ANSYS-Structural Design of Micromachined Fabry-Pérot Filters for WDM Applications

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Introduction

Due to the recent progress in the fabrication of micro-optical devices and the maturity reached in the integration of electromechanical functions on various semiconductor micro-devices, new concepts for optical microelectromechanical systems (OMEMS) have emerged. A variety of optical devices ranging from electrostatically actuated micromirror systems to continuously tunable semiconductor lasers have been developed [1,2]. Many concepts of Fabry-Pérot filters have been proposed for different cavity lengths ranging from 1.2 to 30 µm with corresponding channel spacing and densities for applications in wavelength division multiplexing (WDM) systems operated at 1.55 µm [3,4,5]. These tunable frequency selective systems commonly use movable Bragg mirrors realized by suspended thin membranes. The latter can be plane or corrugated and are obtained by micromachining processes based on selective etching of III-V-semiconductor materials. A controllable movement of the membrane is obtained using electrostatic actuation. A concept of thermal actuation has also been recently proposed [5].

Starting with initial definition of material and geometrical parameters corresponding to the required filter specifications for WDM systems, the following step in the filter design is the mechanical characterization of the system movable part. This step allows the optimization of the deflected mirror geometry as well as the determination of its electromechanical response. The deformation state of the fabricated multilayer membrane structure depends on the material combination and the geometry. Differences in the material properties of individual layers and the quality of multilayer interfaces can give rise to built-in stresses leading to an offset in the response. The first contribution to the built-in stress arises from the differences in the layer material properties such as lattice constant and thermal expansion coefficients. The second contribution which is difficult to characterize analytically depends on the epitaxial growth quality of the different layers and the smoothness of their interfaces [6].

Taking these effects into account one can find an appropriate membrane geometry which in combination with a suitable electrode configuration will allow to obtain a continuously controllable and reproducible plane movement of the mirror.

This is important for a possible integration of a photodetector on the movable part of the membrane, which has to remain plane and parallel corresponding to the second mirror during tuning of the filter.

Analyses have been carried out with the ANSYS FEM (Finite Elements Method) Program for two types of electrostatically actuated Fabry-Pérot filters. This is based on an approximation replacing the electrostatic force which bends the membrane by a pressure applied on the electrode surfaces of the moving part. The first analyzed device which is described in [5] consists of an GaAs/AlAs two-chips system filter with a 77 µm thick movable mirror and 21 µm resonator length. The Bragg mirrors have been defined by quarter wavelength stacks of 11.5 GaAs/AlAs pairs. Gold spacing bars have been used to support the upper mirror and define the resonator length as well as the electrodes separation. The second device, which has a similar geometric form as the one described in [7] and the same resonator length, uses a selectively etched thin membrane (10 µm) as movable Bragg mirror. The membrane consists of a quarter wavelength stack of 45.5 InGaAsP/InP pairs. The electrostatic actuation occurs by applying a voltage between the mirror and an electroplated gold electrode in form of an airbridge above the membrane. The distance between the two electrode systems is about 5 µm. A GRIN (gradient index) lens is used as the fixed mirror to complete the Fabry-Pérot system.

Results and discussion

Multilayer element types have been used to define the movable Bragg mirror structures. Analyses have been made using shell as well as solid element types.

A comparison of the measurement and simulation results is presented in Fig. 3 for the GaAs/AlAs filter. A double clamped multilayer structure was used for the GaAs/AlAs Bragg mirror. For the applied actuation voltage of up to 35 V the filter transmission and wavelength tuning characteristics have been measured.

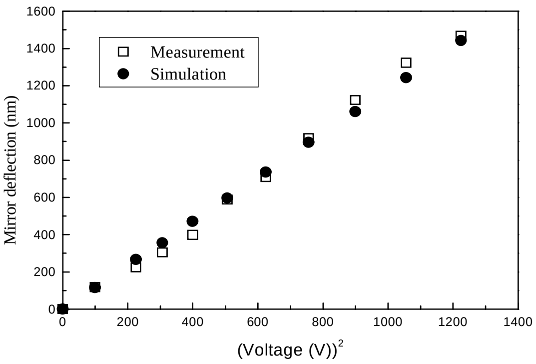

Fig. 3. Measured and calculated mirror deflection under applied voltage. Deflections up to 1.46 microns have been reached for a wavelength tuning range of about 103 nm.

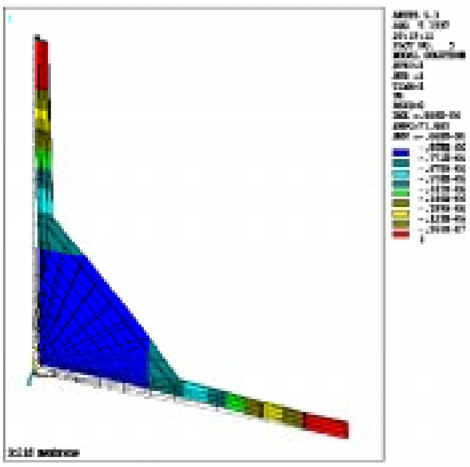

Fig. 4. Deflection profile of a simulated Bragg-mirror for the InP-based device. The parameters to be optimized are the supporting beam length, width and thickness as well as the membrane-to-electrodes surface ratio for a plane movement of the mirror. measured.

Simulations using the transfer matrix method were done to derive the mirror deflections at the different tuned wavelengths. The latter could then be compared with the calculated deflections. A good agreement has been reached between the simulation and the measurement results. Unlike the first design with a considerably thick mirror and with only the electrodes and supports geometry as simulation parameters, the sensitivity and the mechanical stability of the second design depend on numerous parameters. For this design the photodiode will be integrated on the moving mirror. Optimization have been carried out to determine values of membrane supporting beam lengths, widths and thicknesses as well as the membrane-to-electrodes surface ratio leading to not more than 1 ‰ difference in the deflections on the photodiode area for the required tuning voltages. Fig 4 shows an example of an obtained deflection profile corresponding to a determined set of the membrane geometrical parameters.

Conclusion

Structural analyses have been carried out for two electrostatically actuated Fabry-Pérot filters based on two different material systems and membrane design. A mechanical model replacing the tuning electrostatic force with a mechanical pressure on the mirror electrode surfaces was used. Simulation and measurement results have shown a good agreement for a fabricated GaAs/AlAs two-chip filter. They will also be used for the InP-based device in production. However a complete simulation taking into account phenomena such as the membrane pull-in behavior is needed.

References

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