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All Optical Micro Electrical Mechanical Switching Systems Losses Analysis

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Abstract*— This paper has presented the developed novel optical micro-electro-mechanical systems, (MEMS) and nano-electro-mechanical, (NEMS) optical components for applications including imaging, switching, and optical integrated circuits. Moreover an analog micro mirror array for network switching applications, and a nano scale photonic crystal switch for integrated photonic circuit applications will be described. The effect of variations of output power in respect of control signal wavelength, data signal power and control signal power are measured and plotted. The switch is designed with GS switching scheme to achieve high contrast ratio and the monolithic integration provides the required stability

Index Terms— Optical switch, Crystal photonic, Mechanical systems, Photonic Devices, and Integrated photonics.

I. INTRODUCTION

Micro-electro-mechanical systems, (MEMS), technology enables the creation of micro-optical elements which are inherently suited to cost effective manufacturability and scalability as the processes are derived from the very mature semiconductor micro fabrication industry [1]. Indeed, optical MEMS components have been successfully incorporated into commercial systems for displays1 and more recently optical switches. The extremely rapid growth of optical MEMS technology driven by miniaturization, lightweight, low energy consumption, and reduced cost, is projected to continue in response to the demand for large scale optical switching in fiber optic networks [2, 3].

In optical fiber communication, an optical switch used in optical fibers or integrated optical circuits (IOCs) to switched signals from one circuit to another selectively. Switching can be done by mechanical means, such as physically shifting an optical fiber to drive one or more alternative fibers, or by electro-optic effects, magneto-optic effects, or other methods. The type of switches needed for an optical path depends upon the requirement of switching speed like electro-optic or magneto-optic effects based switches used for fast switching applications. Different approaches have been proposed and used for optical switching. There are mainly two possible approaches that can be categorized as electro-optical switching and all optical switching [4-7].

One of the most promising applications of microelectromechanical systems (MEMS) technology is in optical communication in general and optical cross connect (OXC) switches in particular. The OXC switches in today's network rely on electronic cores. As port count and data rates increase, it becomes increasingly difficult for the electronic switch fabrics to meet future demands [4]. It is widely acknowledged that electronic switch fabrics are the bottleneck in tomorrow's communication networks. This bottleneck has stimulated intensive research in developing new all-optical switching technologies to replace the electronic cores. All-optical networks offer many advantages compared to conventional optical to electronic and electronic-to-optical networks [8-10], including cost-effectiveness, immunity from electromagnetic interference, bit rate/protocol transparency, and ability to implement wavelength-division multiplexing (WDM) with relative ease. Therefore, it is desirable to manipulate the data network at the optical level with optical switches. The optic switches are used to reconfigure/restore the network [11-13], increase its reliability, and/or act as the optical add/drop multiplexer (OADM). There are, indeed, many technologies competing to replace the current electronic switch fabrics. A successful optical switching technology will have to demonstrate superiority in the areas of scalability, insertion loss, polarization-dependent loss (PDL), wavelength dependency, small size, low cost, crosstalk, switching speed, manufacturability, serviceability, and long-term reliability. Conventional mechanical switches, which are based on macroscopic bulk optics, utilize the advantages of free-space optics; however, they suffer from large size, large mass, and slow switching time. On the other hand, guided wave solid state switches have yet to show great potential because their high losses and high crosstalk limit their scalability [14]. The recent development of free-space optical MEMS technology has shown superior performance for this application. MEMS optical switches not only retained their conventional counterparts' advantages of free-space optics such as low losses and low crosstalk, but also included additional ones such as small size, small mass, and sub milli second switching times. Furthermore, MEMS fabrication techniques allow integration of micro-optics, micro-actuators, complex micromechanical structures, and possibly microelectronics on the same substrate to realize integrated micro systems.

An optical amplifier amplifies an optical signal directly, without the need to first convert it to an electrical signal. An optical amplifier may be thought of as a laser without an optical cavity, or one in which feedback from the cavity is suppressed [13]. Stimulated emission in the amplifier's gain medium causes amplification of incoming light. Semiconductor optical amplifiers (SOA) are amplifiers which use a semiconductor to provide the gain medium [15]. Such amplifiers are often used in telecommunication systems in the form of fibre pigtailed components, operating at signal wavelengths between 0.85 µm and 1.6 µm and generating gains of up to 30 dB. The semiconductor optical amplifier is of small size and electrically pumped. It can be potentially less expensive than the EDFA and can be integrated with semiconductor lasers, modulators, etc [16-19].

II. ALL OPTICAL SWITCHING SYSTEM SCHEME

For all optical switching, the control of light by light is basic need for an all optical switch as shown in figure 1. To achieve this, an optical control signal is used which changes the optical properties of a nonlinear medium. The device then performs the switching of input data signal, due to the changed transmission properties when it passes through the medium. As illustrated in the Figure 1, an all-optical switch uses two inputs, data signal optical input and a second for the control signal. For different switching applications special requirements are needed. demultiplexing, add/drop multiplexing, sampling are some of these special applications in the all-optical switching [20].

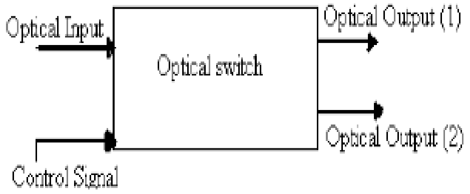

Fig. 1. All optical switching structure scheme [6, 21].

In case of all-optical demultiplexing [4], the switch requires high contrast ratios. While low distortion and high contrast is necessary for add drop multiplexing. To perform all optical switching two aspects viz. the switch geometry and the switching scheme are must to be considered in designing of switches. The nonlinear interferometric switches are suitable in term of geometrical point of view to be used for communication systems. Due to the same reason, an MZI switch has been used as switching element in the proposed design (fig. 2).

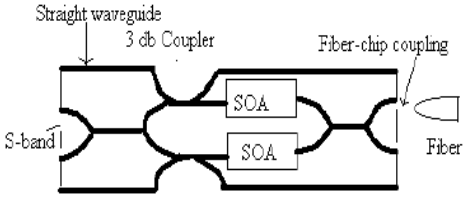

Fig. 2. Integrated all optical switching system based on semiconductor optical amplifier [8, 22].

In modulator, coupler splits the signal in to two beams, which then travel through two distinct arms of same and a second 3-db coupler is used to merge both and finally splits again. Switching action is achieved by varying the phase difference between the light beams [23-25]. The all-optical switch has been one of the most investigated components in OTDM communication networks. In high-speed OTDM systems, the all optical switches are essential whenever the data rate exceeds the speed of electronics [3]. An optical amplifier amplifies an optical signal directly, without the need to first convert it to an electrical signal. An optical amplifier may be thought of as a laser without an optical cavity, or one in which feedback from the cavity is suppressed. Stimulated emission in the amplifier's gain medium causes amplification of incoming light. Semiconductor optical amplifiers (SOA) are amplifiers which use a semiconductor to provide the gain medium. [26]. Such amplifiers are often used in telecommunication systems in the form of fiber pigtailed components, operating at signal wavelengths between 0.85 μm and 1.6 μm and generating gains of up to 30 dB. The semiconductor optical amplifier is of small size and electrically pumped. It can be potentially less expensive than the EDFA and can be integrated with semiconductor lasers, modulators, etc.

III. MATHEMATICAL MODEL ANALYSIS

The optical switch is nowadays playing a significant role in optical communication networks. For example, in an all optical network (AON), optical switches select the directions of the signal, adding or dropping information, protecting networks, and so on. These functions can be realized with traditional electrical switches after converting the optical signal to an electrical one, which is then converted back to an optical signal for further transmission [21]. The fundamental mode field distribution of single-mode fiber (SMF) can be well approximated by a Gaussian function. The following empirical expression describes the waist w_0 of the Gaussian beam:

$$\omega_0 = \left(0.65 + \frac{1.619}{V^{1.5}} + \frac{2.879}{V^6}\right) a \qquad (1)$$

where w_0 is the waist of the Gaussian beam, *a* is the core radius, and V is the waveguide parameter given in [12]. The beam will diverge when it leaves the fiber enter into a free space because there is no total reflection. The Gaussian beam coming from the fiber propagates in free space and its beam size is given as follows [26]:

$$\omega = \omega_0 \left[1 + \left(\frac{\lambda Z}{\pi \omega_0^2}\right)^2\right]^{0.5} \qquad (2)$$

The Gaussian approximation analytical model to describe insertion losses in fiber splices, coupling loss due to misalignments, as well as the difference between the mode field radii of the two fibers [27, 28]. The total insertion loss can be calculated from:

$$L = -10 \log\left[4 \frac{D}{B} \exp\left(-\frac{AC}{B}\right)\right] dB \qquad (3)$$

Where $A=(k\, w_T)^2/2$, $k=2\pi n_0/\lambda$, and

$$B = G^2 + (D+1)^2 \qquad (4)$$

$$C = (D+1)F^2 + 2DFG\,Sin(\Delta\theta) + D\left(G^2 + D + 1\right)Sin^2(\Delta\theta) \qquad (5)$$

$$D = (\omega_R / \omega_T)^2 \qquad (6)$$

$$F = \frac{2\,\Delta x}{k\,\omega_T^2} \qquad (7)$$

$$G = \frac{2\,\Delta Z}{k\,\omega_T^2} \qquad (8)$$

Let $\Delta x = 0$ and $\Delta q = 0$, so that, the relationship between the insertion loss and the distance between the ends of the two fibers can be written in the form of [29-32]:

$$L = -10 \log\left[\frac{4}{M^2 + 4}\right] \qquad (9)$$

Where $$M = \frac{\lambda Z}{\pi\, n\, \omega_0^2} \qquad (10)$$

Lateral misalignment loss: Let $\Delta z = 0$ and $\Delta q = 0$, so that the relationship between the insertion loss and the lateral distance between the ends of the two fibers has the form of [33]:

$$L=-10\log\left[\exp\left(-\frac{\Delta x^2}{\omega_0^2}\right)\right] \qquad (11)$$

where Δx is the lateral misalignment distance. As well as the angular misalignment loss: Let Δz = 0 and Δq = 0, so that the relationship between the insertion loss and the angular misalignment between the ends of the two fibers has the form of [34]:

$$L=-10\log\left[\exp\left(-\frac{\pi\, n_0\, \omega_0 \sin(\Delta\theta)}{\lambda}\right)^2\right] \qquad (12)$$

Scattering loss at the mirror surface is related to surface roughness. The total integrated scatter is used to measure the fractional scattered power from an ideal smooth, clean, conducting surface. The scattering power due to surface roughness is expressed as [23, 34]:

$$\eta=1-\exp\left(-\frac{4\pi\sigma\cos\theta_i}{\lambda}\right)^2 \qquad (13)$$

where η is the percentage of scattering loss, σ is the root-mean-square (RMS) roughness of the mirror surface, θ_i is the incident angle, and λ is the the light wavelength.

IV. SIMULATION RESULTS

All optical switches have been deeply investigated based on its insertion loss, fiber coupling loss analysis and try to enhance it performance operation characteristics over wide range of the affecting operating parameters as shown in Table 1.

Table 1. Proposed operating parameters for all optical switching systems [4, 7, 8, 12, 15, 22, 28].

Operating parameter	**Symbol**	**Value**
Transmission distance	Z	50 μm-300 μm
Operating wavelength	λ	0.85 μm-1.55 μm
Incident angle	θ_i	10 degree-60 degree
RMS mirror roughness	σ	20 nm-100 nm

Based on the modeling equations analysis over wide range of the operating parameters, and the series of the Figs. (3-11), the following features are assured:

i) Figs. (3-5) have assured that as transmission distance and operating signal wavelength increase, this results in beam waist increases.
ii) Figs. (6-8) have indicated that coupling fiber loss increases with increasing transmission distance while with decreasing operating signal wavelength.
iii) Fig. 9 has demonstrated that fiber coupling insertion loss increases with increasing root mean square mirror roughness at the assumed set of the operating parameters.
iv) Fig. 10 has indicated that scattered power percentage decreases with increasing incident angle.
v) Fig. 11 has approved that scattered power percentage increases with increasing root mean square mirror roughness and decreasing both operating wavelength and incident angle.

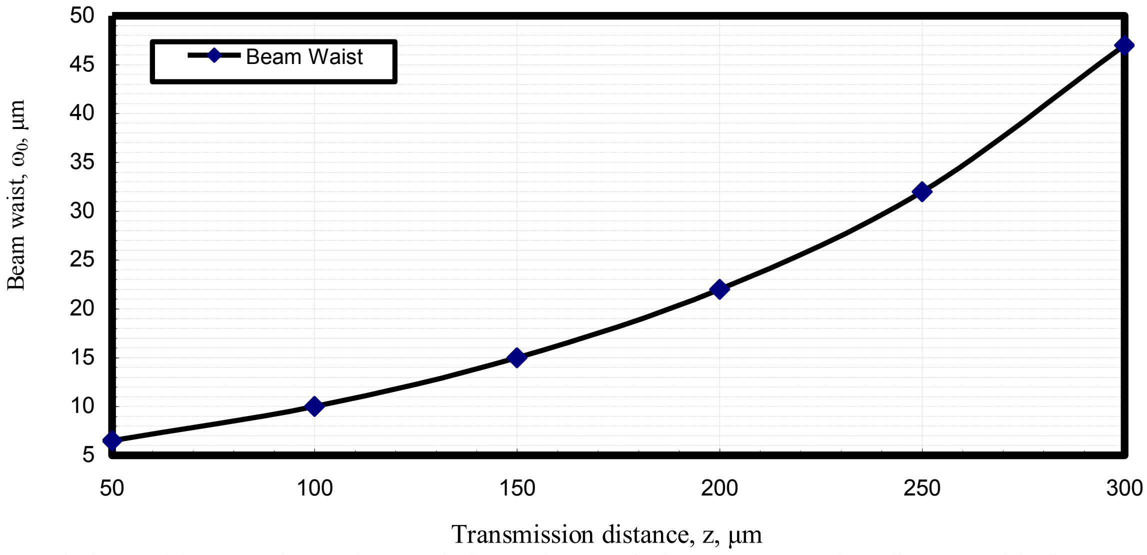

Fig. 3. Variations of beam waist against variations of transmission or propagation distance with first operating signal wavelength (λ=0.85 μm).

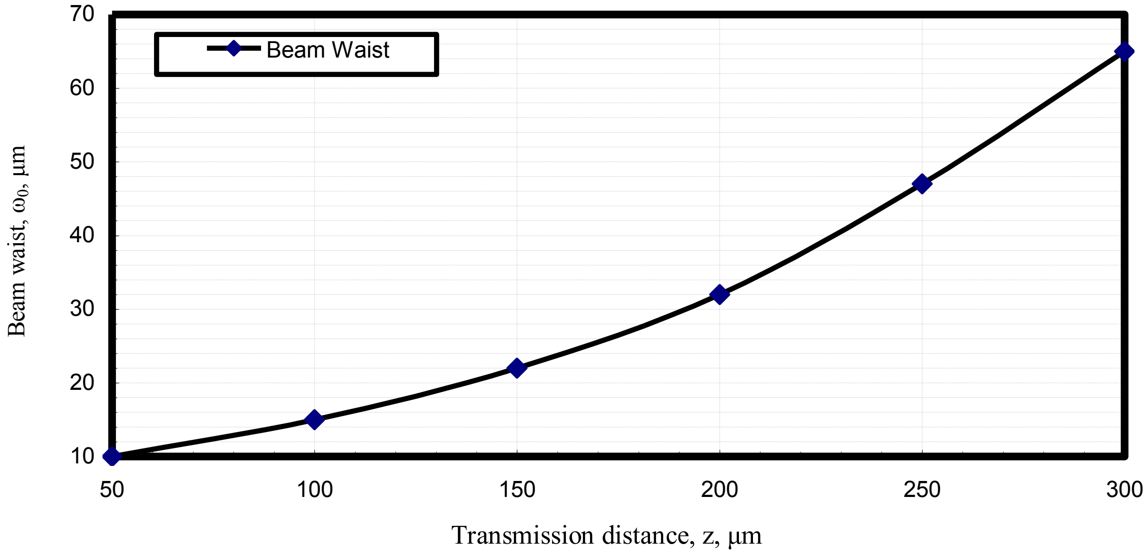

Fig. 4. Variations of beam waist against variations of transmission or propagation distance with first operating signal wavelength (λ=1.30 µm).

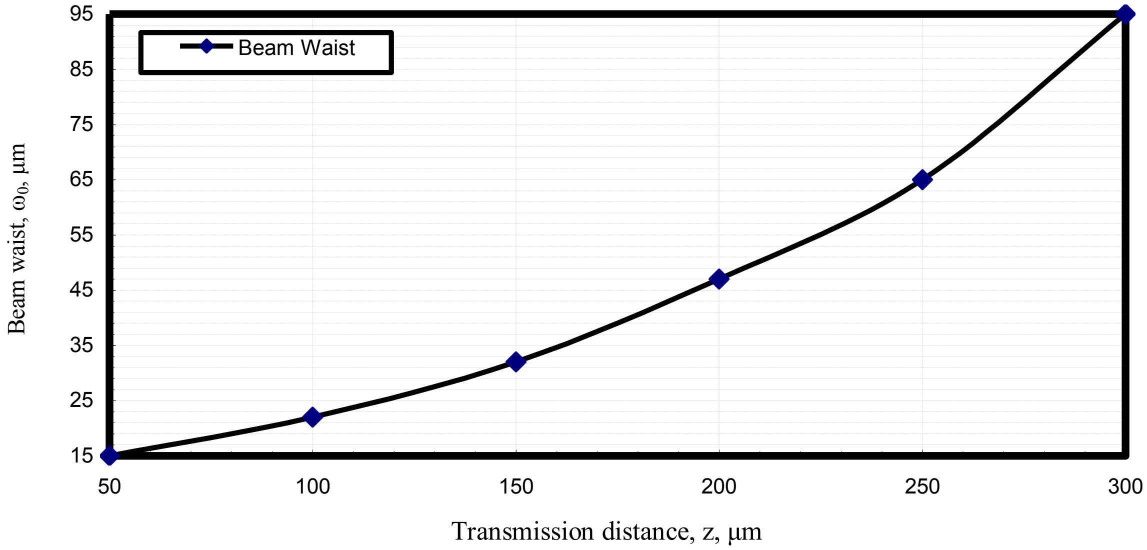

Fig. 5. Variations of beam waist against variations of transmission or propagation distance with first operating signal wavelength (λ=1.55 µm).

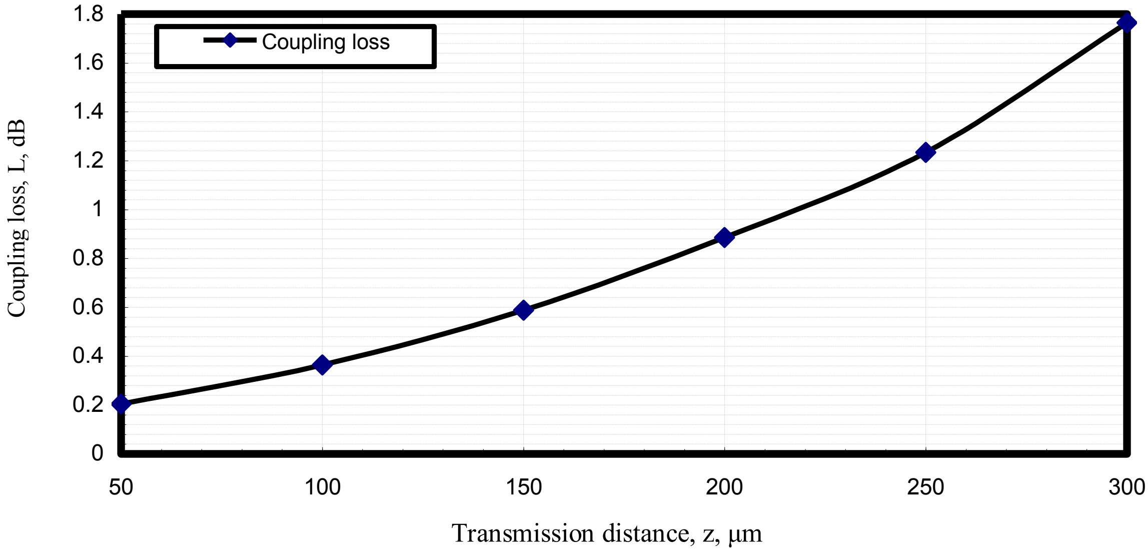

Fig. 6. Variations of coupling loss against variations of transmission or propagation distance with first operating signal wavelength (λ=0.85 µm).

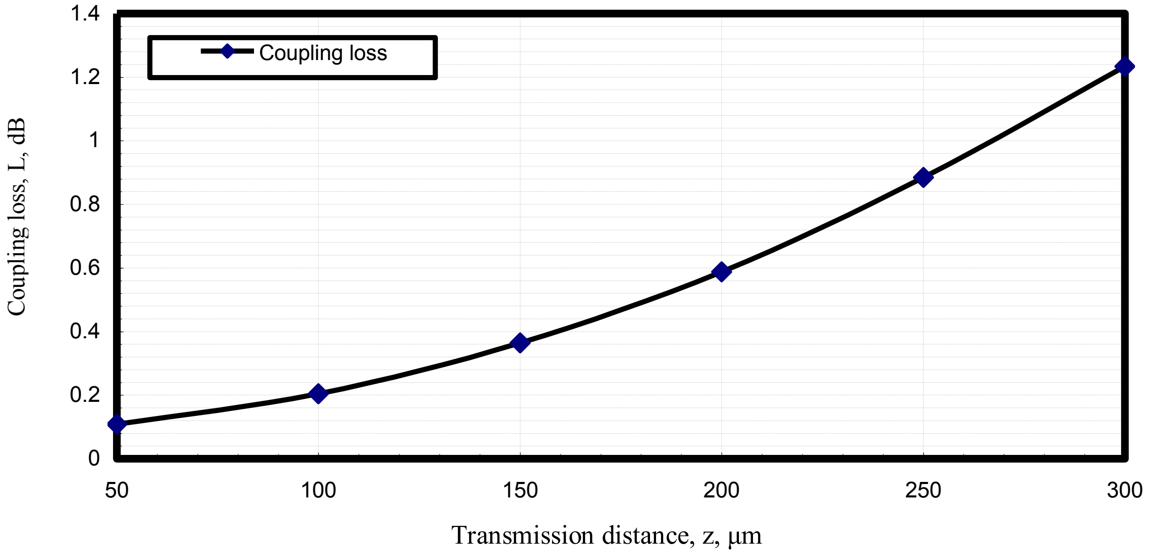

Fig. 7. Variations of coupling loss against variations of transmission or propagation distance with first operating signal wavelength (λ=1.30 μm).

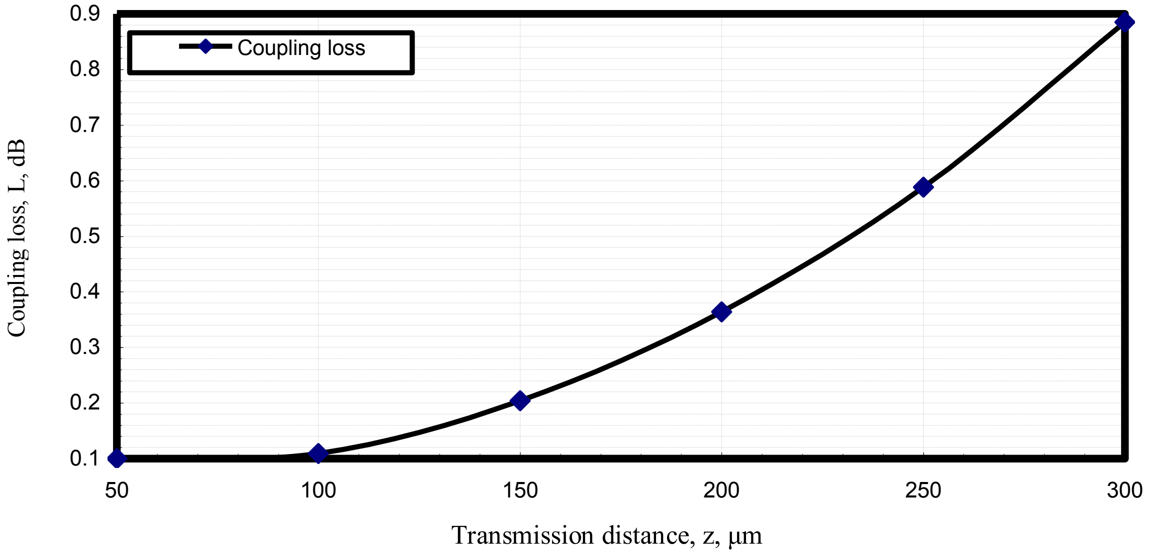

Fig. 8. Variations of coupling loss against variations of transmission or propagation distance with first operating signal wavelength (λ=1.55 μm).

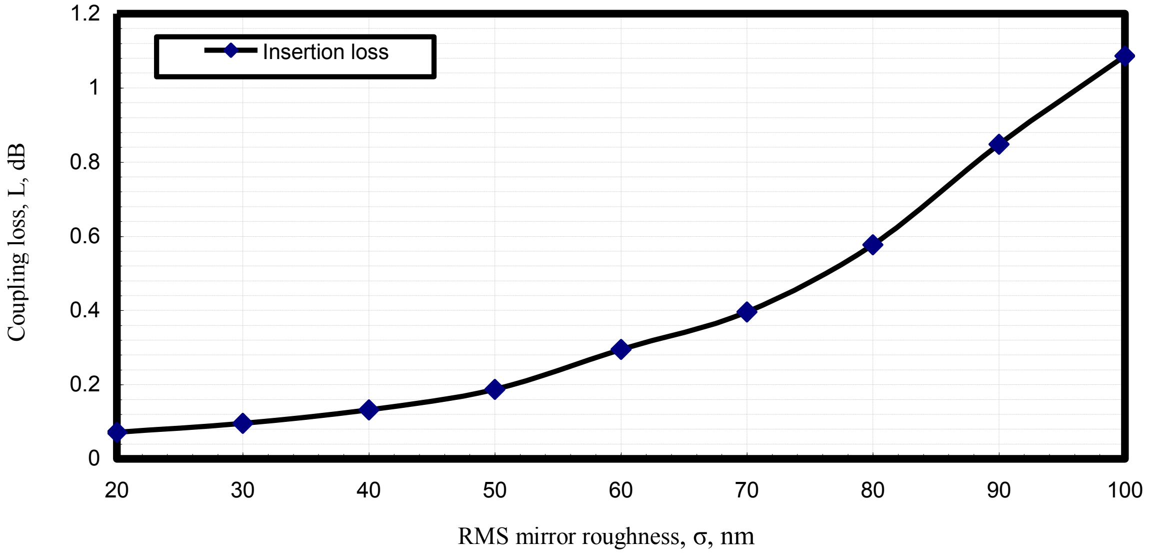

Fig. 9. Insertion coupling loss in relation to root mean square roughness at the assumed set of the operating parameters.

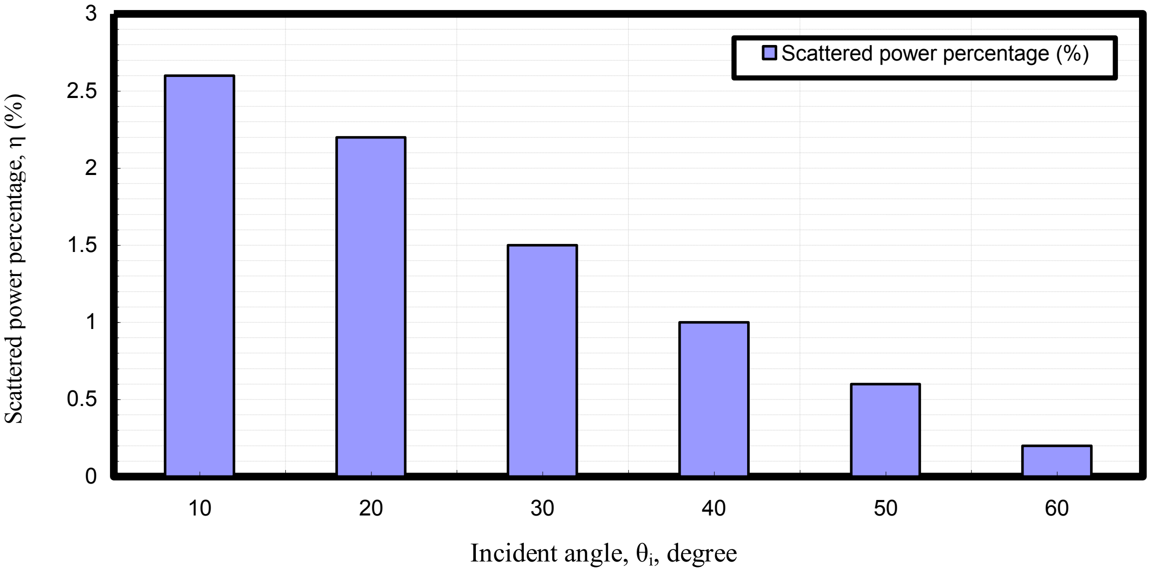

Fig. 10. Scattered power percentage in relation to incident angle at the assumed set of the operating parameters.

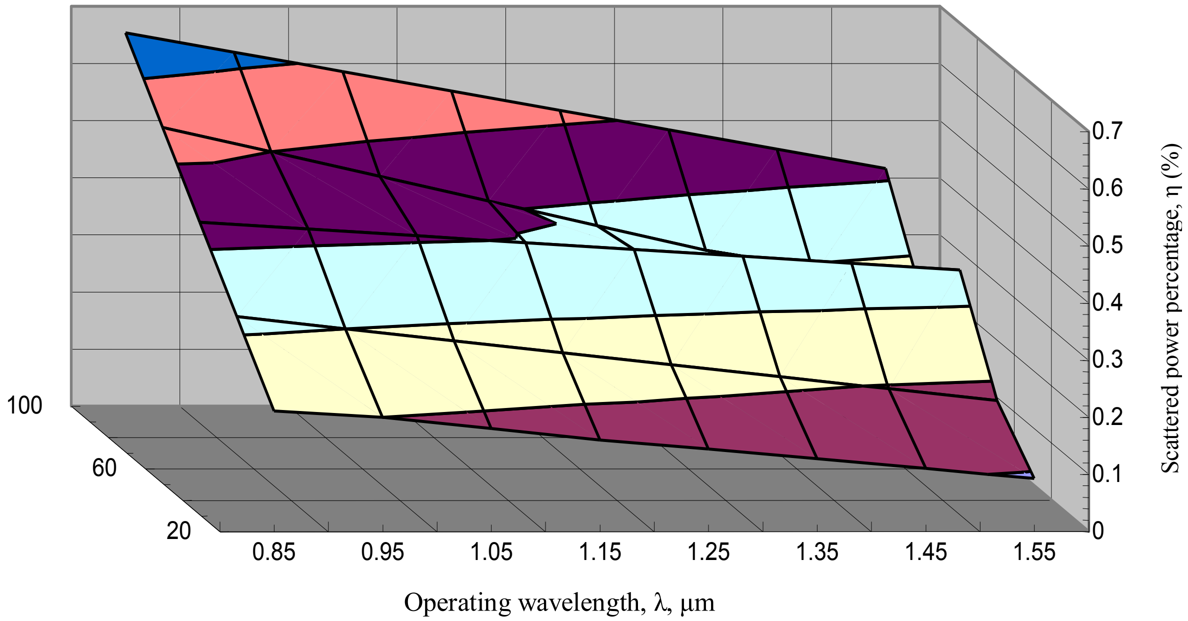

Fig. 11. Scattered power percentage in relation to root mean square roughness and operating wavelength at the assumed set of the operating parameters.

V. CONCLUSIONS

With the development of optical communication, optical switches and switch matrices are gaining their significance with the rising demand for low-cost, small-footprint, and high-performances optical devices MEMS technology-based optical switch has begun to attract great interest. The specific subsystem has the capability to switch, simultaneously, between different wavelength channels and different light paths, and has applications in optical networks such as reconfigurable OADMs and tunable wavelength converters. The photonic subsystems and even the whole optical communication system draw on MEMS technology and integration demonstrate the merits of compact size, low weight, batch fabrication, high mechanical reliability, and easy integration with the IC circuits.

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