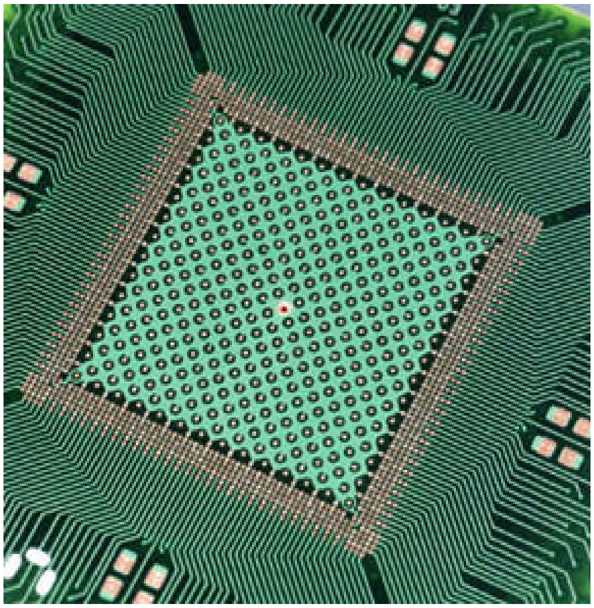
b) Measure angular distribution of species from a surface at various temperatures to analyse energy disposals. In thermal equilibrium condition, it should follow Knudsen law ($d\phi/d\theta=\cos\theta$). (e.g. the etching reaction of Br_2+GaAs(100))



LIF rotational spectra of Br_2 before and after scattered from GaAs(100) surface are shown above. The transition of V'-V" is 17-0 band.

Summary:

To gain performance increases in chips, scientists are constantly looking for ever-higher resolutions for printing circuit lines and etching methods. Current industry efforts are aimed at achieving resolution of a cuicut line smaller than 250 nanometers(nm) which has two main advantages: 1) smaller features will allow chips to contain more circuit elements; 2) smaller devices are typically higher performance (fast).



Our experiments will provide with more detail information about etching processes.