Strain-Tuning of Periodic Optical Devices: Tunable Gratings and Photonic Crystals

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The advancement of micro- and nano-scale optical devices has heralded micromirrors, semiconductor micro- and nano-lasers, and photonic crystals, among many. To further advance the state-of-the-art, dynamically tunable devices are required not only for demand-based reconfiguration of the optical characteristics, but also for compensation to external disturbances and relaxation of tight device fabrication tolerances.

We develop the concept of strain-tuning for periodic optical devices – such as diffractive gratings and photonic crystals – on a deformable membrane piezoelectrically actuated with nanometer resolution as a means to achieve tunability. The spatial modulation of periodic elements not only provides tunability in silicon microphotonics, where electro-optic effects are negligible, but also achieves ultra-fine resolution with low power and voltage requirements through piezoelectric microactuators. In contrast to thermal means, moreoever, piezoelectric strain-tuning provides significantly faster response and better localization of tunability.

For the first part (Figure I), we demonstrate strain-tuning for the fundamental diffractive grating element. We achieved high-resolution analog tunability, as opposed to digital tuning recently reported, in microscale diffractive optics. The device is microfabricated through a combination of surface and bulk micromachining. Device characterization shows grating period tunability with nanometer resolution (detection-limited), with a maximum 0.21% membrane strain. The results are in good agreement with analytical theory and numerical models, and present immediate implications in research and industry.

For the second part, we demonstrate the strain-tunable deformable membrane platform for strain-tuning of a silicon photonic band gap microcavity waveguide. The small-strain perturbation on the optical resonance is analyzed through perturbation theory on unperturbed full 3D finite-difference time-domain numerical models (Figure II). Device fabrication involves X-ray nanolithography, electron-beam nanolithography and the integration of micro- and nano-fabrication methods. Experimental characterization (Figure III) achieved dynamic resonances with a 1.54 nm tunable range (at 1.55 μm optical wavelengths), in good agreement with our predictions. This first demonstration of strain tunability in photonic crystals is general in design, and contributes to the development of micro- and nano-scale photonics.