# Light pipe of Aixtron 200/4RF-S MOVPE reactor

## Epitaxy

Epitaxy is the ordered crystalline growth on a substrate. The term *epitaxy* comes from the Greek language: *epi* = "above" and *taxis* = "in ordered manner". Epitaxial films may be grown from gaseous or liquid precursors. Epitaxy is different from other thin-film deposition methods, such as thermal evaporation, which deposits polycrystalline or amorphous films, even on single-crystal substrates. If a crystalline film is grown on a substrate with the same chemical composition, the process is called *homoepitaxy*; if the chemical composition is different, then the process is called *heteroepitaxy*.

## Basic reactor structure

This teaching module describes the basic design of the Aixtron 200/4RF-S MOVPE reactor system. Generally, the design of MOVPE reactors is divided into two types of designs with different gas-flow geometry. One type of design is the *vertical type reactor* and the other is the *horizontal type reactor*. In the vertical type reactor, the carrier gas and the precursor gases flow in the vertical direction. In the horizontal type reactor, the gas flow is in the horizontal direction. Our Aixtron 200/4RF-S MOVPE reactor has a horizontal type reactor design. ***Figure*** 1 shows the schematic diagram of the Aixtron MOVPE reactor.

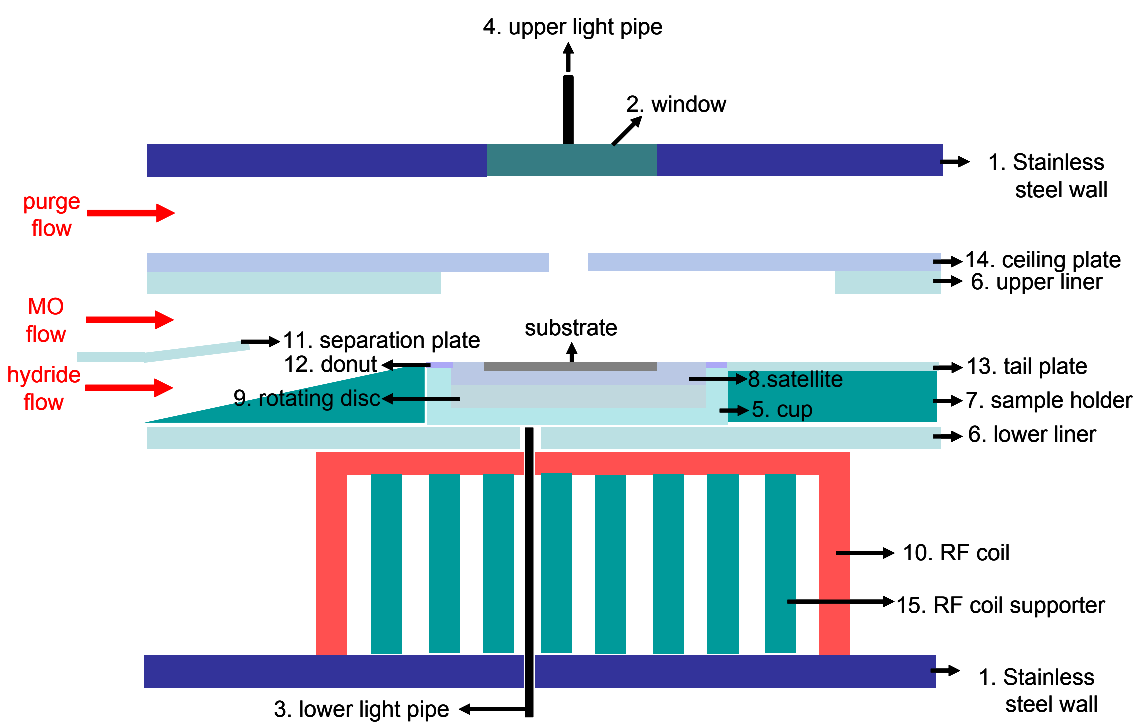


Figure 1: Schematic diagram of 200/4RF-S MOVPE reactor

The wall of the reactor chamber is composed of stainless steel (part #1). There are three glass windows (part #2, two other ones are not shown here), inlets for MO sources and hydride gases, inlets of purge gas, and the lower light pipe (part #3) which penetrates through the stainless steel wall. Two of the three glass windows are used for the view-ports and the third one is for the upper light pipe (part #4). The upper light pipe is used to measure the reflectance and surface temperature. The lower light pipe is used to measure the temperature of the cup (part #5). The cup is made of quartz.

The epitaxial growth process takes place within the liner tube (part #6) wherein the sample holder (part #7) with the corresponding satellite is located in a gas flow. The upper and lower liner wall, shown separately in ***Figure*** 1 has the shape of a tube. The satellite (part #8) is a SiC coated graphite disc. The substrate, for example sapphire, is located on the satellite. Beneath it, there is a SiC coated graphite disc, called the rotation disc (part #9). The flow of gas through openings in the rotation disc makes the satellite rotate. The rotation disc is heated by the radio-frequency (RF) wave from the RF coil (part #10) and the heat is transferred to the rotating satellite, predominantly by thermal radiation.

As shown in the ***Figure*** 1, there is a gas-separation plate (part #11) at the reactor entrance point. The function of the gas-separation plate is to keep MO and hydride precursor gases separated so that they will meet only shortly before the substrate. This is done to avoid chemical pre-reactions that results in unwanted adducts and low growth efficiency (A chemical **adduct** is a product of a direct addition of two or more distinct molecules [1]. For example, TMAl-$NH_3$ is an adduct product of TMAl and $NH_3$). In our MOVPE system, the hydride gas ($NH_3$) flows below the separation plate so that the ammonia ($NH_3$) is closer to the hot substrate. This is done because ammonia is a compared that is harder to crack than the metal organic precursors.

Donut (part #12), tail plate (part #13), and ceiling plate (part #14) are subject to strong deposition by parasitic reaction products. For this reason, these parts can be exchanged very easily. Also, the flow of purge gases at the three glass windows avoids any deposition on these windows.

## Lower light pipe

The lower light pipe is used to measure the reactor temperatures by optical pyrometery. We start by defining the relevant temperatures. There are six important temperatures occurring in our reactor system:

- ***Set reactor temperature***: This is the temperature set in the recipe. The RF voltage is regulated based on the set reactor temperature.
- ***Measured reactor temperature***: This is the temperature measured by the lower light pipe as shown in ***Figure*** 1. The light pipe tip position is a little bit below the cup.
- ***Actual reactor temperature***: This is the true, actual, or real reactor temperature. However, we cannot know this temperature exactly, so, the surface temperatures are introduced.
- ***Measured surface temperature***: This is the temperature measured by the upper light pipe which is located on the top of the reactor as shown in ***Figure*** 1.
- ***Corrected surface temperature***: This is the surface temperature calculated from the measured surface temperature by using the equation

$$T_{\text{corrected}} = \frac{1}{\left(\frac{1}{T_{\text{surface}}}\right) - \frac{1}{4400} \times \log_{10}\left(\frac{1-0.3}{1-\frac{R}{100}}\right)} \qquad (1)$$

  where $T_{\text{corrected}}$ is the corrected surface temperature, $T_{\text{surface}}$ is the measured surface temperature and $R$ is the optical reflectance of the wafer surface. ***Figure*** 2 shows the relationship between the corrected surface temperature and the measured surface temperature with the reflectance being a free parameter.

- ***Actual surface temperature***: This is the real surface temperature. We think that this value is the same or very similar to the corrected surface temperature.

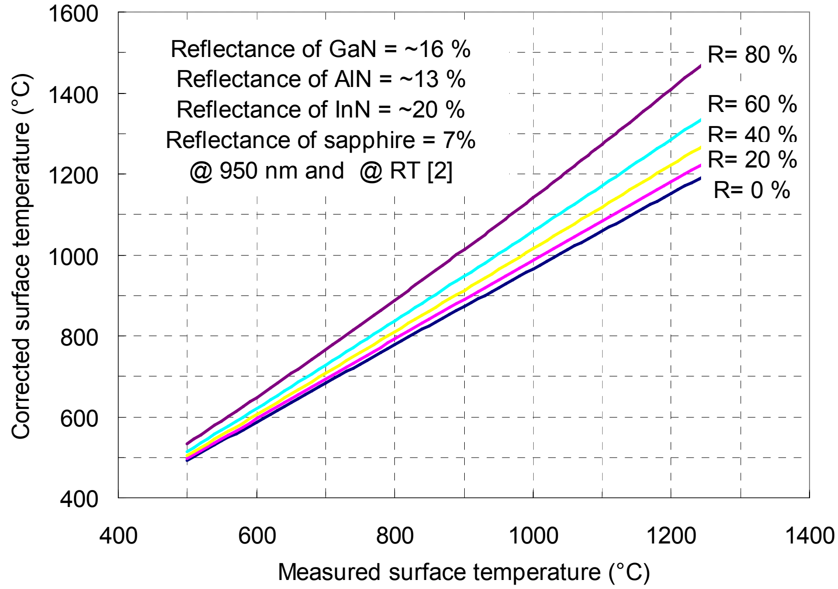


Figure 2: Relationship between the corrected surface temperature and the measured surface temperature with the reflectance of the substrate surface being a free parameter.

Next, the structure of the lower light pipe is described. ***Figure*** 3(a) and (b) shows the photograph and the schematic diagram of the lower light pipe, respectively. The light pipe is surrounded by a sapphire rod and the height of the lower light pipe is little bit lower than that of the sapphire rod in order to protect the light pipe. The sapphire rod including the light pipe is sealed using an O-ring to make a vacuum in the reactor. On the outside of the reactor, the light pipe is connected to an optical fiber that in turn is connected to a sensing unit.

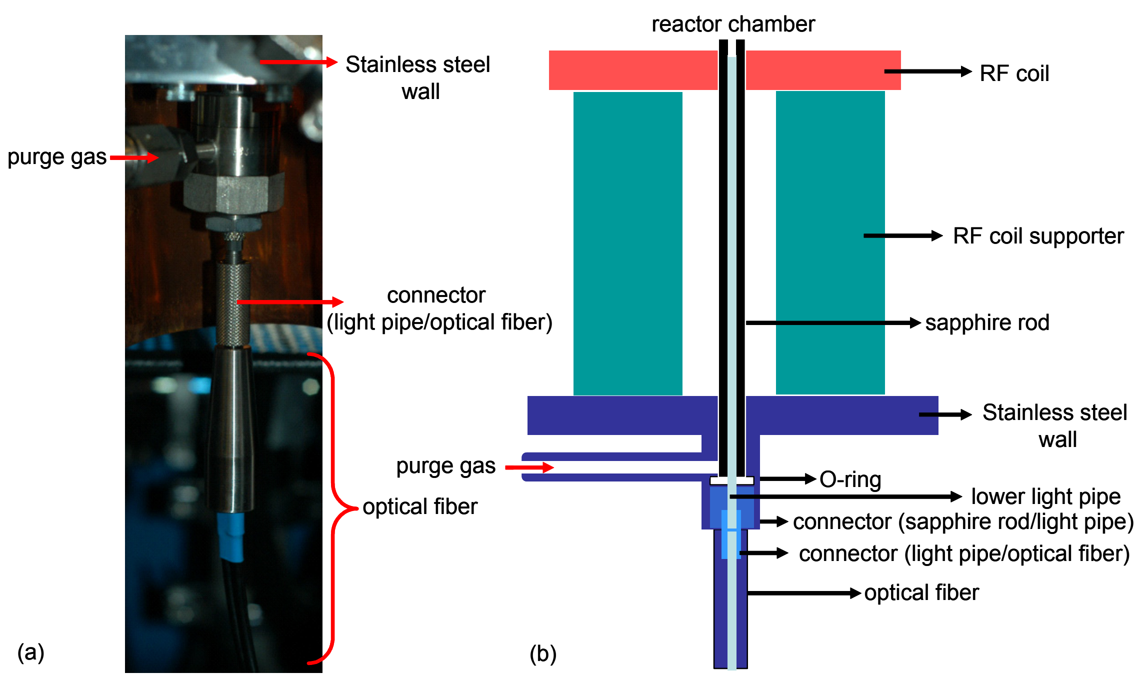


Figure 3: (A) Picture and (B) schematic diagram of the connection of the lower light pipe.

If there are unwanted deposits on the top of the light pipe, the measured reactor temperature could be lower than the one measured using a clean light pipe (without any deposits). So, if the light pipe is not clean, more RF power is needed to reach the same measured reactor temperature. At the same time, the actual surface temperature could show a higher temperature even at same set reactor temperature. In this case, we need to disconnect the light pipe and investigate whether the top of light pipe is deposited by some material. After the light pipe is taken out, it can be investigated using naked eyes and an optical microscope. If some kind of deposition layer, or contamination, or discoloring on the top of light pipe is observed, the light pipe can be cleaned by solvents such as IPA and methanol using a cotton swab. If the deposited layer is too thick, it can possibly be removed by heating the top of the light pipe using the flame of a torch or lighter.

## How does the light pipe work?

A black body is an object that absorbs all electromagnetic radiation that falls onto it. No radiation passes through it. None is reflected. It is this lack of both transmission and reflection to which the name refers. These properties make black bodies ideal sources of purely thermal radiation. That is, the amount and wavelength (color) of electromagnetic radiation they emit is directly related to their temperature. Black bodies below around 700 K (430 °C) produce very little radiation at visible wavelengths. Black bodies above this temperature, however, begin to produce radiation at visible wavelengths. As the temperature increases, the peak wavelength start at red, go through orange, yellow, and white before ending up at blue. As the temperature decreases, the peak of the black body radiation curve moves to lower intensities and longer wavelengths as shown in ***Figure*** 4. The relationship between the temperature $T$ of a black body, and wavelength $\lambda_{max}$, at which the intensity is maximum, is given by

$$T\lambda_{max} = 2.898... \times 10^{6} \text{ nm K} \tag{2}$$

This equation is called "Wien's displacement law". So, the wavelength of the glow from the cup or rotation disc thorough the lower light pipe is detected, and then it can be converted to the measured reactor temperature, after a calibration.

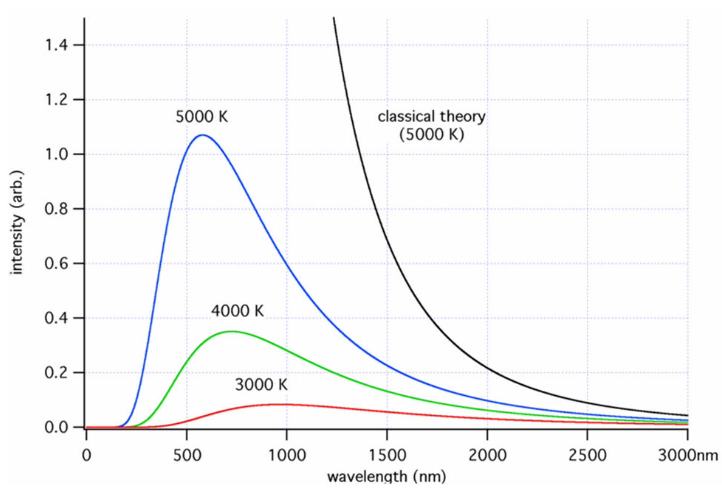


Figure 4: Relationship between the temperature $T$ of a black body, and wavelength $\lambda_{max}$ [3].

## Reference

[1] http://en.wikipedia.org/wiki/Adduct (accessed in 2007)
[2] http://www.ioffe.rssi.ru/SVA/NSM/Semicond (accessed in 2007)
[3] http://en.wikipedia.org/wiki/Black_body (accessed in 2007)