3.1 Publishable summary

http://chimono.lens.unifi.it/

Beneficiary Number *	Beneficiary name	Beneficiary short name	Country	Date enter project**	Date exit project**
1(coordinator)	Laboratorio Europeo Spettroscopia Non-lineare	LENS	Italy	1	42
2	Imperial College London	Imperial	UK	1	42
3	Technische Universitaet Wien	TUW	Austria	1	42
4	Fritz-Haber-Institut der Max-Planck-Gesellschaft	MP	Germany	1	42
5	Johannes Gutenberg-Universität Mainz	JOGU MAINZ	Germany	1	42
6	Rheinische Friedrich-Wilhelms-Universität Bonn	UBONN	Germany	1	42

The CHIMONO project aimed to demonstrate detailed control of molecules using integrated electric, magnetic, radio frequency, microwave and optical fields. We wanted to explore the possibilities for integrating all these components on a microchip, bringing molecules close to the microchip surface, and controlling molecules adsorbed on ultra-thin optical fibers. These objectives were very ambitious and went significantly beyond the experimental state-of-the-art at the time the proposal was conceived. In order to achieve these objectives we followed several different approaches for trapping and detecting molecules.

1) Association of ultracold atoms on an atom chip. The cooling and trapping of atoms on atom chips is now a well-established technology, and our aim was to create ultracold molecules on a chip by binding together pairs of atoms without heating them up. A Feshbach resonance provides the required heat-free pathway from free atoms to loosely-bound molecules. In experiments in Firenze, we made a mixture of Potassium (K) and Rubidium (Rb) Bose-Einsten condensates, and from this mixture made ultracold KRb molecules using a resonantly-modulated magnetic field close to two Feshbach resonances. Association of molecules by magnetically tuneable Feshbach resonances is not possible in standard AtomChip experiments. In Vienna two novel paths were followed: (1) a new strategy using rf-induced Feshbach resonances was developed and experimentally investigated with Rb atoms. The experiments were not successful, mainly because of technical problems related to electronic noise in the setup. (2) The second strategy was to trap atoms in an optical lattice on the atom chips, which will allow the magnetically-tuneable Feshbach resonances identified in Firenze to be used for molecule formation on the atom. Vienna was able to demonstrate trapping and cooling of Rb atoms in an optical lattice trap on the atom chip. We have therefore clearly identified a route for the production of an ultracold molecular gas on a chip and demonstrated all the necessary steps.

2) Decelerating and trapping a molecular beam on a chip. Using a specifically designed deceleration-acceleration sequence, in Berlin we have demonstrated the filling of up to 200 microtraps on a chip decelerator directly from a pulsed molecular beam of CO, the deceleration of the whole array of minima to a standstill and spatial focusing of the re-accelerated CO molecules such that they all arrive at the same time on a detector. In the last year we showed how a magnetic field can be used to eliminate the loss of molecules caused by time-varying electric fields on the chip driving transitions to un-trapped states. We also developed a microstructured elliptical mirror to focus molecules onto the chip and so increase the number of trapped molecules. Finally, we concentrated on coupling a cryogenic source developed at Imperial with a macroscopic traveling-trap decelerator in Berlin. These developments make substantial progress towards increasing the density of trapped molecules, the range of species that can be trapped, and the lifetime of the trapped molecules.

3) Fluorescence detection of adsorbed or trapped molecules. In Vienna we realized the first integrated fluorescence detector for single atoms on a chip. The detector will also work well for any molecule that can scatter a few tens of photons from an excitation laser, and, at Imperial, we have shown how, for some molecules, this can be done using a well-chosen set of laser frequencies. Meanwhile our partners in Bonn and Mainz enjoyed great success with adsorbed molecules on the nanofiber-waist of a tapered optical fiber that had been developed in Mainz. Adsorbed molecules offer a promising route to single molecule detection and ensemble functionalization. For detection we concentrated on spectrally addressing single molecules from an ensemble adsorbed on a nanofiber in a cryogenic environment. A statistical analysis of the spectroscopic data obtained shows that we can already address as little as ten molecules at a time. Further improvements in the sample preparation should thus allow us to reach the single molecule regime.

In Bonn photoswitchable molecules were adsorbed on the nanofiber surface from organic solvents. The internal state of the molecules was measured via their state-dependent light absorption. Repeated switching between the states was achieved by exposure to the evanescent field of a few nanowatts of light guided in the nanofiber. Switching rates, cyclabilities and photodestruction probabilities were experimentally characterized and theoretically modeled. This demonstrates the optical control of internal molecular states on optical nanostructures.

4) Addressing via superconducting microwave resonators. The integrated fluorescence detector developed in Vienna was further developed, and a new generation currently being built will also work well for any molecule that can scatter a few tens of photons from an excitation laser, and Imperial have shown how, for some molecules, this can be done using a well-chosen set of laser frequencies. Meanwhile in Bonn and Mainz we enjoyed great success with adsorbed molecules on nanofibers that had been developed in Mainz. Adsorbed molecules offer a promising route to single molecule detection and ensemble functionalization. For detection we concentrated on spectrally addressing single molecules from an ensemble adsorbed on a nanofiber in a cryogenic environment. A statistical analysis of the spectroscopic data obtained shows that we can already address as little as ten molecules at a time. Further improvements in the sample preparation should thus allow us to reach the single molecule regime. Furthermore the Mainz group, now in Vienna, and the Vienna group have designed a chip where a nano-fiber is integrated. The chip is currently being fabricated.

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4) Addressing via superconducting microwave resonators. In Vienna have improved and further developed planar superconducting microwave resonators. The quality factor of these resonators reaches now $Q=10^6$ which is high enough to reach the regime of strong coupling between the micro wave photons in the resonator and collective states in an ensemble of ultra cold atoms or molecules, for polar molecules it should be possible to achieve strong coupling also for single molecules. The key question to solve is now to bring the atoms/molecules into the cryogenic environment needed to operate the micro wave resonators. In Vienna an apparatus was developed to move atoms from a room-temperature environment into the cryogenic environment of the resonators. Future development will allow decelerated or associated molecules to be coupled to the resonators, and even integration of nanofibers bring optical photons to the molecules.