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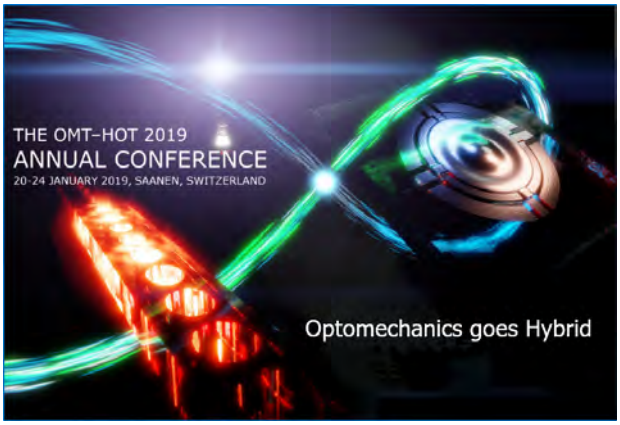
March 2019, No. 3

# Optomechanical technologies newsletter

Editor: Edouard Ivanov, ESR Sorbonne Université (SU)




## Highlights

Most of the fellows in the OMT project have begun or are nearing the start of the second year of their PhDs. It is made clear from the testimonies below that we have all been working to the best of our abilities on developing our projects – and ourselves in the process – as far as we can. This has confronted many of us with significant challenges, but has by no means dispirited us; the ubiquitously light tone, even in the scientific section, serves as evidence for that fact.

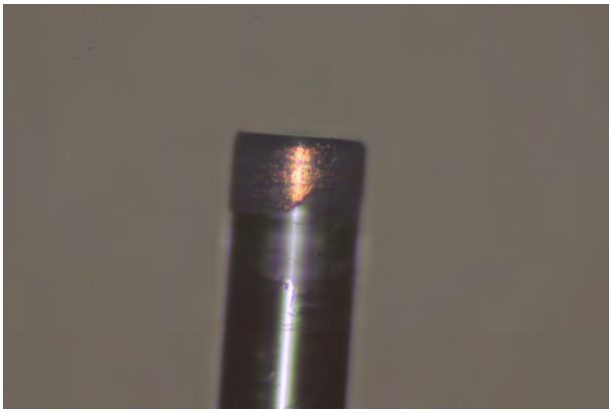
Our duty to scientific outreach and dissemination has not been neglected either, and the following sections feature several original initiatives by our fellows.

*(Image representing our 2019 annual meeting. Courtesy of ESR Simon Hönl, IBM)*

## ESR Science News


**Irene Sanchez (ESR UKON)**

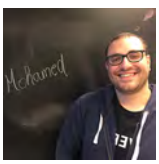
Many things have happened since our last newsletter in August 2018. I have bought almost all of the components we need for the fiber-based cavity, and the coated fibers have finally arrived from the coating company (LaserOptik GmbH). We have now learned how to clean high quality mirrors and how to fit them in small ferrules. Below is a figure of the coated fiber-mirrors.



Bright-field image of a fiber-mirror. Courtesy of OMT fellow Irene, UKON.


**Paolo Piergentili (ESR UNICAM)**

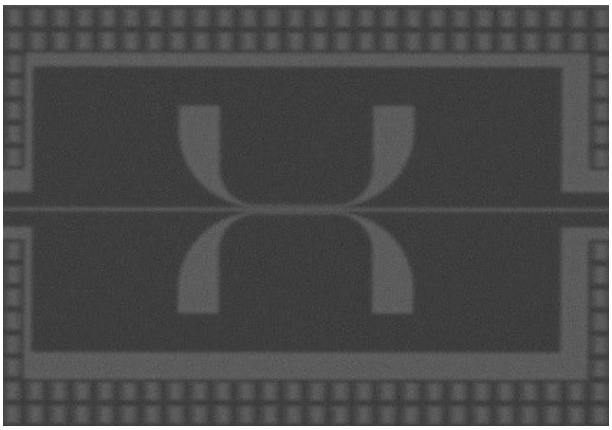
For the past few months I have spent most of my time working in the lab: I am trying to measure the synchronization of two $Si_3N_4$ membranes placed inside a high finesse Fabry-Pérot cavity. Meanwhile, we have repaired the dilution refrigerator, and just before Christmas we measured a minimum temperature of 20 mK: the cryostat is again ready to carry out optomechanical experiments at very low temperatures.




**Mohamed Ashour (ESR Bosch)**

My first samples have finally arrived, and I am working on post-processing them to make them usable for the experiment we have. At the same time, I am developing a comprehensive theoretical model: it proposes a more accurate method of predicting the behavior of the optomechanical phase shifters for different geometries and materials, under various operating conditions. The figure

below shows a scanning electron microscope image of one of the very first samples of these phase shifters.



The first optomechanical phase shifters. Courtesy of OMT fellow Ashour, Bosch.

**Giuseppe Modica (ESR CNRS)**

During the past 6 months a big move-out and subsequent move-in took place on our side at C2N-CNRS. In fact, our lab moved from Marcoussis to Palaiseau in a new building where a huge new clean-room will become operative in the near future. The move was quite intense, and we carefully unmounted everything from the old setup to mount again every part in the new lab. Even if this was time-consuming, I ultimately have to say that it was a really good opportunity for me to gain a better understanding of all the parts and devices which I usually work with to perform electrical, optical and optomechanical experiments. Building a setup from scratch may be the best way to really understand the technologies that allow us to make science!


**Corentin Gut (ESR UNIVIE)**

While he was writing his thesis, my colleague Ramon made some insightful and clever comments on how to look at data; it turned out to work well, and we were able to fish the shy quantum knot of correlation out of the sea of data we produced in February last year. But at that time, part of the argument was missing. For several months, my daily routine was to come up with arguments to convince my colleagues of the *right way* to handle data: one day arguing "it is certainly fine", and the next day the argument would go: "this is heresy!" But I believe we have it now.
From my point of view, part of the solution was to learn that, at some point, one needs to decide that a data set is "good enough" - even though the experiment could be repeated again and again, with fixes and improvements at each iteration, to approach the best data set. The issue is the limit of iterations that (inevitably) grows large... The key step was to tackle the argument differently; I found for myself a precise statement of what "good enough" might mean (in my wildest thoughts I had the Heisenberg-Von Neuman cut in mind - in my tired dreams I was trying to explain to my real analysis lecturer how to pick the positive epsilon). And then I checked whether the data set is indeed *good enough*. Hey, I believe it is!


**Mohammad Bereyhi (ESR EPFL)**

*"The falling leaves, drift by my window,*
*The autumn leaves of red and gold..."*

It's no surprise how much I love this song! This fall was a bit hard and I saw many leaves falling - in my PhD let's say. I suppose nothing ever goes as planned, and that's why you always need a "plan B". In September, I was able to finish the fabrication process of near-field optomechanical transducers that I started working on from the beginning of 2018. I spent some time in the lab in order to characterize the samples and look for the "hero". Unfortunately, due to the challenging fabrication of long mechanical resonators combined with the hybrid process, we were not able to achieve samples with higher performance than our already existing ones. This required working for a while in the lab and re-iterating on our fabrication. The next step was to move on of course. While working on the hybrid process, I spent some time looking at the "clamp" designs of nanobeams and tried to understand some contradicting results in the literature. This led to a manuscript which I ended up writing on "Clamp-tapering" - a method useful for improving the mechanical quality factor of stressed nanobeams. At the moment I have switched gears and I am trying to develop a new hybrid design for room temperature optomechanics, because I guess that's why I came to EPFL in the first place!

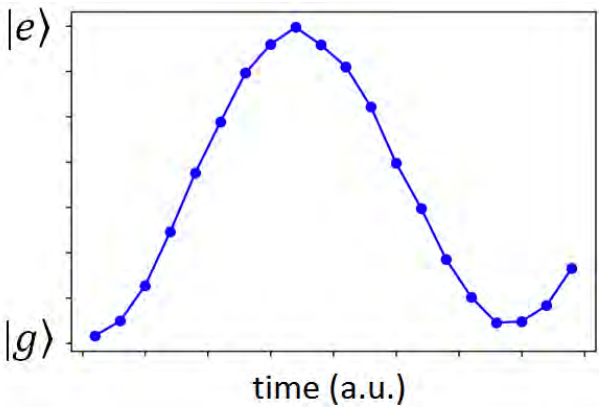

**Simon Hönl (ESR IBM)**

My days and nights these days are spent in the clean-room, trying to get a new device design to work. It always seems so easy to draw something on a piece of paper but once you are in the lab everything turns out to be more complicated - the devil is in the details, as they say. For the most part I think I am on the right trajectory

and, to be honest, I am really stoked about my project and want to make it work in the time that still remains in my PhD. The problem is that the ultimate goal is so prohibitively ambitious that it will probably take years to get it to work: scalable quantum networks based on cavity optomechanics.
For now, my daily concerns are: which sacrificial layer to use for which step? which chemical to etch which product? - "can I use an $SiO_2$ sacrificial layer here? It should be more porous than thermal oxide, so maybe I should use oxynitride instead so I can match the etch rates in buffered HF ..." These types of concerns. It seems a bit mundane considering the scope of the project but, sadly, a PhD seems to entail that one has to do everything by oneself, from the "great plan" to the itty-bitty details.
Overall I am very happy with my project, however. I think there was never a better time to work in quantum technologies, in the sphere of influence of quantum computing in particular.


**Byoung-Moo Ann (ESR TU Delft)**

I have been developing a "quantum tool box" for non-classical microwave photons in superconducting resonators. By benchmarking the photon number trapping mechanisms, one can stabilize Fock states in the resonator mode, and I found that it is experimentally feasible within a circuit QED architecture.




Experimental measurement of the Rabi oscillations of a qubit. Courtesy of OMT fellow Byoung-Moo, TU Delft.

On the experimental side, there have been many updates. Most importantly, we have been able to coherently control a superconducting qubit and read its quantum state. The above picture shows the coherent Rabi oscillation between the ground and the excited state.
The next step would be the flux control of the qubit, that enables us to turn on and off the coupling between the qubit and the resonator.


**Tirth Shah (ESR FAU)**

The past few months as an OMT fellow were filled with many exciting scientific events; and a slow but steady progress in my PhD project. I am designing an etching pattern on silicon chips, such that one can achieve robust transport of phonons along the desired paths, and an optomechanical excitation and readout of these phonons via laser light. I feel like an architectural physicist, since I have to come up with new etching patterns on silicon chips. Overall, my work is very close to the experiments, which is something that every theoretical physics student desires.

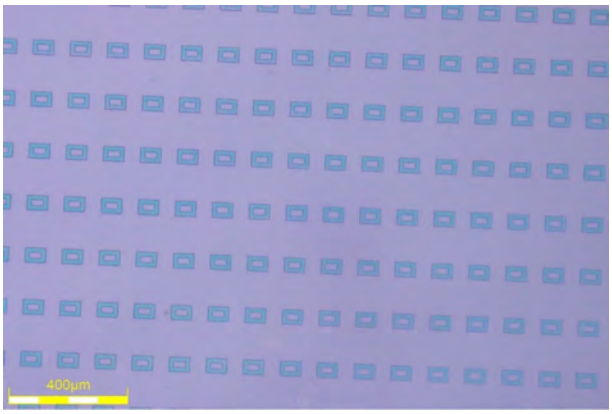

**Alberto Beccari (ESR EPFL-IBM)**

In the last six months my work has been converging to the limit cycle of scientific progress: try turning some knobs in the cleanroom $\rightarrow$ possibly get some viable devices $\rightarrow$ observe them in the mechanical characterization setup $\rightarrow$ get some wildly scattered data with debatable meaning $\rightarrow$ convince yourself that you have an explanation $\hookleftarrow$ back to the cleanroom. This applies in particular to some strained silicon wafers we have acquired, where the device layer is so thin that surface quality is completely dominant over bulk properties, and it is quite difficult to understand what changes from one fabrication run to another. The world is a complicated place, and we humans are already in trouble understanding a graph of a two-variables function.


**Khannan Rajendran (ESR UGENT)**

These past few months I have been working on implementing an optomechanical complaint transfer printing scheme for 2D materials. Most of my effort has been focused on optimizing the pattering of graphene coupons. Fabricating in the cleanroom has been a continuous learning experience with new challenges to explore every day. But like all things in life there are some exceptions and mine has been graphene. As some of my colleagues here can testify, while graphene is truly is a wondrous material, it is extremely frustrating to work with. Nevertheless, what is life without a little frustration, and so I have come to enjoy my time spent in the cleanroom. I'm also looking forward to next step: the dry-transfer printing

of my coupons and measuring the optical and mechanical properties of the membrane. If the technique proves to be successful, I hope to extend its implementation to other graphene-like materials.




ESR Khannan's (UGENT) "beautiful un-patterned graphene coupons"

**Edouard Ivanov (ESR SU)**

The months since August have been whimsically cruel to us over in central Paris. A substantial amount of our fabrication runs ended in failure, and left us with virtually no samples to measure for a significant stretch of time. But for lack of better options we persevered, and finally managed to measure a sample, down to 10 mK even, thanks to our collaborators. Current stages of research still have us trying to converge on a design, but it is often difficult to pin down what exactly good *means*. One design may have much higher coupling, but at the cost of a dramatically increased effective mass. And then perhaps it also excessively couples to exterior noises... But all these concerns translate to me writing on a whiteboard for long periods of time, and I would never complain about that.

**Sampo Saarinen (ESR UCPH)**

The most startling realization since the last newsletter has been that the two year mark of my PhD is passing very soon. While extensions are more often rule rather than exception, it is imperative to remember that there is a deadline - Memento mori, if you will. This also means that it's not long until I'll have to start considering time after Copenhagen. With that in mind, I'm very much looking forward to the OMT mentoring.

On the other hand, a long project - a room temperature integrated radio frequency to optical transducer - has finally reached a milestone and we have prepared and submitted a manuscript. Other projects, such as quantum electromechanics and fiber mirror cavities are moving forward and I believe there is a very real possibility that the following months will bring beautiful results - with caveats of course. Old advice is to multiply budget and allocated time by three and at least the latter part has held true to this date.
On a more mundane side I have been part of the purchasing process of a dilution refrigerator, and in March we'll finally have an operational fridge. To be honest, I'm perhaps more excited than I should be. In any case, it's time to put the lessons of the OMT Cryocourse workshop to use.

**Mohammad Haque (ESR AALTO)**

It has been almost two years since I began, in June 2017, and I am nearly halfway through my PhD now. As such, the last six months have been quite hectic. I am currently finalizing my theoretical calculation on optomechanics mediated by the quantum capacitance of qubits. The non-linearity introduced by it enhances the optomechanical coupling by several orders of magnitude, potentially reaching the single photon strong coupling regime. Along with the optomechanical coupling, the system also exhibits Kerr type non-linearity.
On the experimental side, preparation of both the suspended graphene samples and superconducting microwave cavities with DC local gates is ongoing. Hopefully, I will have working samples very soon, and start low temperature measurements. The aim is to find proximity induced superconductivity in the graphene samples and the resulting optomechanical effects can be read out from the superconducting cavities.

**Hossein Masalehdan (ESR UHAM)**

By the beginning of April, it will be a year since I joined OMT. It was a great opportunity for me to fulfill my enthusiasm involving experimental quantum optics. In the past months, I have developed my setup to make a noiseless laser light for my measurements, sometimes reaching the mode matching condition above 99%. Locking the cavity is a time-consuming process, while practising and building custom-made electro-optical components is fun!

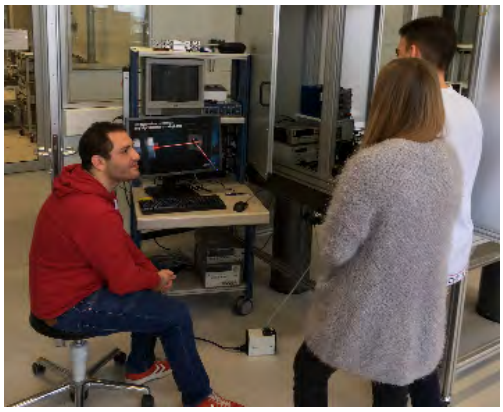
# Outreach @OMT

by Irene Sanchez (ESR UKON)

For the past few weeks, I have been working on a topic that really interests me: the under-representation of women in STEM fields. Particularly, I have been working on a presentation that I will give to high school students in Spain on behalf of the Women's International Day (on March the 8th). The idea of my presentation will be to motivate young students - particularly female ones - to pursue a career in STEM, given the gender gap still present in those fields. For that, I am putting together a video in which my female friends working in STEM fields share their experiences.

by Mohamed Ashour (ESR IBM)

I have had the pleasure of participating in the Bosch BOGY program, where students from high schools come to visit our site to learn more about our work. I have presented our lab to a brilliant group of students, and they even carried out measurements themselves during a hands-on tutorial. The image below shows the students as I was explaining the concept of my project to them.



ESR Ashour (Bosch) with students during the Bosch lab tour.

by Hossein Masalehdan (ESR UHAM)

In January, I gave a lab tour for high school students where they saw how nonlinear optics converts invisible light into the visible regime, as well as using micromechanical oscillations to detect and record very specific mechanical waves (sound!).

by Mohammad Bereyhi (ESP EPFL)

My fellow graduate student, Alberto, and I took part in a lab tour for high-schoolers. It was a pretty unique experience I might say, talking about our research to people who have no idea about what can be done with what they learn in their textbooks. I hope they will now enjoy their physics class more!

High-school students visiting the laboratory of Photonics and Quantum measurements at EPFL. Courtesy of OMT fellow Mohammad, EPFL.

by Alberto Beccari (ESR EPFL-IBM)

Mohammad and I had some fun in November taking a class of high-schoolers from Valais (the swissest of Swiss cantons) into our lab and encouraging... ehm... discouraging.... mmh... biasing their preferences about beginning a Bachelor in Physics or Engineering. Within the allotted sixty minutes it was a nontrivial challenge to provide an introduction to radiation pressure, optical cavities, and micromechanical oscillators, and to illustrate some of the shiny tools arranged on our optical tables, but I think we managed to arouse some interest about high power lasers and vacuum chambers.

ESR Alberto (EPFL-IBM) showing students an image feed from an optical microscope, pointed at some of the mechanical resonators fabricated at EPFL.

by Khannan Rajendran (ESR UGENT)

As a member of the Photonics Society of Gent, I organized our annual outreach exercise – "Light Night". The event was a set of interactive lectures on the 2018 Nobel prize in Physics, with talks on non-linear optics and optomechanics, and specifically on optical gradient forces and its applications. The event was a phenomenal success and was attended by over a hundred university students.

Prof. Filip Beunis of LCP, UGent demonstrating optical trapping and force sensing on a DNA strand using a telephone cord. Courtesy of OMT fellow Khannan, UGENT.

by MOHAMMAD HAQUE (ESR AALTO)

Students playing the "Save the Astronaut" game. Courtesy of OMT fellow Mohammad, Aalto.

Outside of research or lab work, I have participated in an outreach activity at the end of September during the "European Researchers' Night" in Helsinki. While there, I presented the OMT travelling exhibition, the "Save the Astronaut" game.

by EDOUARD IVANOV (ESR SU)

A festival of science (the "Fête de la science") is held every year at Sorbonne Université, touching all areas of science. This event is open to all, and we had visitors from primary and secondary school classes, as well as curious passers-by of all ages. I organized lab tours for anyone interested, trying to illustrate what the typical scientific environment and routine are like.

(left) ESR Edouard (SU) explaining the principles of a simple optomechanical experiment. (right) ESR Edouard describing the operation of VIRGO, and trying his best not to scare the children with collapsing stars.

by TIRTH SHAH (ESR FAU)

For my outreach event in September, I have created a computer game called "Laser Sword Soccer", where the players have to steer the ball using light in order to score a goal. I learned the new skill of making amateur games through this event. In addition, I also got plenty of opportunities to improve my scientific communication skills through the ETN program.


Screenshot of the Laser Sword Soccer game. Courtesy of OMT fellow Tirth, FAU.

# Our fellow globetrotters

by Paolo Piergentili (ESR UNICAM)

At the beginning of January I spent one month in Prof. Marquardt's group, in Friedrich–Alexander–Universität in Erlangen (Germany) for my OMT training secondment. It was a fruitful experience where I simulated the optomechanical setup I am currently studying in the lab. In January another important event took place: the OMT-HOT Annual meeting. I had the chance to give a talk about the results I achieved in the lab during my one and a half years as an OMT fellow.

by Mohammad Ashour (ESR Bosch)

I recently attended our annual OMT-HOT meeting in Saanen, Switzerland. It was a very interesting experience for me to act as a chairperson of one of the sessions in this conference. I also learned a lot from my peers working on projects that share methodology with my work.

by Giuseppe Modica (ESR CNRS)

Regarding my project, I had the opportunity to spend some time in Thales-RT for my secondment. There I was able to familiarise myself with accurate VNA measurements that will help me to develop and upgrade my next generation of prototypes of optomechanical systems.

by Byoung-Moo Ann (ESR TU Delft)

I gave a presentation about the stabilisation of Fock states in a harmonic resonator modes at our last OMT-HOT annual conference, in January 2019.

by Mohammad Bereyhi (ESR EPFL)

A wise person once told me "OMT is about an extended PhD experience, think outside the box!". Well, I cannot agree more that she was and still is right. This motivated me to go for a challenge: there was a proposal call at EPFL for ideas on "Open-Science" practices and platforms. Since I have worked quite a lot in cleanroom facilities at EPFL (CMi), I often encountered the issue of poor documentations for fabrication processes, especially if a process fails. Of course nobody is going to publish it, but it can prevent others from failing. With my PhD advisor, Prof. Kippenberg, we wrote a proposal for an online platform for posting and sharing process specific knowledge - a fabrication arxiv. The project was granted funding for 3 years this past February. We are very excited to start the implementation of what we call "NanoFab.Net".

by Hossein Masalehdan (ESR UHAM)

On the first of May, I will go to TU Delft for my secondment to learn more about the membrane fabrication process, and hope to bring the membranes I will fabricate to Hamburg.

by Mohammad Haque (ESR AALTO)

Thanks to the opportunities offered by this network, I have given my first scientific talk at the OMT conference this January, held at the beautiful location of Saanen - Switzerland.

by Edouard Ivanov (ESR SU)

I have spent a little over a month for my secondment in Finland, at the university of Aalto, trying to absorb as much information as possible about cryogenic measurements, with the local "gurus". Though I have by no means become an expert in so little time, I am ready to put my knowledge to practice, and continue trying to achieve quantum control over our samples.

by Tirth Shah (ESR FAU)

I presented my first poster on "Steering sound at the nanoscale" during the OMT Cryogenics workshop at Aalto University. Furthermore, I gave my first conference presentation during the OMT-HOT 2019 Annual Meeting at Saanen. One more upside of having OMT workshops at different partner institutions is that you get to visit and experience many beautiful places in Europe.

# Workshops and conferences


The OMT Cryocourse participants visiting the Bluefors factory.

We met in Finland earlier this semester, at the end of September, to attend the "Low temperature measurement techniques" workshop, organized by our partner institution Aalto. It comprised the Cryocourse lecture series, which covered an eclectic mixture of topics: from introductory statistical physics to the advanced quantum physics of superconducting and superfluid states of matter, via detailed engineering of cryostats. Such a program is invaluable to anyone working with a low-temperature environment, as several of us do. The workshop was complimented by a guided visit of the headquarters of the Finnish start-up Bluefors Cryogenics, a well-received tour of a company in soaring development. For a bit of relaxation, and to immerse ourselves in the Finnish culture, we went for a midnight dip in the sylvan saunas, leaving everybody fresh and energized - an altercation with steam requiring medical intervention notwithstanding.

As is our annual tradition, we all met at the conference held in Saanen. Of course, the particularity of this event is that "we call" encompasses more than us OMT ESRs: it is a conference jointly organized with our sister project, HOT (Hybrid Optomechanical Technologies), and focuses on the topic of optomechanics. This event is a double opportunity to discuss our specialty with leading experts in our field, which, judging from the gathered feedback, seems to have been fruitful for many of us. It also gave us the chance to present our progress – be it in the form of a poster on an oral presentation.

This conference is also the time when we hold a yearly recap meeting with Antonella, to ensure everyone provides feedback and satisfies any queries one may have. We can raise a big thank you to Simon for representing us this term on the supervisory board, and a second one to Irene for volunteering to do so next year! –Edouard Ivanov

Fellows and PIs during the traditional OMT jump at the 2019 annual conference, with the beautiful backdrop of the Swiss alps.