Distribution of Cavity-Modes in Narrowband Filters with Chirped Thin-Films

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Narrowband optical thin-film filters are commonly based on a discrete cavity surrounded by highly reflecting mirrors. By distributing the cavity over the whole device by using chirped layers similar filter properties can be obtained. With this approach additional design parameters can be accessed and the distribution of the electric field of the resonant mode modified.

1 Introduction

Thin-Film Fabry-Pérot filters consist of a periodic arrangement of layers with quarter wave optical thickness (QWOT) and a defect of the periodicity which represents the filter cavity. In the base configuration the defect is an additional QWOT layer. The periodic structure provides high reflectivity over a broad spectral range (stop-band) whereas the defect determines a narrow filter line with high transmission inside the stop-band.

Instead of adding a single layer as defect in the thin-film stack, the according optical thickness can also be divided into several parts with varying thickness and added to several or all layers of the filter, leading to chirped layer structure (Fig. 1). As the layer representing the resonant cavity is now distributed over the device, also the related spatial distribution of the electric field can be modified for the resonant mode. A comparable approach has been developed for gratings of DFB laser with good success [1, 2].

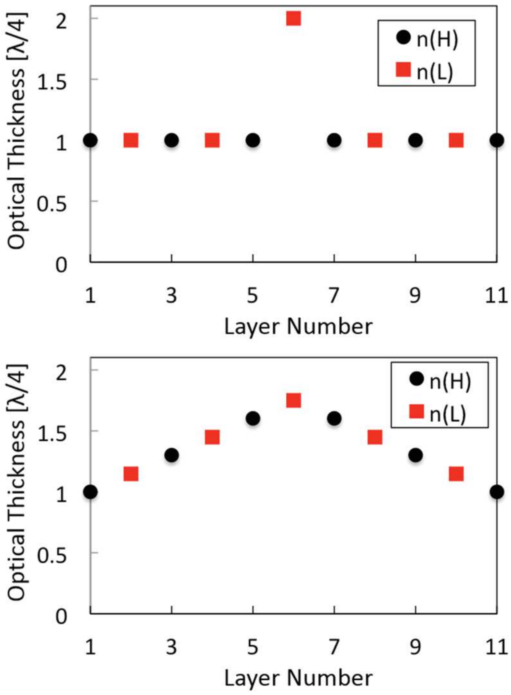

Fig. 1 *Layout of a Fabry-Pérot filter with discrete cavity and of a filter with triangular chirp function.*

2 Properties of Chirped Filters

Based on the concept of distributing the defect layer thickness, new design parameters become accessible and can be employed to modify the filter properties.

Distribution of the defect layer thickness can be achieved with various different function, like a triangular or a Gaussian function. Good narrowband transmission can be achieved, with symmetric function having a maximum in the central part of the filter. The choice of similar functions affects the transmission spectrum only in a minor way, but can be used to fine-tune the overall behavior.

The sum of all increased layer thicknesses is linked to the cavity length of a conventional filter and is termed chirp volume. Increasing this parameter red-shifts the resonant wavelength. The condition of a resonant cavity is not simply multiples of λ/2, but becomes a function of all other design parameters.

Another new design parameter is the chirp distribution giving the number of layers that are modified in their optical thickness. Chirping of only a few or all layers of a device directly affects the distribution of the electric field of the resonant mode.

The contrast of the refractive indices of both layer materials and the total number of implemented thin-film period have an influence on the stop-band reflectivity and hence the full-width at half maximum of the filter line, that is comparable to conventional Fabry-Pérot filters.

Negatively chirped filters, i.e. with chirp functions leading to reduced layer thicknesses result in narrowband filters as well. This can be understood, when considering a conventional periodic thin-film reflector and removing one layer instead of adding it as discussed before.

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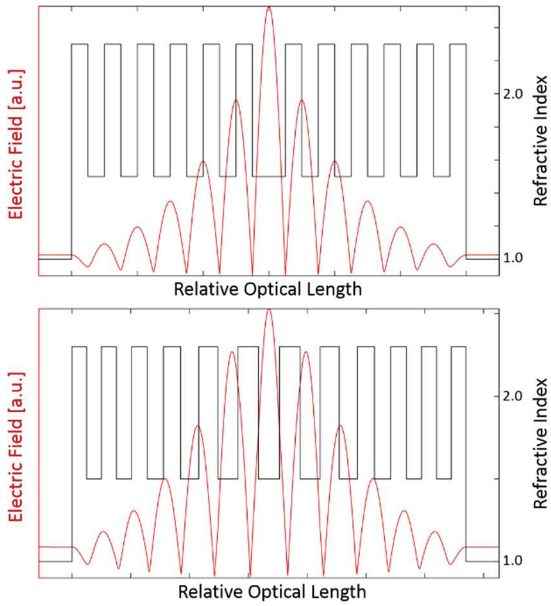

Fig. 2 *Electric field distribution of a resonant mode in a Fabry-Pérot filter (top) and a chirped filter (bottom).*

For the investigation of the fundamental filter properties of devices with different chirp functions and with respect to all available design parameters we implemented our own numerical software based on the transfer matrix method and adapted to chirped filter layouts. Beside the spectral transmission this approach can also provide the electric field distribution. In Fig. 2 the wider distribution of the electric field of a resonant mode in a chirped filter is shown in comparison to a conventional Fabry-Pérot filter.

3 Results

After the numerical investigation of the basic filter properties a design with positive, respectively, negative Gaussian chirp-function over 23 layers of Nb_2O_5 and SiO_2 has been chosen for the experimental verification. The layers were deposited using an ion beam sputtering process that provides high optical and mechanical quality and accuracy of the design parameters. A crossection of the fabricated layer stack with positive chirp was prepared by FIB and is shown in the SEM micrograph of Fig. 3. Results of the optical characterization regarding the transmission spectrum of the positively chirped filter is shown in Fig. 3 (bottom). A similar spectrum was measured for the filter with negative chirp. The spectral behavior is in good agreement with the numerical calculation. The main deviation is a smaller peak transmission, which is most likely linked to residual losses in the thin film stack. One option to reduce this influence is an additional oxygen plasma during sputter deposition to avoid formation of elemental Si during the process.

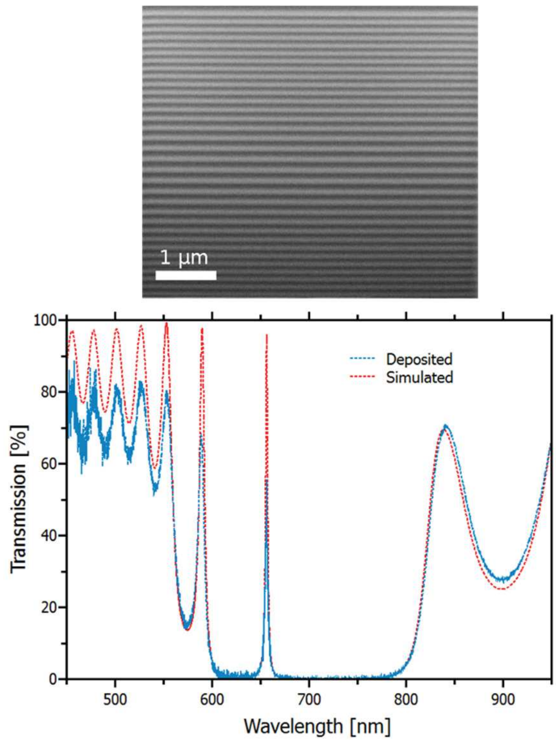

Fig. 3 *SEM micrograph (crossection) of a chirped thin-film filter, deposited by ion beam sputter deposition (top). Filter spectrum of a numerical design and the according fabricated filter (bottom).*

4 Conclusion

The investigation on chirped thin-film filters has shown, that a narrowband filter can be obtained by distributing the additional layer thickness of the cavity of a conventional Fabry-Pérot filter over many layers. New design parameters become available and the distribution of the electric field can be modified. Chirped filters were fabricated and characterized, showing the expected transmission properties. The new approach to thin film filters is promising especially for lasers like VCSEL, as the resonant mode can be tailored for optimum overlap with the active material [3].

References

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