Liquid-Core ARROW Platform for Organic Particle Detection

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Abstract—The Liquid-Core ARROW platform, which can be used for single bioparticle detection, is outlined. The platform has been used successfully for detecting individual H3N2 viruses. These results clearly illustrate the ARROW platform’s capability to function as the go-to platform for a mission to Mars whose goal is to detect organic polymers in the soil. A presence of organic polymers would be a strong sign of past life on the planet. The ARROW is ideal for such a mission not only because of its capabilities in detection, but also because it is lightweight, cheap to produce, and requires only low power to operate.

I. Introduction

In this article we introduce a testing platform, called a Liquid-Core ARROW, which would be capable of detecting linear ionic polymers or monomers and describes the fabrication process. We discuss the reasons why the Liquid-Core ARROW platform is ideal for being used in a mission to the planet Mars in order to assist in the search for life on the planet. Some of these reasons include that the platform can be integrated into a small, lightweight handheld device; the ease and low cost of fabrication and production of the platform; the sensitivity of the platform; and the speed of test results possible from the platform.

We present some initial results and successful detection of individual H3N2 viruses with the Liquid-Core ARROW that demonstrate the platform’s advantages [6]. The results also show how some minor design changes could improve the platform’s sensitivity. We outline the main ideas behind that future work. This is included at the end of the results section.

II. Background

In our experience here on Earth we have discovered that living organisms are made up of many different organic polymers [1]. We can therefore extrapolate that it is highly likely that if there is life on another planet that it will consist of similar organic polymers or particles. If we discover evidence of organic polymers in the soil of Mars that would be incredibly strong evidence that life on Mars did exist [1].

Typical platforms used today to detect and identify organic polymers here on Earth often require the use of large optical setups, including a long list of expensive and very fragile devices that are used to help detect the particles. For obvious reasons, traveling to Mars is an extremely difficult and expensive task and any extra cargo or weight included become very cumbersome. This creates a need for a platform that is capable of detecting very small organic polymers or particles. The Liquid-Core ARROW platform presented in this article is made using standard Microfabrication techniques and procedures [1], making it a very small platform for particle detection. The platform is actually a lab-on-a-chip, self-containing almost all of the parts necessary for organic particle detection; only a limited set of materials would need to be combined with the platform in order for it to accomplish its task on Mars. This makes the Liquid-Core ARROW platform the ideal device to use in order to attempt to detect
any residual life that may be hiding in the soil on Mars.

III. Liquid-Core ARROW Platform

In this section we describe the ARROW platform and the principles behind how it works. Figure 1a shows the basic layout for the Liquid-Core ARROW platform discussed.

![Figure 1. (a) The Liquid-Core ARROW platform. (b) A cross-section of the hollow-core ARROW waveguide. [5]](image)

The most important part of the platform is what is called the hollow-core ARROW waveguide. This is the channel in figure 1 that is in an s-like shape. A cross-sectional view of the ARROW waveguide is shown in figure 1b. This component is hollow in the center which allows for a liquid sample to be pumped through it. Normally, a hollow channel cannot function as a waveguide because of the low index of refraction of air or water.

Typically waveguides use the phenomenon called Total Internal Reflection (TIR) in order to trap the light in a channel. Total internal reflection can be demonstrated very simply by taking a look at Snell’s law shown in the following equation where $n_1$ is the index of refraction of the core material and $n_2$ is the index of the cladding or surrounding material. $\theta_1$ is the angle at which the light is incident on the boundary and $\theta_2$ in the angle of refraction of the light that passes through the boundary.

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

If $n_1 > n_2$ and $\theta_1$ reaches a high enough value, then $\theta_2$ becomes imaginary and all of the light remains trapped in the core of the waveguide. This principle generally cannot be used if the core material is either air or water whose indices are around 1 and 1.3 respectively. This is because there are no strong structural materials that have indices of refraction lower than these values.

This leads to the reason why the ARROW waveguide is unique. By using the principles of multiple beam interference we can surround an air or liquid core with a dielectric stack or Bragg mirror and rely on its reflective properties in order to force the light to stay within the hollow core. This allows us to have a closed hollow channel that is still capable of guiding light down the core [8]. The exact optical properties and interference phenomenon used in the ARROW waveguide are not within the scope of this article but figure 2 is included to show the basic idea of how the ARROW waveguide is set up [8].

![Figure 2. ARROW Waveguide. [4]](image)

In order to couple light into and out of the ARROW waveguide we make use of standard SiO$_2$ ridge waveguides. These
waveguides function by making use of the principle of TIR which was discussed earlier.

There is also a ridge waveguide that runs perpendicular to the hollow-core ARROW waveguide. This waveguide is typically excited by a HeNe laser, with a wavelength of 633nm. The red light is guided down the ridge waveguide until it intersects with the ARROW waveguide. A sample runs through the ARROW waveguide that has been mixed with specific phosphorescent biomarkers. If there are any particles present that the biomarkers can bind themselves to, then the laser will excite the biomarkers and cause them to light up. Their signal will then travel down the ARROW waveguide, couple into the ridge waveguide and off the chip. We can then detect the signal and therefore determine if any specific particle is present.

IV. Fabrication

Here we outline the general fabrication process used to create the hollow-core ARROW waveguide.

First the bottom Bragg mirror layers must be deposited with precise thickness. Usually a Bragg mirror consists of two different alternating materials stacked in several layers. We use Silicon Dioxide (SiO$_2$) and Tantalum Oxide (Ta$_2$O$_5$) in our devices [7]. Our Bragg mirrors use six total layers, alternating back and forth between SiO$_2$ and Ta$_2$O$_5$ [7]. The exact thickness needed for the layers is a topic that is beyond the scope of this paper. They are determined by maximizing the reflectivity of the Bragg mirror being fabricated.

Once the bottom layers have been deposited we can then pattern a sacrificial material that will be used to form the hollow-core of the channel. This material is patterned using typical photolithography methods.

The next step is to grow the top ARROW layers over the sacrificial material. Once again six layers are ideally used in order to create the top and side wall Bragg mirrors and we use same two materials for the top layers as we did for the bottom layers (SiO$_2$ and Ta$_2$O$_5$).

Once the top layers are deposited, the sacrificial material can be exposed using a selective etch. Then a wet etch can be performed in order to etch away the sacrificial material which leaves a hollow-core channel surrounded on all four sides by the six-layer Bragg mirror.

The last step of fabrication is to attach reservoirs to the ends of the hollow-core in order to allow for the closed system in which we can run some sample through the hollow-core to perform particle detection. Figure 3 shows the main steps described above and figure 4 shows what the Liquid-Core ARROW platform looks like upon completion. Figure 4 also gives an idea of the relative size of each individual chip fabricated using these method. They are approximately 1cm x 1cm.

![Figure 3. The major process steps in the hollow-core ARROW waveguide fabrication. [4]](image-url)
V. Results

This section describes the results obtained testing of the ARROW platform. In order to test the detecting capability of the platform the H3N2 virus was introduced into the platform as a sample and detected using the Liquid-Core ARROW platform [6]. Figure 5 shows the platform with the virus sample being introduced through one of the reservoirs.

The chip was then aligned to the HeNe laser and the necessary detectors. Figure 6 is a photograph of this setup.

In order to get a light signal from the viruses they must be tagged with a fluorescent biomarker. If the biomarker matches an organic particle then the biomarker will bind with the particle. If the biomarker binds to a target then it will fluoresce when hit with the laser light. If there is no binding then the biomarker will not fluoresce. Figure 7 is an illustration of this principle and shows that the biomarker only lights up if it successfully binds to a target [6]. This means that if we get any light signal to our detector that we know it is correlated with one particle of the organic molecule that was being targeted by our biomarker.

After mixing the H3N2 virus with the appropriate biomarker the sample was run through the platform while the HeNe laser
excited the intersection point at the hollow-core ARROW waveguide. Figure 8 shows the results from the experiment performed.

There are 565 easily distinguishable spikes shown in the figure. Each one of these spikes corresponds to one tagged H3N2 virus passing through the laser intersection point. The platform was used successfully for single bioparticle detection of the H3N2 virus.

These results clearly demonstrate that there still exists a need for some improvements in the Liquid-Core ARROW platform. First, is that the noise level can be reduced. Figure 8 shows that some of the 565 peaks detected only rose slightly above the noise levels of our detector. A strategy that can be used to lower the noise level would be to create a platform with multiple intersection points with the hollow-core waveguide. As a particle flows down the channel it will then give off multiple signal peaks. These peaks will be time-related and with some signal processing the extra time variable can be used to help lower the noise level by orders of magnitude!

The second improvement has to do with the reason why the peaks in figure 8 are not all the same height. All of the particles do not travel down the center of the hollow-core channel where the laser intensity is greatest. This means that if a particle is traveling far from the center and closer to one of the walls then the signal it gives off will be lower than that of a particle in the center. If a particle is far enough from the center of the channel then it may not give off any signal at all. In order to eliminate this problem, particles can be focused toward the center of the channel using hydrodynamic focusing. Figure 9 shows an idea of how this focusing can be added into the ARROW platform.

VI. Conclusion

We conclude that Liquid-Core ARROW platform being developed at Brigham Young University and the University of California Santa Cruz is the ideal platform for being included in a mission to Mars for life detection. The ARROW platform is extremely small compared to the other techniques that would be capable of life detection; can be produced cheaply; has an incredibly high sensitivity; and gives fast test results with low power.

VII. Acknowledgements

The author would like to thank the team at UCSC who have done much of the work needed in order to test and characterize the ARROW platform that was discussed in this paper. The author would also like to thank Dr. Aaron Hawkins, Dr. Holger Schmidt, Lynnel Z., Matthieu G.C., Matt Stott, and Michael Olson who helped in the development and fabrication of the ARROW devices made at BYU.
VIII. References