Integration of an Optical Fiber in an Ion Trap

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Abstract

It was tried to integrate an optical fiber inside an ion trap. The trap used consisted of electrodes inserted inside a PCF-cane. It was tried to replace the central electrode by an optical fiber. We first build an UHV-feedthrough to get the fiber inside the trap chamber. Then we build a positioning system to facilitate the building of the trap. Finally we try to insert the fiber inside the trap body, testing several modifications of the fiber. It was found that etching the fiber partially and coating it with electrically conducting epoxy allowed the fiber to fit inside the PCF-cane and to have low electrical resistivity.

Contents

1 Introduction

The goal of this semester project was to integrate an optical fiber into an ion trap. The basic principle of an ion trap is to confine an ion inside an ultra-high vacuum chamber using oscillating electric fields. One of the main application of such a trap is quantum information processing. In this context, one has to be able to manipulate the electronic state of the trapped atom and also to measure the photons produced by electronic transitions. This detection is ordinarily done by a CCD camera placed outside the UHV-chamber.

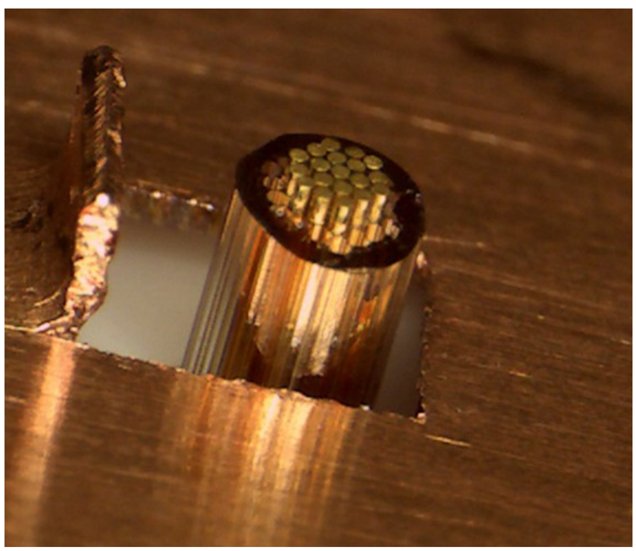

Figure 1: General view of the trap.

Having an optical fiber directly built into the trap chamber would have several advantages: it would provide greater scalability to the system and also it would allow to collect more photons.

The ion trap used in this project was a fiber trap. The trap body consists of a glass cane in which the gold wires used to generate the trapping potential are inserted. The glass canes were originally employed to manufacture photonic crystal fibers (PCF). The canes are hollow and consist of cylindrical holes arranged in an hexagonal pattern around the center of the cane. These holes are used to hold the trap electrodes, which consist of 19 gold wires inserted into the innermost holes (see fig. 1). When generating the trapping potential, the central electrode always stays grounded. It can thus be replaced by an optical fiber, as long as some requirements are met: the coating of the fiber should be electrically conducting in order to prevent charge from building up at the tip and the fiber materials should be UHV-compatible.

The building of the trap body is done in several steps: first the gold wires are inserted into the cane and their tip are coated with wax. The tips of the wires are then polished and lastly the wax is dissolved using acetone.

2 Vacuum Feedthrough

2.1 Setup

To couple the fiber to the outside world, we decided to simply drill a hole in an UHV flange, push the fiber through and then fill the hole with UHV epoxy. In order for the whole device to be UHV tight, the hole needs to be the smallest possible, we thus drilled a 1 mm diameter hole through the flange. We then inserted the fiber in the hole and sealed it with UHV glue. During this process, one has to take care not to leave too much glue on the vacuum side of the flange, since this could lead to outgassing once the system is put under vacuum. It is also important to prevent glue from flowing to the vacuum side of the flange during the curing. To accomplish this, we maintained the flange in a vertical position for the whole curing process, using clamps.

2.2 Test

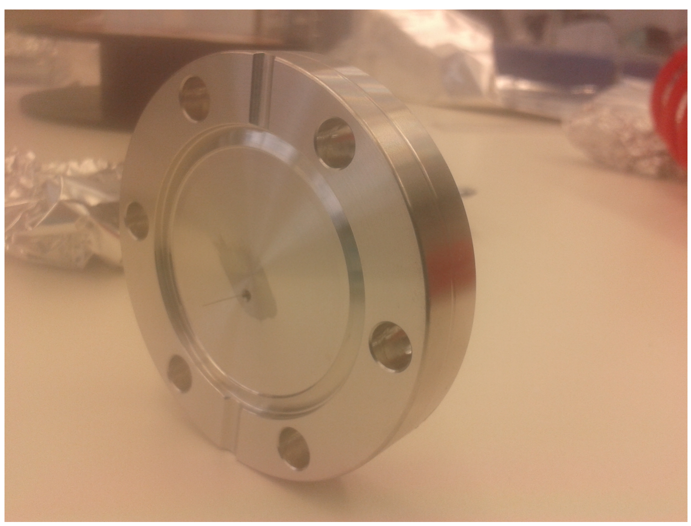

Figure 2: Overview of the vacuum feedthrough

Once the glue was cured, we had to check that the feedthrough didn't leak or outgass under UHV conditions. We thus put the system under vacuum using the usual procedure:

First we cleaned the system using the following cleaning scheme:

1. Rinse under running water.

2. Pre-clean using Acetone and standard paper tissues.

3. Clean three times in ultrasonic bath, using first DI-water, then acetone and finally isopropanol.

Then we started pumping the system with a turbopump and baked it. The oven was set ro reach 160 °C, with a heating rate of 100 s/°C. When a pressure under 10^{-6} mbar was reached, we turned on an ion pump to reach even lower pressures. We let both pumps run for one day past the end of the baking, pumping the system while it cooled. The final pressure we reached was $4.3 * 10^{-8}$ mbar.

3 Positioning System

The most challenging part in the building of a fiber trap is the insertion of the wires inside the PCF-cane. This is due to the difficulty of avoiding any bending of the wires, but also to the great care which has to be taken in order not to damage the glass structure.

To make this step easier and less time-consuming, we tried to build a positioning system to help insert the wires. The basic principle of this positioning system is to attach both the cane and one wire to some support and then use micrometer screws to move each one and insert the wire into the cane. This was done by fixing micometer screws used for optical alignment onto an aluminium plate. The glass cane was held using a homemade support with a screw and the wire was held by an SM1-Threaded Fiber Clamp from Thorlabs. The whole setup can be seen in Figure 3.

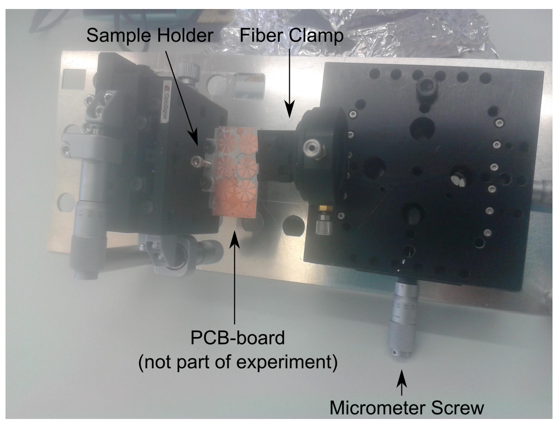

Figure 3: Overview of the positioning system.

We had to make several attempts to figure out the optimal distance between holders for the cane and the wire. We found that if too much space was left between them, then it became difficult to keep the wire straight and avoid bending. Once the optimal adjustment of the components was found, the positioning system turned out to make the insertion of the wires much easier. It should be noted that it is better not to lay the positioning system flat under the microscope but instead to set it in a diagonal fashion, to allow the user to see into the cane.

4 Pretests

We then turned to the task of inserting an optical fiber into the central hole of the PCF-cane. We first tested several modifications of the fiber to find out which adjustments were needed.

4.1 Complete Etching

Since the gold coated fibers had a diameter of 150 μm and the holes in the glass cane were approximately 144 μm thick, we had to change the size of the coating to allow it to fit inside the glass cane. Our first idea was to etch the tip of the fiber down to its glass core and then to use this smaller tip to get the fiber into the cane, hoping that the glass walls would rip off any excess gold along the way.

To remove the gold coating we used Aqua Regia. Aqua Regia is made by mixing nitric acid and hydrochloric acid in a 1:3 volume proportion. We used HCL37% and HNO_3 65%[1]. Our original recipe also contained water but it was found out to be too weak to etch the coating. The fiber was left in the acid for 30 minutes, allowing the coating to be completely removed (see 4).

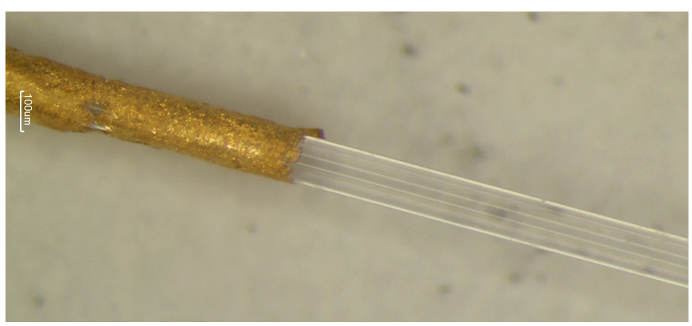

Figure 4: Fiber after 30 minutes etching.

The produced fiber would not fit in the cane. When inserting it, a small amount of gold got ripped off (see 5), but the gold was too hard to be removed in this way. Furthermore the absence of coating at the tip of the

[1] We disposed of the Aqua Regia by neutralizing it with water in a 1:1 volume proportion and then stored it in a plastic container for later disposal.

fiber made it very fragile, the fiber broke as soon as it became misaligned with respect to the cane.

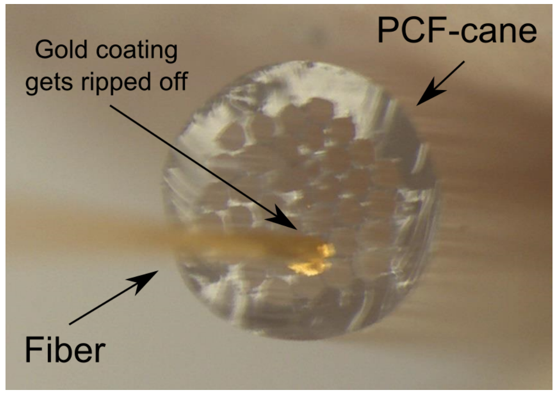

Figure 5: Gold coating getting ripped off by the glass walls.

4.2 Partial Etching

Instead of completely removing the gold coating, we also tried to just etch it a bit, in order to produce a fiber of the optimal size, with some coating left.

To do this we also used Aqua Regia and tried to find out how long we had to etch the fiber to get the desired thickness. We put 5 fibers in Aqua Regia, etched each one for a different amount of time and then measured the resulting thickness using a microscope.

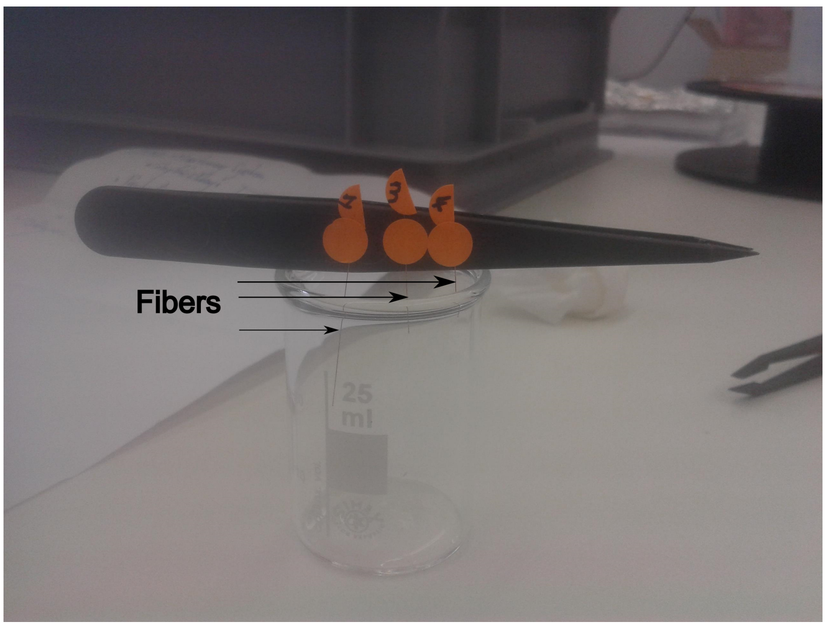

Figure 6: Different fiber samples before etching.

The etching time for each fiber and the final thickness are summarized in table 1.

Duration [min]	**Diameter [μm]**
5	148
10	143
15	142
20	122
25	120

Table 1: Etching duration and resulting diameter for each fiber.

The diameters listed in the table are only mean values, in fact the thickness of the etched fibers was non uniform. There is an uncertainty of about 4 μm on these results, but it cannot be evaluated accurately since it depends on the calibration of the microscope and on its focus. Already for the third fiber(15 minutes etching) the tip had no coating left. On the fourth one the glass core was visible in several places but there was still a bit of coating left. The last fiber had no coating left.

The non-uniformity of the etching is due to the fact that chemical reactions usually start around impurities or irregularities of the material, thus some spots, like the tip of the fiber, will be attacked first by the acid and will hence be etched more, those irregularities can be seen in 7.

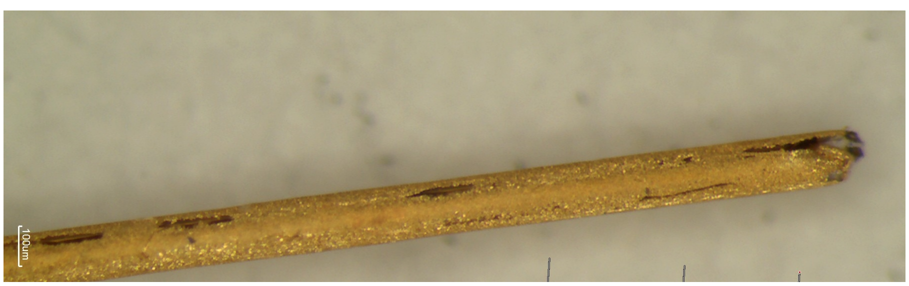

Figure 7: Fiber after etching.

From this experiment we deduced that the optimal etching time was around 16 minutes and thus did the same test again, but only probing around this duration, the results are summarized in table 2.

Duration [min]	**Diameter [μm]**
15	140
16	137
17	135

Table 2: Etching duration and resulting diameter for each fiber.

The core of the second fiber(16 minutes etching) was visible in some places and it was apparent on the majority of the third fiber.

To deduce which diameter was the optimal one, we tried to insert each of the fibers in a glass cane, We found out that even the fibers whose core was apparent in several place wouldn't fit in the holes. This result is very surprising since the holes were approximately 145 μm wide and the smallest fibers with some cladding left had a diameter around 130 μm, which implies that they should have been able to fit into the holes.

In order to get a better idea of the sizes involved, we turned back to the wires used in the trap and measured their diameter. The wires were found to be 127 μm wide; nevertheless they were hard to get into the holes since they always have some bend. This means that we cannot expect the fibers, which have a 125 μm glass core, to fit in easily, even when completely etched. This shows that the fiber cannot be expected to fit inside the cane by means of some small etching of its coating.

4.3 Complete and partial Etching

To get around the impossibility of etching the fiber to the right diameter we tried another procedure: etching the fiber only a little bit and then using the glass cane to rip off the excess gold. The goal of this procedure was to have the excess gold get cut off by the edges of the hole upon insertion. Due to the fragility of the fiber, great care had to be taken during this process, in particular we had to avoid bending.

The practical implementation was done as follows: we etched a first part of the fiber down to the glass core, in order to use it to guide the rest of the fiber. Then we partially etched another part(the one which will be in the cane at the end) and finally left the rest of the fiber untouched. The precise design and lengths of the various parts is shown in 8.

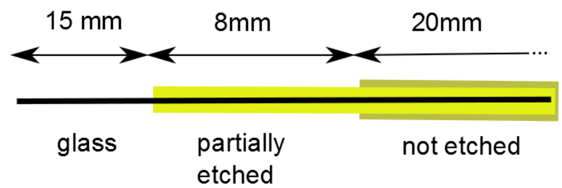

Figure 8: Schematics of the resulting fiber.

The fiber was etched using the usual procedure. The second part was etched down to a diameter of 138 μm, the glass core was visible in some places.

We then tried to put the fiber into the cane using our homemade positioning system. We first inserted the part where the coating had been completely removed and then used it to guide the rest of the fiber by pulling it.

We found out that it was impossible to reduce the diameter of the gold coating using this procedure. The gold always retained its cohesion and either got ripped off as a whole or stayed in place and caused the fiber to break upon pulling.

4.4 Homemade Electrically Conducting Fiber 1

Due to the repeated failures when using gold coated fibers, we tried to produce a custom fiber to fit our needs. Such a fiber should have a prescribed diameter, a conducting coating and should be ultra-high vacuum (UHV) compatible.

To do this we used an ordinary plastic coated fiber (Thorlabs 780HP, 125 μm core) as a base and a UHV-compatible conducting epoxy (Epo-Tek H20E) to coat the fiber.

Our goal was to first coat the fiber with the epoxy and then insert it into the glass cane before curing the epoxy, so that the glue could get evened by the glass. Since shorts between the wires used in the trap have to be avoided, one should be careful not to leave any epoxy at the back of the cane. We thus used the following design: the coated fiber was inserted into a glass cane, then the cane was cleaved in the middle and the back part was pulled back, in order to leave the bottom of the first part epoxy-free. The design is summarized in Figure 9.

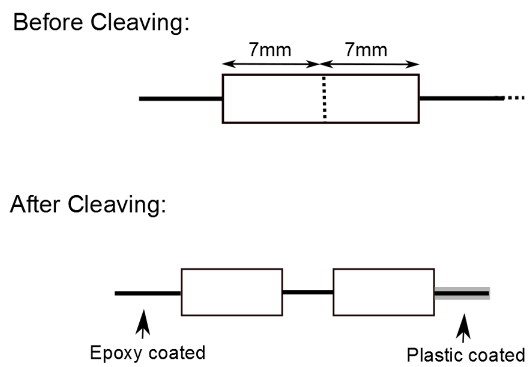

Figure 9: Schematics of the resulting arrangement.

We first removed the plastic coating of the fiber and coated it with epoxy. Then we used an aluminium foil to remove excess epoxy and produce a thin film. We then took a 14 mm long glass cane and scratched it in the middle. We pushed the epoxy coated fiber through the cane till 5 mm stuck out of the front end of the cane. When assembling the rest of the trap, this tip will be polished together with the gold wires. We then cleaved the glass and pulled one part back to get a result like in Figure 9. Finally we cured the epoxy. It should be noted that one has to take care not to pull the fiber back during the process, since this will leave epoxy at the front of the cane and create shorts between the wires.

Once the epoxy was cured we measured the conductivity of the fiber using a multimeter. The part of the fiber which went through the glass was found not to conduct at all. We deduced that some parts of the fiber inside the cane were left uncoated and hence couldn't conduct.

To solve this difficulty, we adapted our design: we tried to push the fiber back and forth inside the cane to distribute the glue evenly. Then we also cleaved the front end of the cane to remove any epoxy left. This design turned out to be unusable since we found out that it was impossible to cleave the front of the cane without moving the fiber a bit, which left epoxy on the cane and hence produced potential shorts.

4.5 Homemade Conducting Fiber 2

Due to the impossibility of producing an epoxy coated fiber in one step, we tried to break down the process in several steps. Our goal was to first coat the fiber and cure the glue, without inserting it in a glass cane, to get a custom fiber, which we could then insert in a cane of our choice.

To do this we coated the fiber with epoxy as before but then inserted it in a smaller cane (137 μm holes). We pushed the fiber entirely through the cane to produce an even coating and finally cured the glue.

The resulting fiber was found out to be easy to insert into our cane (using the positioning system). Any excess epoxy got ripped off upon insertion. The fiber was found to have a resistivity of 70 Ω/cm. This was far too high to suit our needs but was also well above the manufacturer's data(16.3 Ω/cm). The only (hypothetical) reason we found for this discrepancy is the following: according to the manufacturer, the epoxy contains silver spheres with a diameter of approximately 45 μm to ensure conduction so our coating may be too thin to contain enough spheres to be in the range of validity of the technical data.

To get a more conductive fiber we tried to reduce the core diameter before coating it, in order to make the coating thicker. To achieve this we used a fiber polishing kit from Thorlabs with grit size ranging from 5 μm down to 0.3 μm.

We found out that it was difficult to reduce the diameter of the fiber by a significant amount using this method, due to the fragility of the fiber without its plastic coating.

In the end, this experiment with conducting epoxy showed us that it was possible to manufacture a conducting fiber by coating it with glue, but that the obtained resistivity was far too high. This motivated our next try to produce a conducting fiber.

5 Homemade Gold/Epoxy-coated Fiber

Drawing inspiration from the results mentioned in last section, we tried to coat a partially etched gold coated fiber with conducting epoxy, covering the damaged coating with glue. In this situation, the epoxy has three roles to play: it should first ensure conduction in the places where the gold coating is absent. It should also make the fiber more resistant to bending and lastly is should hold the coating together to prevent it from getting off during the insertion of the fiber in the glass cane.

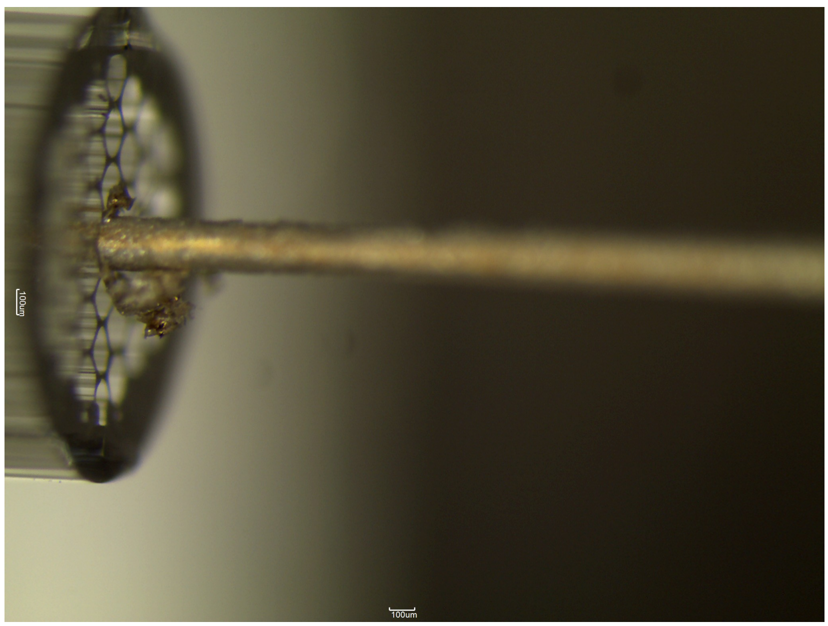

Figure 10: Gold-epoxy coated fiber getting inserted in PCF-cane.

Practically, this was done by first etching a fiber for 16 minutes in Aqua Regia (see Section 4.2), producing a fiber with 137 µm mean diameter with its core visible in some places. Then the fiber was covered with conducting epoxy by pulling it through an aluminium foil filled with epoxy. During this process we tried to make the glue coating as thin as possible by pinching the aluminium foil. We then cured the epoxy using the usual procedure.

The resulting fiber was found to be very easy to push into the glass cane(using the positioning system). During the insertion, the epoxy played its role very well, holding the gold together but also allowing any excess coating to get ripped off by the glass. Furthermore the resistivity of the fiber was found to be smaller than 0.33 Ω/cm. This is as good as the gold wires and more than sufficient to fit our needs.

6 Conclusion

To summarize, we were able to show that it was possible to integrate an optical fiber into an ion trap. The manufacturing of a UHV-feedthrough was found to be relatively straightforward, provided one has access to the suitable equipment. The insertion of the fiber inside the body of the trap was found to be challenging due to irregularities in the sizes of the glass cane used to build the trap. We found that it was possible to circumvent this by coating a partially etched fiber with electrically conducting epoxy. The so produced fiber was found to fit inside the PCF-cane, and its electrical resistivity was found to be under 0.33 Ω/cm.

References

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