

Continuum Photonics, Inc.

Aaron A. Bent (VP Marketing and Business Development), Nesbitt W. Hagood (Chief Technology Officer)

5 Fortune Drive, Billerica, MA
978-670-4910

Design Optimization for Optical Switching

How the choice of actuation technology ultimately impacts the optical performance of a tunable optical device

Introduction

Despite false starts of the last 2-3 years, optical switches will remain a key element of upcoming communication networks. To date, the majority of next generation optical switches have relied on micro-mirror approaches using micro-electromechanical systems (MEMS) technology. However, these technologies often require engineering tradeoffs that optimize on silicon processing, at the expense of optical system performance.

Micro-mirror devices have found commercial success in scanning technologies, but face more challenges in communication switching. This is the result of using a component (tip-tilt micro-mirror) optimized around a process technology, and adapting it to serve the role of both a precisely tunable analog device, and the primary optical element in the switch. Limitations arise intrinsically from the choice of actuation technology to move the micro-mirrors: low-force air gap electrostatic motion. Furthermore, requirements for optical performance place considerable constraints on dimensional accuracy of the micro-mirrors (flatness requirements, pre-stresses, thermal response, etc.) and coatings – items not always compatible with MEMS processing technologies. Ultimately, these tradeoffs can result in less than ideal optical insertion loss, polarization and wavelength-dependent sensitivities.

The Engineering Problem

The goal is to re-state the engineering problem, such that it is possible to use bulk optics (with superior optical characteristics), and de-couple the optical performance from the process by which the switching occurs. An alternative is beam-steering – a technique well-known in the open literature. However, an actuator with substantially higher force than electrostatics is required to implement this in a small package. Piezoelectric ceramics, a solid-state actuation material that changes size according to voltage applied, is capable of such force.

But, nothing comes for free. Traditional force-displacement design curves are shown in Figure 1 for both piezoelectric materials and electrostatic devices. Piezoelectric actuators are capable of 5-6 orders of magnitude (1,000,000x) more force than electrostatics per unit area. However, the displacement of piezoelectric materials (typically measured in microns) is far less. Motion of the piezoelectric alone is not sufficient to move optical elements the amount required for reasonably sized switches (64-256 channels) – it is necessary to trade some force to obtain more motion.

The design tradeoff, and advantages

The final engineering solution is illustrated in Figure 2. This beam steering implementation uses MEMS – a simple impedance-matched mechanical lever to amplify the motion of the piezoelectric material. The new device still has enough force to move bulk optical components, but now amplifies the several microns of piezoelectric motion into several degrees of optics pointing capability. The design also eliminates micro-mirrors – every optical path now comprises only two fibers, and two lenses. This removes multiple reflection and light scattering elements, and results in switching with very low optical impairments: very low optical insertion loss, polarization dispersion losses, and channel cross-talk. All of these characteristics are imperative for communication and instrumentation applications.

A further systems-level advantage accrues from this design. The overall mechanical system remains far stiffer than systems based on electrostatics – by as much as 1000x, resulting in frequency response profiles far easier for closed loop control, and the rejection of external vibrations by passive techniques. Ultimately, the choice of an underlying technology can have a tremendous impact on the overall systems design and resulting device performance: in this case, piezoelectric actuation enabled a new class of device (beam-steering), which circumvented the limitations of existing switch architectures, and resulted in superior optical switching characteristics.

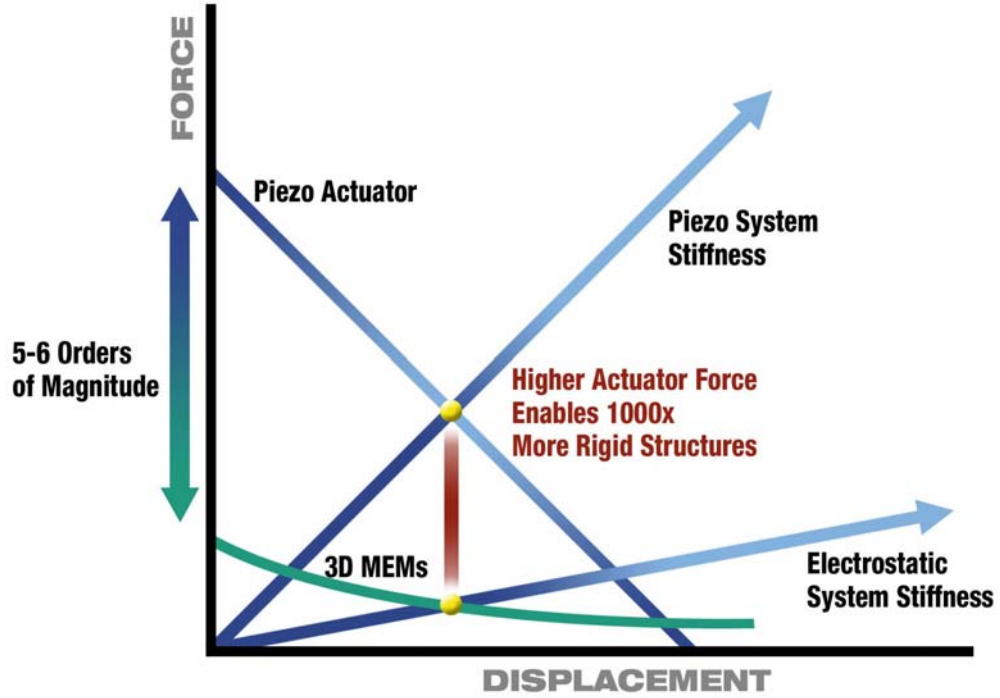


Figure 1. Load-displacement design curve. Piezoelectric materials are capable of very high force actuation, but are limited in stroke. More traditional approaches to optical switching use electrostatic actuation (creating forces using voltage across an air gap), which are unable to move bulk optics due to low force capability.

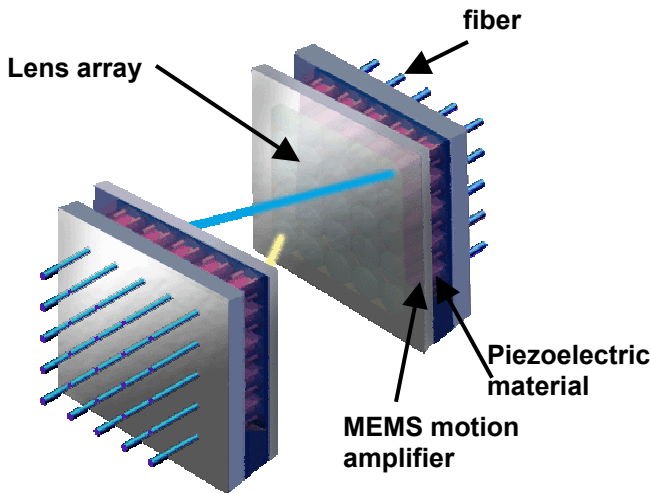


Figure 2. Beam-steering switch architecture. This architecture is enabled through an optimized system design, trading a portion of the high force of piezoelectric actuators with a MEMS motion amplifier. The result is the ability to use bulk optics and greatly enhanced optical performance.