Wireless Communication in a Magnetron Sputter Deposition System

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Contents

Introduction

The following work is the result of a collaboration at the University of Twente between the XUV Optics focus group on one side, and Scintilla, the study association for Electrical Engineering students, on the other side. This project deals with the set-up and testing of a wireless connection inside the Microsystems MS1600 coater, one of the machines XUV uses to produce high precision optics. As shown in Figure 1 this large, hexagonal vacuum chamber contains a rotating arm with at its end a rotating substrate holder. The coater is able to deposit thin optical layers onto the substrate by means of magnetron sputter deposition.

As a single production process may take half a day, it would be useful if the product in development can be checked during production such that perhaps modifications to the coating process can be made in time. These measurements can be done by placing a measurement system inside the substrate holder. However, the measurements have to be transferred outside of the coater which is problematic due to the moving arm. During this project, a communication system has been developed which is placed inside a specially designed, vacuum sealed substrate holder. This document briefly describes the design and set-up of this subsystem, and includes guidelines on how to configure and use it during a coating process.

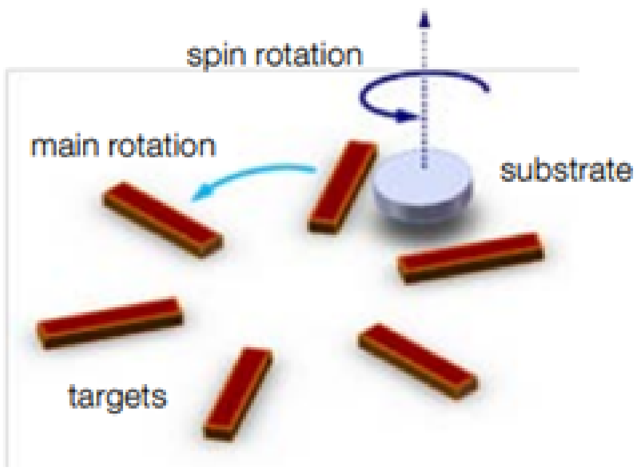

Figure 1: The arm with substrate holder rotating inside the MS1600 coater.

Analysis

Previous work

During earlier tests, it has already been verified that it is possible to establish a wireless network inside the coater despite the (possibly) challenging environment. For this test, two antennae were mounted inside the coater, about 1.5 meters apart. A Wi-Fi network was introduced in the coater at one side by connecting a router to the antenna, and a laptop was connected to the network via the other antenna and a USB Wi-Fi adaptor. The amount of magnetrons in operation was varied throughout the experiments. We concluded that turning on the sputtering magnetrons (both in DC and RF mode) and substrate arm movement had little to no influence on the stability of the Wi-Fi connection. Read-speeds in the range of 1-8 MB/s were obtained, Write-speeds were in the range of 0.5-3 MB/s. The USB-adaptor and BNC cables seemed to be the limiting factor in this situation.

Design requirements

Now, a setup has to be designed which is to be built into the substrate holder. This system should be able to log measurements during a coating process and make them available to the user outside of the coater via the Wi-Fi network. A computer and matching power module will be bought for this, which together are able live up to the following requirements:

- An operating temperature of at least $50°C$, as the substrate holder can only lose heat by means of radiation due to the vacuum.
- A power budget of 10 W.
- The system should be able to work continuously for 10 hours on the supplied battery in order to cover a full coating process.
- The computer should be capable of handling camera data and compressing the images such that there is less data that has to be sent over the wireless data link.
- The computer should be able to process and log images at a rate of 10 frames per second.
- The computer will be placed inside a special container with an atmospheric pressure. It therefore only has to be able to work under normal atmospheric pressure.
- The computer and power module have to fit inside the substrate holder.

Design

Hardware overview

The designed communication system can be split up into the two ends of the Wi-Fi channel, being the side of the substrate holder and the side of the user. For a simplified overview, see Figure 2. For a complete list of all hardware components used, refer to Appendix C.

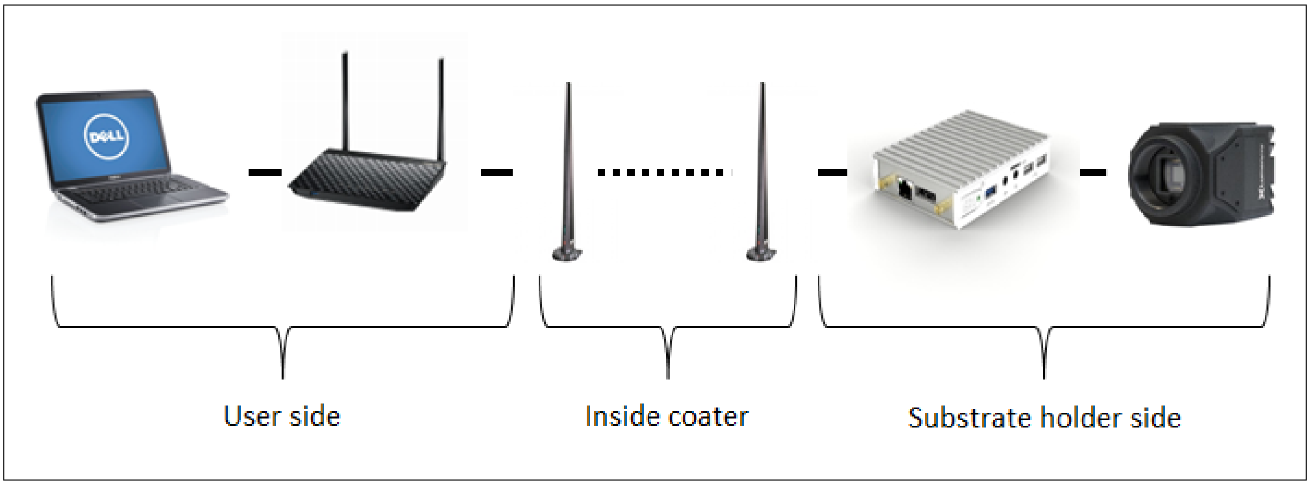

Figure 2: Basic overview of the communication system from camera to user.

The substrate holder side contains a tiny (fitlet-i) computer, two rechargeable battery packs, a measurement system and a black/white camera which acts as the final readout device of the measurement system. The images captured by the camera are saved in computer memory. The computer is connected to an antenna at the outer side of the substrate holder via an SMA-cable and a throughput. Figure 3 shows a photograph of the substrate holder's internals.

The 5GHz Wi-Fi network is established inside the coater by using a router. This router, located just outside the coater, is connected to an antenna inside the coater via a BNC-cable and a throughput. Any user can then connect to the router network, and therewith to the substrate holder side such that the camera images can be retrieved and analysed.

Software outline

To capture the data and send it to an external location, a software solution has been designed. It is partly based on the Software Development Kit (SDK) of Lumenera, the manufacturer of the camera used, and is built up of a binary and some scripts which use third-party tools to process the data. Each part will be treated in the following part.

Lusnaps

This is a binary based on **'main.c'** in the src folder, and it is the part that communicates with the camera and takes snapshots in the 'bmp' format. The number of images per minute and the exposure time can be configured using a file called **'params.txt'** in the folder from which the binary is called. It should have the following contents (otherwise the program will not function!):

```
numOfPics:  <number of pictures per minute, integer>
exposure:  <exposure time in ms, float>
```

The program is loosely based on the snapshots example program in the Lumenera SDK. It first reads the parameters

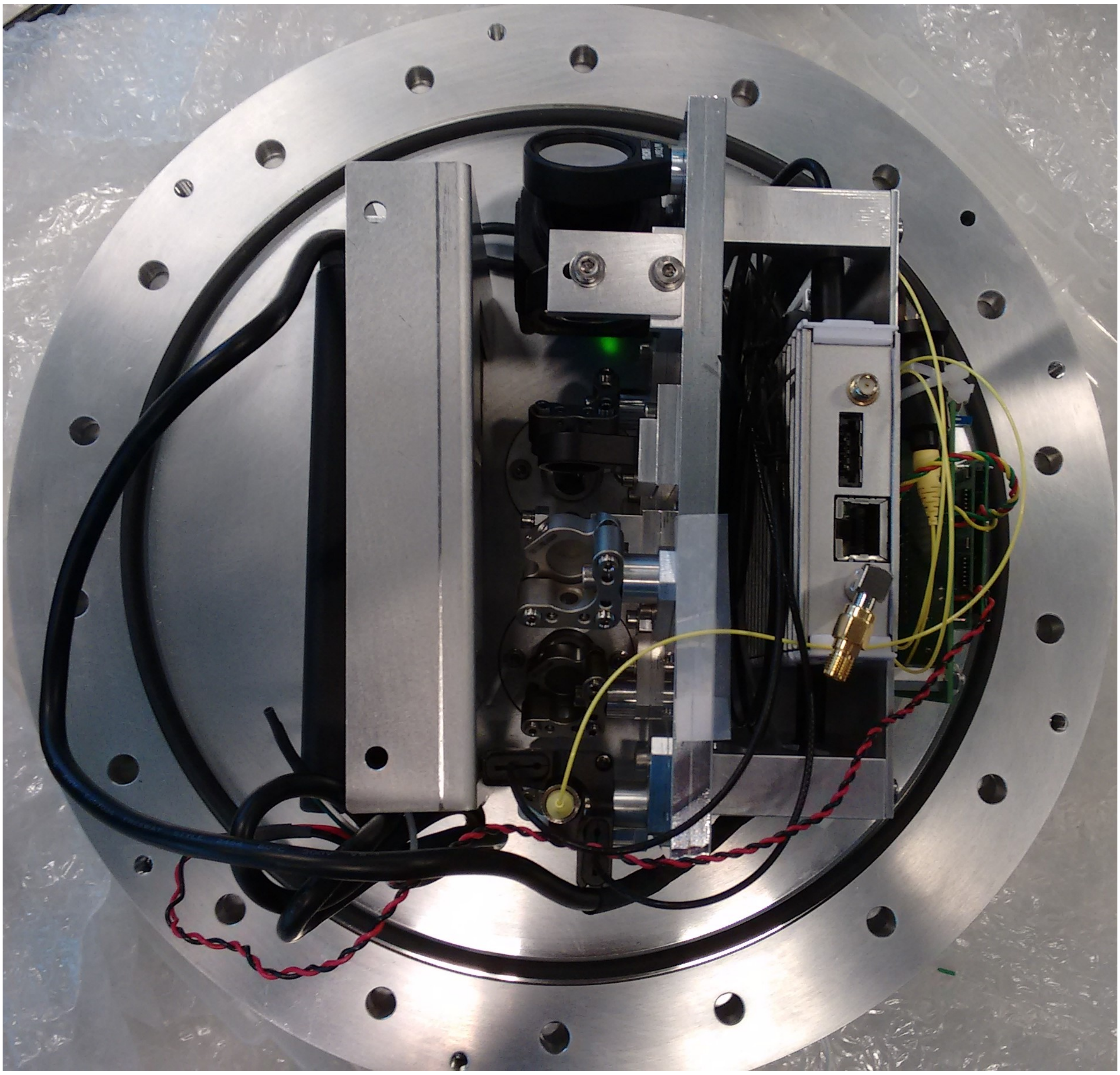

Figure 3: Internals of the substrate holder as of June 29, 2016. From left to right: Battery packs, measurement setup including camera, fitlet-i computer, measurement electronics.

from the file, then initializes the camera and starts taking pictures which it saves in bmp format with the timestamp (and an alternating 'a' or 'b') as filename. It reads the number of pictures per minute each time a picture is taken, so that can be configured on-the-fly. To change the exposure time, a restart of this binary is needed.

startConversion.sh

This script starts the conversion scripts to convert the bitmap pictures to jpeg (for space and bandwidth reasons). It starts two scripts (**aConvert.sh** and **bConvert.sh**) which in turn perform the actual conversion.

aConvert.sh and bConvert.sh

These scripts convert the bmp images from the camera to jpeg. First they copy the bmp files to the folder **processed**, and then start the program **mogrify**, part of the **imagemagick** toolkit which converts the bmp files to jpeg file by file.

sendFiles.sh

This script takes the converted jpg files and sends them to a location which is to be reached using smb. It uses **smbclient** for that purpose. It first moves all the jpg files from the **processed** folder to the **sending** folder. After sending, the files are moved to the **sent** folder, in which they will stay.

makeImage.sh

This script is basically a wrapper for the other scripts, as it only starts all of them and then doesn't perform any action. It contains the local destination folder in which the file **params.txt** should be present.

kill.sh

This script is a cleanup script to be used when the capture needs to be stopped. It basically stops all the components of the software solution.

startInterface.sh

This script can be used to start the temperature sensing and piëzo control interface, part of the measurement system inside the substrate holder. It first works around a bug in xauthority on Linux and then starts the interface. If it is to be used via SSH, X-forwarding needs to be on and an X-server needs to be installed on the client.

Logging

All the scripts log their output to provide helpful information when debugging. These logs can be partly found on the Fitlet in the `/var/log/xuv` folder, and partly on the device on which the conversion is started. On that device, the logs will be placed in the `D:\ms1600_images\logfiles` folder. The logs are identified by the script that started them and by the date and time on which the conversion started.

Results

The designed subsystem has been built and testing during coating processes on August 12, 2016. The following conclusions can be drawn on basis of these tests:

- A Wi-Fi connection was established inside the coater with a speed of at least 4 MB/s write and 1 MB/s read. For the full results, see Table 1. The low speed in the loadlock can be explained by the long BNC-extension cable used to reach the antenna feedtrough of the loadlock, as that was not certified for 5 GHz.
- The computer is able to compress and log camera images at a rate of 5 frames per second with an exposure time of 100ms, though this currently results in excessive heating of the computer.
- The system is able to operate continuously at a rate of 1 frame per second, reaching a core temperature of approximately 100 degrees Celsius. The expectation is that with fully charged battery packs, a coating process of up to 5 hours can be covered.

Table 1: Full results Wi-Fi connection

#	**Coater circumstances**	**Location substrate holder**	**Write speed**	**Read speed**
1	Not operational	Loadlock, not yet pumped down	1.9 MB/s	1 MB/s
2	Not operational	Coater, fully pumped down	4 MB/s	3.6 MB/s
3	DC-magnetron has just been shut down	Coater, fully pumped down	7 MB/s	4.5 MB/s
4	Arm rotating	Coater, fully pumped down	4 MB/s	1.5 MB/s
5	Arm rotating, some RF-magnetrons enabled	Coater, fully pumped down	4.5 MB/s	1.5 MB/s
6	Arm rotating, all RF-magnetrons enabled	Coater, fully pumped down	4.5 MB/s	1.5 MB/s

Future Improvements

The desired communication goals have been reached, but as this subsystem is only a prototype some improvements can still be made:

- Currently, the antennae used in this system are not adapted to their application. Very basic wire antennae of arbitrary length have been used since it is difficult to obtain antennae that are suited for the high vacuum environment of the coater. Antennae that are designed for 5GHz Wi-Fi communication are expected to result in higher data transfer rates.
- The BNC cable and transmission which connect the router to the antenna inside the coater may not be well suited for high frequency communication. An SMA cable and throughput, such as the one used at the substrate holder side, may result in higher data transfer rates.
- The software does not contain much error correction code, so if an error occurs or if the computer cannot handle the data rate, the acquisition will either stop or run into problems. Also, some monitoring should be added to make it more robust. This also entails sending an e-mail to an admin when an error has occurred, to eliminate the need for an admin to be present at every coating to monitor the system.
- The computer can easily heat up to 100 degrees Celsius when processing images at the highest rate. In order to avoid overheating, we propose three options:

  Currently, the Fitlet is mounted into the substrate holder by its plastic cover.The computer's cover could be stripped off such that it can be mounted into the substrate holder by its inner metal shield. The expectation is that would allow better direct heat flow from the computer to the substrate holder's inner construction. Alternatively, a heat sink designed for the fitlet-i is available online. According to reviews this is able to reduce core temperature by 10 to 30 degrees Celsius. Another option would be to add a slowly rotating fan to the design inside the substrate holder to enhance air flow in the holder.
- The setup contains two accupacks. Currently the most power hungry components, the camera and the computer, are powered from the same accu, since the camera is powered via the usb 3.0 port of the fitlet computer. This means that the operation time can be improved by either powering the camera from the other accupack by adding a 12 to 5 volt converter and using an usb cable that allows an external power supply or adding a circuit that combines both accupacks into one.
- To be able to measure the energy that is still in accu's during a coating, connecting the accu's via a resistor divider to the termocouple readout circuit might be investigated.

Appendix

A. Guidelines: Logging and receiving during a coating process

Standard usage

The section contains the protocols that are likely to be used the most.

Preparing for measurements

Before being able to do measurements you have to prepare the setup with the following procedure:

1. Make sure that the battery pack connected to the computer is fully charged and that the measurements electronics battery pack has at least two bars left. This should enable the computer to log measurement images for at least 5 hours.
2. Check that the antenna on the outside of the substrate holder is still in place and is not touching anything but the core of the connector.
3. Connect the battery packs to the Fitlet and measurement electronics. The Fitlet should automatically connect to the Wi-Fi network inside the coater, also when a disconnection has occurred.
4. Check that the camera's USB cable is connected to the computer's USB 3.0 port. Connecting to other USB ports will result in errors.
5. Check that the usb cable of the piezo and temperature sensor measurement device is plugged in.
6. Make sure that one of the antenna connections on the computer is connected to the throughput on the substrate holder.
7. Make sure the router's antennae are connected to the coater with the supplied cables and that the router's power supply is plugged in. Also check that the computer to which the measurement results should be sent by the Fitlet is connected to the router.
8. The ip-address of the computer that is used to connect to the substrate holder should be set to 192.168.1.3. This can be done by assigning the mac address of your network card to this ip-address in the router. To access the router follow the procedure "connecting to the router".

Start logging

To start the logging process you need to perform the following actions on a Windows device on which the tools in MS1600_capture.zip have been extracted:

1. Make sure the computer inside the substrate holder can make a connection with the router. This can for example be achieved by following the procedure "Preparing for measurements" and placing the substrate holder inside the coater.
2. Connect your device with an Ethernet cable to one of the yellow ports on the router. You may also try to connect to the router's Wi-Fi network, but a good connection is only guaranteed when one of the antenna connections on the router is connected to a standard antenna. To connect via Wi-Fi you can use the following credentials:
   Wifi-name: ms_1600_5GHZ
   Password: magnetron
3. Make sure the following folders exist and are shared:
   D:\ms1600_images\
   D:\ms1600_images\logfiles

4. Go to the folder in which the tools have been extracted
5. Doubleclick on `startCapture.bat`, enter the password for the Fitlet's `xuv`-user twice (`magnetron2`). The capture will begin and the images will be sent to the preconfigured destination.

Note: this action can also be done on a Linux-device by opening an SSH-client connection to the Fitlet and executing the following command: `sudo /usr/local/scripts/makeimage.sh`.

Readout of the measurements

To read out the images taken by the camera in the substrate holder you have to follow the following procedure:

1. After following the procedure "Start logging", the images will be available on the preconfigured destination (e.g. D:\ms1600_images on the used laptop)

Stop logging

To stop the logging process you need to perform the following actions on a Windows device on which the tools in MS1600_capture.zip have been extracted:

1. Make sure the computer inside the substrate holder can make a connection with the router. This can for example be achieved by following the procedure "Preparing for measurements" and placing the substrate holder inside the coater.
2. Connect your device with an Ethernet cable to one of the yellow ports on the router. You may also try to connect to the router's Wi-Fi network, but a good connection is only guaranteed when one of the antenna connections on the router is connected to a standard antenna. To connect via Wi-Fi you can use the following credentials:
   Wifi-name: ms_1600_5GHZ
   Password: magnetron
3. Go to the folder in which the tools have been extracted
4. Doubleclick on `stopCapture.bat`, enter the password for the Fitlet's `xuv`-user twice (`magnetron2`). The capture will be stopped.

Note: this action can also be done on a Linux-device by opening an SSH-client connection to the Fitlet and executing the following command: `sudo /usr/local/scripts/kill.sh`.

Start the temperature and piëzo interface

In order to monitor the temperature and change the location of the laser bundle using the provided piëzo motors, an interface has been developed. Before this can be used an X-server, for instance Xming (https://sourceforge.net/projects/xming/) has to be installed and you need to perform the following actions on a Windows device on which the tools in MS1600_capture.zip have been extracted:

1. Make sure the computer inside the substrate holder can make a connection with the router. This can for example be achieved by following the procedure "Preparing for measurements" and placing the substrate holder inside the coater.
2. Connect your device with an Ethernet cable to one of the yellow ports on the router. You may also try to connect to the router's Wi-Fi network, but a good connection is only guaranteed when one of the antenna connections on the router is connected to a standard antenna. To connect via Wi-Fi you can use the following credentials:
   Wifi-name: ms_1600_5GHZ
   Password: magnetron
3. Start Xming via the windows start menu.
4. Go to the folder in which the tools have been extracted
5. Doubleclick on `startInterface.bat`, enter the password for the Fitlet's `xuv`-user twice (`magnetron2`). The interface will show after a few seconds.

Note: this action can also be done on a Linux-device by opening an SSH-client connection with X-forwarding enabled to the Fitlet and executing the following command: `sudo sudo /usr/local/scripts/startInterface.sh`.

Advanced usage

Reading out directly from the substrate holder

If an error happens in the connection of the Fitlet with the remote destination, the remote destination might not contain the latest measurement data. To access the latest data you may want to connect directly to the substrate holder. This can be done with following procedure.

1. Make sure the computer inside the substrate holder can make a connection with the router. This can for example be achieved by following the procedure "Preparing for measurements" and placing the substrate holder inside the coater.
2. Connect your computer with an Ethernet cable to one of the yellow ports on the router. You may also try to connect to the router's Wi-Fi network, but a good connection is only guaranteed when one of the antenna connections on the router is connected to a standard antenna. To connect via Wi-Fi you can use the following credentials:
   Wifi-name: ms_1600_5GHZ
   Password: magnetron
3. Access the Fitlet's logging folder by connecting in windows explorer to \\192.168.1.2\xuv. Be sure to have network detection and sharing enabled on your device for this network. If asked use the following credentials:
   Username: xuv
   Password: magnetron2

Changing the exposure time or measurement frequency

You may want to change the exposure time of the camera connected to the computer or the frequency at which the computer takes measurements.

1. Use the procedure "Reading out directly from the substrate holder" to access the shared folder of the computer.
2. Open the text file **params.txt** located in the shared folder.
3. Change the value of the exposure time (in ms) and the measurement frequency (in measurements per minute).
4. Save the text file. The computer will now immediately change the measurement frequency. To change the exposure time, a reboot will be necessary. To do so, issue the command `# shutdown -r now` while following the procedure "Making changes to the computer".

Making changes to the computer

If you want to make changes to the computer, you might want to access the computer via ssh. If you do not know what ssh is, you should not try to make changes to the computer. The following instructions should be performed on a Windows device on which the tools in MS1600_capture.zip have been extracted.

1. Make sure the computer inside the substrate holder can make a connection with the router. This can for example be achieved by following the procedure "Preparing for measurements" and placing the substrate holder inside the coater.
2. Connect your computer with an Ethernet cable to one of the yellow ports on the router. You may also try to connect to the router's Wi-Fi network, but a good connection is only guaranteed when one of the antenna connections on the router is connected to a standard antenna. To connect via Wi-Fi you can use the following credentials:
   Wifi-name: ms_1600_5GHZ
   Password: magnetron
3. Go to the folder in which the tools have been extracted
4. Doubleclick on `connectFitlet.bat` and enter the password for the Fitlet's `xuv`-user.

Note: this action can also be done on a Linux-device by opening an SSH-client connection to the Fitlet.

Connecting to the router

To change the operating frequency of the router or to check for example the external IP-address of the router, you visit the router's setup menu. This procedure will describe how to do so.

1. Connect your computer with an Ethernet cable to one of the yellow ports on the router. You may also try to connect to the router's Wi-Fi network, but a good connection is only guaranteed when one of the antenna connections on the router is connected to a standard antenna. To connect via Wi-Fi you can use the following credentials:
   Wifi-name: ms_1600_5GHZ
   Password: magnetron
2. Use your browser to visit the IP-address 192.168.1.1.
3. Log in with the following credentials:
   Username: admin
   Password: magnetron3

Changing the source code of the snapshot program

The program to get the images from the camera has been written in C. To change some properties of this program (e.g. make it more robust or flexible), it needs to be recompiled after changing the source. This can be done as follows:

1. Connect to the Fitlet, for example by using the "Making changes to the computer" procedure and make sure the changed code is put on the computer (e.g. by using the procedure "Reading out directly from the substrate holder" to access the shared folder).
2. Put the changed source code in the `examples/snapshots` subfolder of the Lumenera SDK (which should be on the Fitlet in the folder used in the installation process).
3. Run `make examples` in the Lumenera SDK folder. If all runs well, copy the `examples/snapshots/lusnaps` binary to the `/usr/sbin` folder:
   ```
   # cp examples/snapshots/lusnaps /usr/sbin
   ```
4. Don't forget to (re)start the capture to use the new code.

Troubleshooting

- Camera LED flashes green/orange: The camera is running low on power or requires a firmware update. Ensure that it is connected via the computer's USB 3.0 port.

B. How to install Debian on the Fitlet, configure Wi-Fi, install camera drivers and install acquisition software

Installation of Debian and configuration of file sharing

1. Install Debian using Unetbootin (https://unetbootin.github.io/), use DHCP and (if possible) a wired connection for this. If wanted, configure a dual-boot configuration (use the partitioner to resize the Windows partition and create Linux partitions, the bootloader will automatically add an option for Windows)

2. Install utilities:
   ```
   # apt install sudo lm-sensors
   ```

3. Add non-free and contrib repo in `/etc/apt/sources.list` (simply add `non-free contrib` after the `main` word in each repo-line) and
   ```
   # apt update
   ```

4. Install VGA firmware:
   ```
   # apt install firmware-linux-nonfree
   ```

5. Install Wi-Fi packages:
   ```
   # apt install firmware-iwlWi-Fi wireless-tools wpasupplicant
   ```

6. Load Wi-Fi kernel module:
   ```
   # modprobe -r iwlWi-Fi; modprobe iwlWi-Fi
   ```

7. Check `# iwconfig` for the wireless interface (mostly wlan0)

8. Enable the interface:
   ```
   # ip link set wlan0 up
   ```

9. Get the HEX-PSK for your network:
   ```
   # wpa_passphrase <ssid> <psk>
   ```

10. Add the config to `/etc/network/interfaces`:
    ```
    # Wi-Fi

    auto wlan0
    iface wlan0 inet dhcp
           wpa-ssid <ssid>
           wpa-psk <HEX-psk>
    ```

11. Bring the Wi-Fi interface up:
    ```
    # ifup wlan0
    ```

12. Install samba (file sharing):
    ```
    # apt install samba smbclient
    ```

13. Configure share in `/etc/samba/smb.conf`:
    ```
    # XUV share

    [xuv]
        browsable = yes
        read only = false
        path = /data/xuv # Make sure this path is read/writable for the share user, for vfat
    device add uid in /etc/fstab
        writable = yes
    ```

14. Restart samba:
    ```
    # systemctl restart smbd
    ```

Installation of camera drivers

1. Install the prerequisites:
   ```
   # apt install make kernel-headers-amd64 gcc
   ```

2. Transfer the SDK to the Fitlet (using for example smb) and extract:
   ```
   $ tar zxvf Lumenera_Linux_SDK_2.0.0_x86.tar.gz
   ```

3. Run make in the same directory to compile the drivers and install them:
   `$ make`

4. Test connection and drivers:
   `$ ./examples/helloCamera/helloCamera`

Installation of data acquisition software

1. Install the prerequisites:
   `# apt install imagemagick smbclient`

2. Extract the provided tar file:
   `$ tar zxvf data-acquisition.tar.gz`

3. Put the contents of the folder bin in /usr/sbin:
   `# cp bin/* /usr/sbin`

4. Change the location in the file makeImage.sh to the local destination folder for the pictures:
   `$ nano scripts/makeImage.sh`

5. Change the location in the file sendFiles.sh to the remote destination folder:
   `$ nano scripts/sendFiles.sh`

6. Customize the number of images and the exposure time:
   `$ nano config/params.txt`

7. Copy the params.txt to the local destination folder:
   `$ cp config/params.txt /local/destination/path`

8. Put the contents of the folder scripts in /usr/local/scripts (create this folder if it doesn't exist):
   `# cp scripts/* /usr/local/scripts`

Installation of the temperature sensing and piëzo software

1. Install the prerequisites:
   `# apt install python-numpy python-tk python-qt4 libusb-dev unzip`

2. Install Phidgets:

   a) Download source from http://www.phidgets.com/downloads/libraries/libphidget.tar.gz

   b) Extract:
      `$ tar zxvf libphidget.tar.gz`

   c) Install:
      ```
      $ cd libphidget-2.1.8.20151217/
      $ ./configure
      $ make
      # make install
      ```

   d) Download python libraries from http://www.phidgets.com/downloads/libraries/PhidgetsPython.zip

   e) Extract the archive `$ unzip PhidgetsPython.zip`

   f) Install python libraries: `$ cd PhidgetsPython`
      `# python setup.py install`

3. Install Xming on your local computer from https://sourceforge.net/projects/xming/

4. Connect to the fitlet using SSL with X-forwarding, then copy the .Xauthority file from your homedir to the root homedir:
   `# cp /home/user/.Xauthority /root/.Xauthority`

5. Start the temperature sensor script using the files provided: `# python newport-stress.py`

C. List of components

In this section the components that are used in the final communication system are summarised. We will first summarise the components on the substrate holder side. Then the components that have been used at the user side will be listed. In Table 2 shows whether each component is certified to be used with a frequency of 5 GHz. Furthermore in Table 3 all known type numbers of the components are summarised.

The components that are placed inside the substrate holder are:

1. A **fitlet-i** single board computer. This single board computer has a x86 compatible processor and a 2.4GHz and 5GHz dual band WLAN 802.11ac Wi-Fi card and two external female rp-SMA connectors.
2. A **90 degree angle rp-SMA-to-rp-SMA adaptor** is used in order to make the other connectors fit inside the substrate holder. This component is not rated to be used with 5GHz. One side of this connector is a plug and the other side is a jack.
3. An **rp-SMA-to-SMA adaptor** which is used to convert the rp-SMA connection into SMA. The rp-SMA side of this connector is a plug and the SMA side is a jack.
4. An **SMA-to-SMA cable** will be used to connect the jack SMA end of the rp-SMA to SMA adaptor to an SMA plug transmission.
5. An **SMA-to-SMA transmission**. This transmission forms a connection between the inside of the substrate holder at atmospheric pressure and the outside of the substrate holder which is in high vacuum.
6. A ***monopole antenna*** made out of a piece of wire is inserted into the core of the SMA transmission.
7. Two 11.25V and 8.85Ah **Li-ion rechargeable battery packs** plus cables are used to power all electronics inside of the substrate holder.

On the outside of the coater the following components have been used:

8. An **Asus RT-AC55U router** with two female rp-SMA connectors. The router follows the Wi-Fi-ac standard on 2.4GHz and 5 GHz.
9. An **rp-SMA to SMA adaptor** is used to convert the rp-SMA connection. The rp-SMA side of this connector is a plug male, the SMA side is a jack.
10. A 31 cm long **SMA-to-BNC cable** is used to connect the adaptor to the coax-to-SMA troughput on the coater.
11. A **BNC-to-SMA throughput**. No further information is available about this throughput.
12. A 123 cm long **SMA-to-BNC cable** is used to connect the router to the second SMA throughput on the other side of the coater.
13. A 123 cm long **SMA-to-SMA cable** cable is used to extend the 123cm long SMA-to-BNC cable.
14. A second **BNC-to-SMA throughput**. No further information is available about this throughput.
15. A **high-vacuum SMA-cable** of which an image can be found in Figure 4 is connected to both throughputs. No further information available.
16. A vacuum compatible ***monopole antenna*** made out of a piece of wire is connected to the outer side of the transmission.

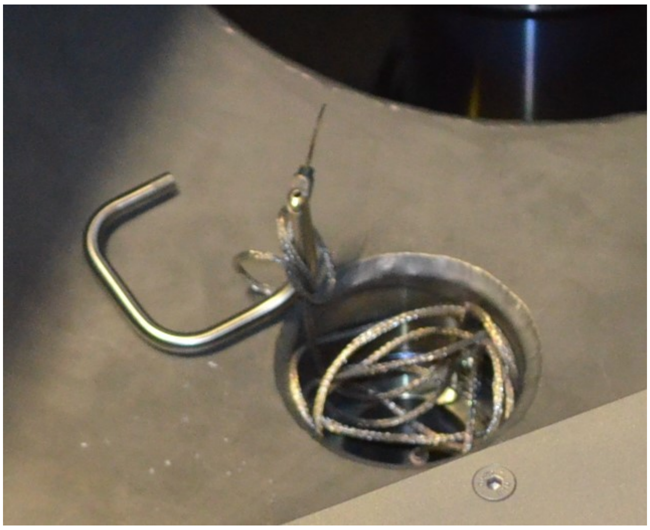

Figure 4: One of the antennae used on the Router side

Table 2: Certification of each component for a frequency of 5 Ghz

#	Component Name	5 Ghz Certification
1	Fitlet-i	Yes
2	90° rp-SMA-to-rp-SMA adapter	No
3	rp-SMA-to-SMA adapter	Yes
4	SMA-to-SMA cable	Yes
5	SMA-to-SMA transmission	Yes
6	Monopole Antenna	No
7	Accu	n.a.
8	Router	Yes
9	Rp-SMA-to-SMA adapter	Yes
10	31 cm SMA-to-BNC cable	Yes
11	DN40CF BNC-to-SMA troughput	Unknown
12	123 cm SMA-to-BNC cable	Yes
13	123 cm SMA-to-BNC cable	Yes
14	DN63CF BNC-to-SMA troughput	Unknown
15	High-vacuum SMA-cable	Unknown
16	Monopole antenna	Unknown

Table 3: Type numbers of each component

#	Component Name	Manufacturer	Manufacturer Type Number	Supplier	Supplier Type Number
1	Fitlet-i	Compulab	FITLET-GI-C67-D8-M120S-WACB-X7		
2	90° rp-sma-to-rp-sma adapter	Linx Technologies Inc.	CONREVSMA010	Digikey	CONREVSMA010-ND
3	rp-SMA-to-SMA adapter	Amphenol-RF Division	132171RP-10	Digikey	ACX1248-ND
4	SMA-to-SMA cable	Cinch Connectivity	415-0029-018	Digikey	J10232-ND
5	SMA-to-SMA transmission	MPF Products Inc.	A2127-2-QF		
7	Li-ion battery pack	RRC Power Solutions	RRC2020	Texim Europe	RRC-2020-RRC
8	Router	Asus	RT-AC55U	Coolblue	RT-AC55U
9	rp-SMA-to-SMA adapter	Amphenol-RF Division	132171RP-10	Digikey	ACX1248-ND
10	31 cm SMA-to-BNC cable	Cinch Connectivity	415-0028-012	Digikey	J3612-ND
11	DN40CF throughput	Vacom	SPE-10048325-520		
12	123 cm SMA-to-BNC cable	Cinch Connectivity	415-0031-048	Digikey	J10116-ND
13	123 cm SMA-to-BNC cable	Cinch Connectivity	415-0031-048	Digikey	J10116-ND
14	DN63CF throughput	Vacom	CF63-BNC-1-GS-DE-CE-SS		