High Precision Optical Coating Deposition System: NBPF-2

Bin Fan and Daiyu Son
OPTORUN Co., Ltd.

By taking advantage of rapid development of fiber optical communication, the optical coating technology has been improved greatly in recent years. A long-term stable, high deposition rate, high-precision real-time optical thickness control coating system becomes key equipment to make the filters for fiber optical communication application. In this paper, NBPF-2, an ion assisted deposition (IAD) based electron beam (EB) evaporation system has been introduced. Some special filters, such as 50 GHz DWDM Filter, Add Drop Filter and Gain Flattening Filter, which consist of hundreds of layers had been deposited with NBPF-2. The critical requirement for coating deposition system has been discussed in this paper.


1. Introduction

Rapid development in scientific and technological applications, especially the fiber optical communication, needs a lot of optical filters with special requirements. These optical filters consist of tens or hundreds of layers. It is usually made of two or more materials in which the thickness of the individual layers should be well controlled. The filters should be stable against exposure to the atmosphere or high power density fields. It means these filters must have a good microstructure and the coating materials should be environmentally stable. Since these filters should be easily reproducible from run to run in mass production, a long-term stable, high deposition rate, high-precision real-time optical thickness control coating deposition system becomes key equipment to make these filters.

In order to meet these requirements, a lot of coating engineers and scientists have been involved in this field and a large array of techniques is used to deposit optical coatings in recent years. IAD (Ion Assisted Deposition), APS (Advanced Plasma System) and IBS (RF Ion Beam Sputtering) are three commonly used energetic processes to deposit environmentally stable filters. IAD and APS processes use electron beam to evaporate the coating materials and use an ion source or a plasma source to assist the deposition. The benefit of using IAD and APS processes is that they can provide a high deposition rate and good uniformity. The filters made by these processes have an amorphous microstructure and low stress. Comparing with IAD process, APS process usually introduces a high insertion loss. The disadvantage of using IAD or APS process is poor repeatability. The uniformity and optical constant have a little shift from run to run. IBS process uses ion beam to bombard the target material and deposit the coating material on the substrate. IBS process has a very steady deposition rate and optical constant of coating material can repeat from run to run. But its low deposition rate, poor uniformity and high stress restrain the application of this process. In some situations, IAD process is the best one comparing with APS and IBS process.

In section 2, an IAD based EB evaporation system, NBPF-2, was introduced. Some special filters and the critical requirement for produc-
2. IAD Based EB Evaporation System

In order to deposit the filters for fiber optical communication applications, an IAD-based system, NBPF2, was developed by OPTORUN Co., Ltd. This system includes two oil diffusion pumps and one Polycold which can evacuate the system from atmosphere to \(1.3 \times 10^{-3}\) Pa in 15 minutes. The automatic evaporation system is composed of two EB sources (JEOL) and one 16cm RF type ion source (Ion Tech). The crucible of high and low material can rotate from 5 min/circle to 2 hour/circle. Usually, Ta2O5 and SiO2 are used as high and low refractive index materials. About 3 kilogram Ta2O5 is pre-melted before evaporation. Substrate temperature and chamber temperature are controlled by two heating systems. The substrate is rotated by a magnetic sealed servo-motor. The maximum rotation speed of substrate is about 1000 rpm. The deposition rate and physical thickness of evaporation are controlled with a six-piece exchangeable quartz crystal monitor. The optical thickness is controlled with an optical monitor system (transmittance mode) by measuring the substrate directly. The schematic alignment of the system is shown in Figure 1.

3. The Critical Requirement for Producing DWDM Filters

Numerous optical filters are used in fiber optical communication systems. Some filters widely used are listed in Table 1.

NBPF2 is specially designed for producing optical filter used in fiber optical communication. It must meet some critical requirements for producing these filters.

Long Term Stability of Deposition System

The filters used in fiber optical communication systems, such as 50 GHz DWDM Filters, Optical Add Drop Filters, usually consists of hundreds of layers. The coating process time of these filters need tens of hours. The specifica-tion of these filters needs a non-stop process. It means there are enough materials to deposit hundreds of layers in one batch run. And during the evaporation, the hardware trouble, such as arcing of the EB Gun, shutdown of Ion source must be avoided. NBPF-2 uses JEOL’s EB gun as an evaporation source. Since JEOL’s EB gun and power supply are specially designed, it effectively avoids the arcing during the coating process.

Substrate Temperature

The pass bandwidth of 50 GHz DWDM filter is only 0.3 nm. A little temperature variation will cause the center wavelength of the filter to shift despite the fact that a special substrate was used. And finally, this shifting induces a disappearing of optical monitor signal. NBPF-2 uses two loops PID heater control system. It can control the substrate temperature in 1°C.

Thickness Monitor System

The thickness monitor system is the most important factor to make DWDM filters. There

<table>
<thead>
<tr>
<th>Band Pass Filters</th>
<th>Edge Filters</th>
<th>Special Filters</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 GHz</td>
<td>0.98 Pump Filter</td>
<td>Gain Flattening Filter</td>
</tr>
<tr>
<td>100 GHz</td>
<td>1.48 Pump Filter</td>
<td>Dispersion Compensation</td>
</tr>
<tr>
<td>200 GHz</td>
<td>LWPF B</td>
<td>cam Splitter</td>
</tr>
<tr>
<td>400 GHz</td>
<td>SWPF</td>
<td>ASE Filter</td>
</tr>
<tr>
<td>Blue/Red Splitter</td>
<td>C/L Splitter</td>
<td>AR Coating</td>
</tr>
<tr>
<td>C/L</td>
<td>Splitter</td>
<td>PBS</td>
</tr>
<tr>
<td>Coarse WDM</td>
<td></td>
<td>Interleaver</td>
</tr>
<tr>
<td>Add Drop Filter</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. The optical filters used in fiber optical communication systems.

![OII Specification](image)

**Fig. 2.** Some important parameter of optical monitor system.

![Transmittance vs. Wavelength](image)

**Fig. 3.** Uniformity of 3 cavity 100 GHz DWDM filter in 84 mm diameter.

Finally, the result was summarized in section 4.
are two kinds of thickness monitor systems. One is an optical thickness monitor system. The other is a quartz crystal monitor system. Wavelength resolution, signal-to-noise ratio and long-term stability are most important specification for the optical monitor system. Wavelength resolution determines the minimum bandwidth of the filter which the optical monitor system can monitor. Signal-to-noise ratio and long-term stability of the optical monitor system determines how accurately the system can operate. Figure 2 shows some important parameters of OPTORUN’s optical monitor system. NBPF-2 uses an optical monitor system to control the optical thickness of sensitive layer and uses a quartz crystal monitor to control the deposition rate and the thickness of insensitive layer. By this thickness monitor system, OPTORUN Co., Ltd produces the 50 GHz DWDM filter automatically.

**Uniformity**

Uniformity is very important parameter for mass production of optical filters. It has a complex relationship with the system structure, vacuum pressure, EB gun spot size, ion beam current distribution and so on. Good uniformity not only improves the yield of every run, but also improves the monitor accuracy of the optical monitor system. Figure 3 and Figure 4 illustrate the relationship of uniformity and optical monitor system.

By adjusting the ion source and EB spot size, OPTORUN improves the uniformity of 100 GHz DWDM filter from 6nm to 3nm in 95 mm diameter.

**Some Optical Filters Produced with NBPF-2**

Figure 5 shows the transmittance spectrum of five-cavity 184-layer 50 GHz DWDM filter produced with NBPF-2. The pass bandwidth at 0.5dB loss point is more than 0.27 nm and the isolation bandwidth at 25 dB loss point is less than 0.55 nm. The insertion loss of this filter is less than 0.5 db. The pass band ripple is less than 0.2 dB. This filter is automatically deposited by NBPF-2 for 16 hours. The result illustrates that NBPF-2 has a good performance in long-term stability, deposition rate and thickness monitor system.

Figure 6 is one Gain Flattening Filter produced with NBPF-2. The insertion loss error function of the filter is about 0.3 dB. We use our optical monitor system to control the quarter wavelength and non-quarter wavelength directly. It illustrates that NBPF-2 has a good long-term stability.

Figure 7 is four consecutive batches produced with NBPF-2. It shows that NBPF-2 has a good repeatability.

The transmittance of 100G 4C filter was measured at the monitor position:

- **Batch1**: BW@-0.5 dB=0.47, BW@-25 dB=1.08 nm, CWL=1549.72 nm;
- **Batch2**: BW@-0.5 dB=0.47, BW@-25 dB=1.09 nm, CWL=1549.71 nm;
- **Batch3**: BW@-0.5 dB=0.47, BW@-25 dB=1.09 nm, CWL=1549.70 nm;
- **Batch4**: BW@-0.5 dB=0.46, BW@-25 dB=1.10 nm, CWL=1549.70 nm.

![Fig. 4. Uniformity effect on optical monitor system (Light spot size = 2mm).](image)

![Fig. 5. Five-cavity 184-layer 50 GHz DWDM filter produced with NBPF-2.](image)

![Fig. 6. Gain flattening filter produced with NBPF-2.](image)
4. Conclusion

Some special optical filters have been deposited by OPTORUN’s IAD-based NBPF-2 system. It illustrates that NBPF-2 has a good performance in long-term stability, deposition rate and thickness monitor system.

5. About OPTORUN

OPTORUN Co., Ltd. designs, manufactures and distributes precision vacuum deposition systems for optical fiber communications. OPTORUN has grown rapidly in the fiber optic industry since it was found on 25th Aug. 1999.

It delivered the first version of DWDM filter deposition system in February 2000 and produced the first 100GHz DWDM filter in March 2000. OPTORUN has shipped a total of 27 deposition systems to DWDM filter manufacturers worldwide so far.

OPTORUN spends 15% of its sales amount in research and development. The R&D includes development of high-resolution and low-noise optical monitors, thickness control software, and critical thin films. OPTORUN is one of very few manufacturers that can demonstrate and deliver process of the making of 50/100 GHz filters and Gain Flattening Filters.

OPTORUN’s primary manufacturing facility is located in 10-1 Takeno, Kawagoe-city, Saitama, Japan.