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Modeling and Simulating Optical MEM Switches

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ABSTRACT

This paper presents the modeling and simulation of a 2x2 optical MEM switch using our system-level, mixed-technology CAD tool, Chatoyant. Simulations include operation in both the "cross" and "bar" states and the mechanical tolerancing of the system.

Keywords: CAD, optical MEMS, MOEMS, optical switches, mixed-technology simulation

1. INTRODUCTION

Recently, optical MEM systems have been transitioning from abstract ideas to marketable products, with applications including projection, switching, scanning, printing, sensing, modulating, and data storage. Among the limiting factors of this transition is the time and cost of physically prototyping and testing these systems. As seen in the VLSI revolution, CAD tools can greatly reduce this prototyping time and cost. Conventional MEM systems seem to be following this trend, and for optical MEM systems to be successful, CAD tools specific to these mixed-domain systems must be developed. As with many new technologies, design methods and tools for optical MEM systems are currently ad hoc. Designers typically use combinations of tools that were built for the individual optical, electrical, and mechanical domains, with little or no integration between them. System level analysis is commonly based only on the experience of the designer, or simply, on assumptions about the ensemble behavior of the components.

Our interest is in modeling optical MEM system-level behavior in a single integrated framework. We have achieved this in our free-space opto-electro-mechanical CAD tool, Chatoyant [2][3]. Chatoyant's component models are written in C++ with sets of user defined parameters for the characteristics of each module instance. Optical propagation is modeled using either Gaussian beam propagation or a more rigorous Rayleigh-Sommerfeld scalar formulation, depending on the degree of diffractive modeling required for the system. Both the electrical and the mechanical models are based on solving non-linear equations using a piece-wise linear technique. Chatoyant performs static simulations to analyze such effects as mechanical tolerancing, power loss, insertion loss, and crosstalk, while dynamic simulations analyze data streams with techniques such as noise analysis and BER calculation.

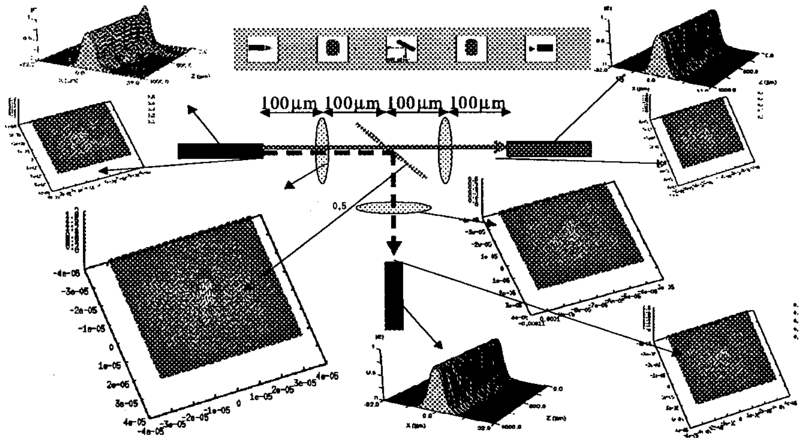

Figure 1: Optical MEM 2x2 Switch Simulation in Cross and Bar States

In this paper, we concentrate on the modeling and simulations of 2x2 optical MEM switches. The simulations are based on the same 2x2 switch architecture, consisting of a set of four fibers in the shape of a "+" sign, with the input and output fibers facing each other. The switch is in the "cross" state when the light is passed straight across the free-space gap. However, to switch to the "bar" state, a micro-mirror is inserted between the fibers at a 45-degree angle, and the light is reflected to the alternate output. For a single input, both states can be seen in Figure 1, represented by the solid and dashed arrows, respectively. The mirror fabrication and positioning can be achieved in a variety of ways. For example, Bell-labs [1] inserts a "see-saw" pivoting mirror into the optical path. UCLA [8] and AT&T [4] use scratch drive

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actuators to assemble and position the mirror between the fibers, and the University of Neuchael, Switzerland [5] uses a combdrive actuator to slide the mirror into place. Systems built with these switches have numerous advantages over typical waveguide or fiber switching systems, including a reduction of coupling loss and crosstalk, as well as being independent of wavelength, polarization, and data format [8]. The switches have been reported to be 10 times smaller and faster than typical fiber-based switches, while requiring only 1/100th of the operating power [6].

2. SIMULATIONS & RESULTS

The first example simulates the operation of a free-space optical MEM switch in both the cross and bar states. The system and simulation results are presented in Figure 1. For this simulation, the focusing system uses two refractive, 100 μm diameter, collimating lenses (focal length of 100 μm) separated by 200 μm. The first lens is placed 100 μm from the input fiber, and the second lens is placed 100 μm before the output fiber. Ideally, this optical system will focus the light onto the output fiber with the same waist size and intensity as the light leaving the input fiber. RSoft's BeamPROP [7] is interfaced with Chatoyant to simulate the light propagation in the fibers by a data file containing the optical complex wave function. The Chatoyant representation of the switching system in the bar state is seen at the top of Figure 1. The single mode fibers, each with a length of 1000 μm and a 10 μm core, have a core/cladding index difference of 0.006 and are optimized for 1550 nm wavelength light. A 1550 nm Gaussian beam with a 10 μm waist is used as a source to the input fiber. The micro-mirror model used to achieve the switch's bar state is assumed to be ideal, with 100% reflectivity. The additional arrows in Figure 1 match Chatoyant's intensity distributions to the component surfaces, and BeamPROP's simulation results of light propagating through the fibers for both the switch's cross and bar states. As the light propagates through free-space, one can see how the beam waist expands. Also notice, how the beam appears oval on the tilted 45-degree mirror intensity output. Both the cross and the bar states have less than 1dB of loss through the free-space switching system and are well accepted into the output fiber.

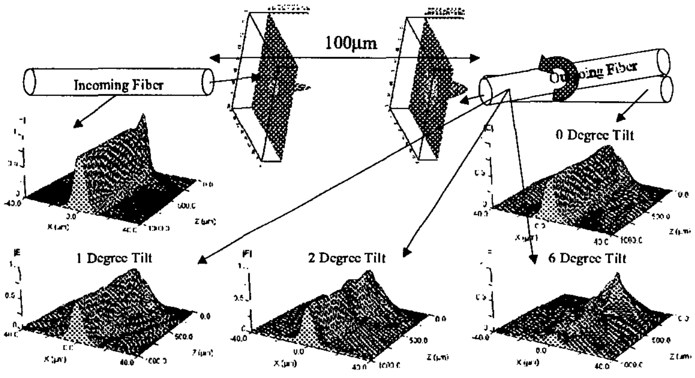

Figure 2: Mechanical Tolerancing of 2x2 Optical MEM Switch

Using Snell's law, the acceptance angle of the fibers is 6.3 degrees. To illustrate the relationship of the acceptance angle to the mechanical tolerancing for the system, this second example shows how tilting the end of the fiber affects the amount of light captured in the outgoing fiber. In Figure 2, we show the system set-up and the simulation results as the beam propagates through both fibers and the free-space gap, for the cases when Chatoyant is used to simulate perfect alignment and tilts of 1, 2, and 6 degrees in the outgoing fiber. In these simulations, no collimating lenses are used, and only the cross state is analyzed. Figure 2 also shows intensity distributions as the beam exits the incoming fiber and propagates through free-space. Again, one can see the beam waist spreads as it propagates through the free-space gap. For the perfectly aligned case, the Gaussian beam at the free-space/fiber interface is close to the fiber's ideal mode diameter and is well accepted into the outgoing fiber. However, as the mechanical rotation is applied, the beam enters the tilted fiber, resulting in the beam bouncing back and forth on the core/cladding interface. As seen in the cases with tilts of 2 and 6 degrees, that as the tilts get larger, the beam is not completely captured into the core and some power is lost through the cladding. When the tilt gets above the acceptance angle of the fiber, hardly any of the beam is left to propagate through the fiber.

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