Modeling and Simulation of Silicon Optical MEMS Switches Controlled by Electrostatic Field

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Introduction:: The use of optical sensors in the industry is still growing. A transmission of signal from the sensors is mostly done by optical fibers. Switching the signals from optical paths may be done by using micromechanical silicon switches. The construction of the optical switch is shown in fig. 1. A silicon beam with an Al layer is an actuating element. It is a mirror and an electrode of an electrostatic actuator at the same time. The second electrode is placed under the beam. A change in the electrostatic field causes a deflection of the beam.

The optical transducer consists of two fibers: the transmitting fiber T and the two receiving fibers R_1 and R_2. A light source lightens the moving mirror surface (the beam's surface) by the transmitting fiber. Reflected light is collected by the receiving fibers. Light intensity in the photodetectors (for the receiving fibers R1 and R_2) depends on the deflection of the beam. By controlling a voltage supplying the electrostatic transducer, the light intensity collected by the receiving fibers R_1 and R_2 can be changed.

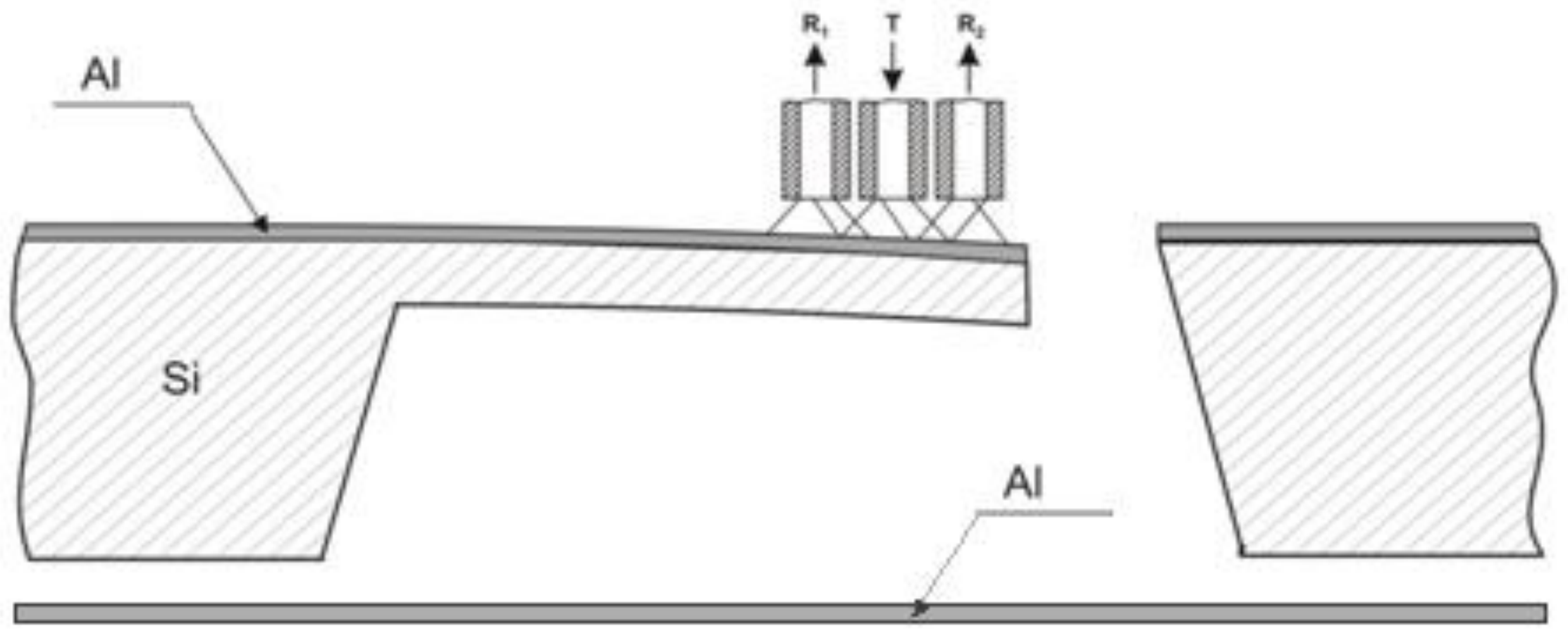

Figure 1. Construction of an optical fiber transducer

Modeling: Electrostatic force acting on the cantilever with mirror can be described by a derivative of electric field energy. For the controlling V voltage supplying electrodes, the force acting on the cantilever (with the mirror on it) is:

$$F = \frac{1}{2}\left(\frac{dC}{dz}\right)V^2 = \frac{\varepsilon_0 A V^2}{2\left(\frac{d}{\varepsilon_r} + t\right)^2} \qquad (1)$$

Where: ε_0, ε_r- permittivity of free space and permittivity of dielectric layer , *A*- plate area, *d*- dielectric layer, *t*- air-gap thickness

For the modeling and the simulation, Comsol Multiphysics 4.3b was used. Figure 2. shows a mechanical construction of the tested structure. The upper part is movable (figure 3.), the electrode is simultaneously a mirror (reflecting the beam coming out of the transmitting fiber) and a controlling electrode.

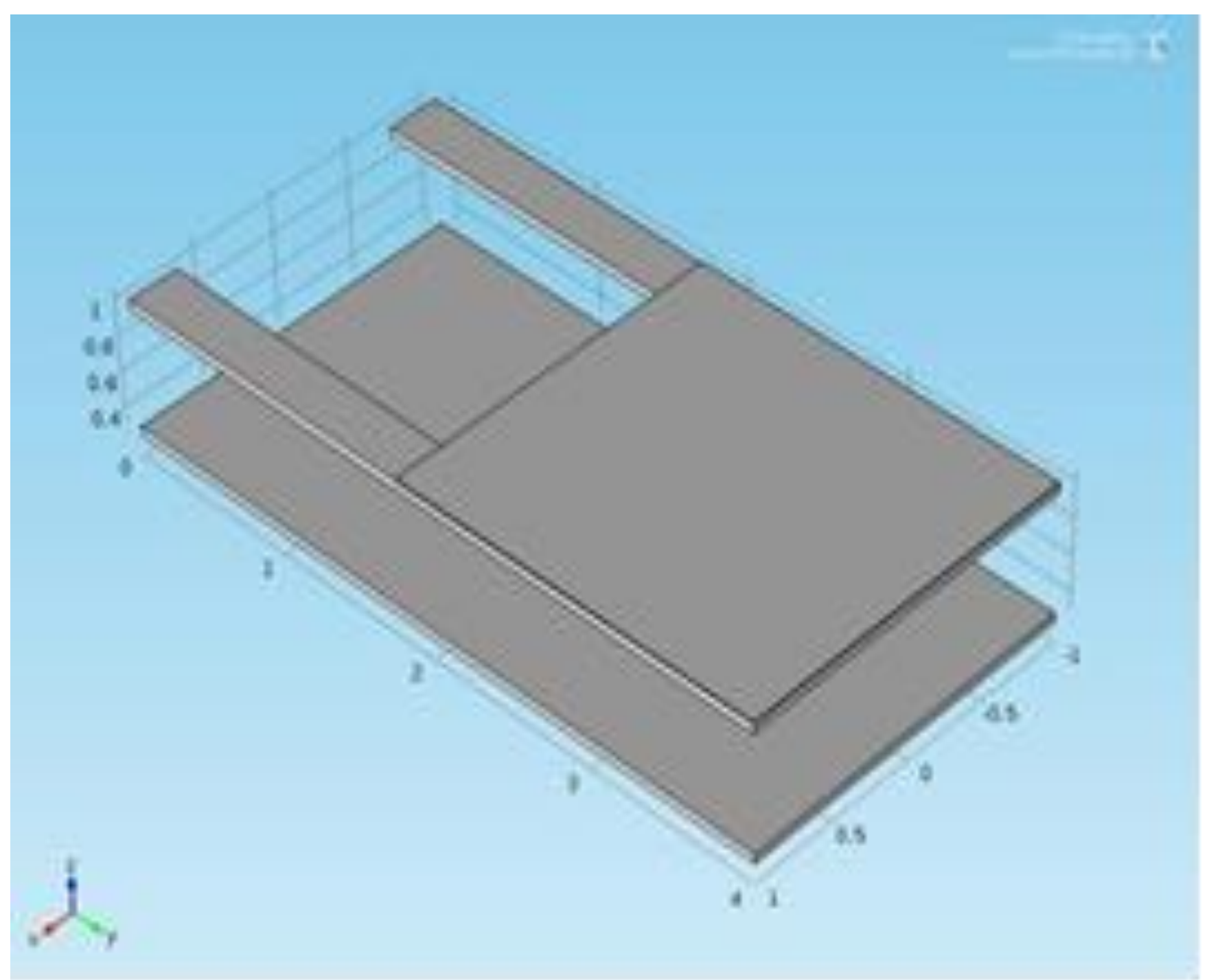

Figure 2. Mechanical construction of the tested structure

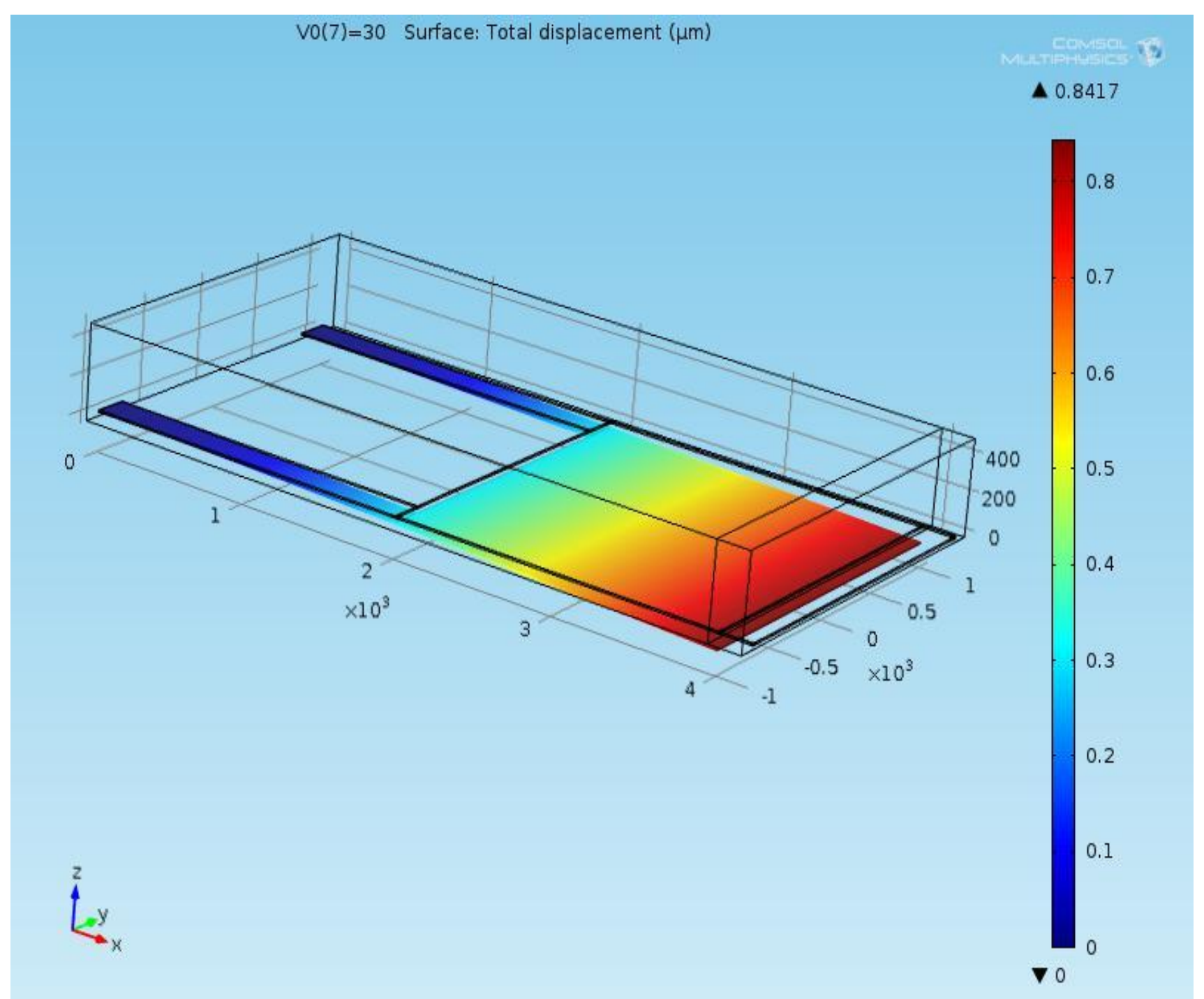

Figure 3. Surface deformation for electric field

The cantilever was attached from the one side by the „fixed constraint" option. Electromechanical interference analysis was used. Upper electrode was designed as a terminal (voltage type). The lower boundary (lower electrode) was marked as a "ground". Prescribed mesh displacement was used in some points, according to the Comsol tutorials, in order to reduce the time of the model computation. Tests were carried out for different types of meshes: user controlled, physics controlled, mapped. The final result was about 800 000 degrees of freedom and time of the computation about 3 hours for the most sophisticated models and 7 voltage parameters (2,5,10,15,20,25,30[V]).

Results: Characteristics show effects of the simulations – an influence of construction's parameters and controlling voltage on a deflection of the upper electrode for the cut-out cantilever constructions (figure 2, 3).

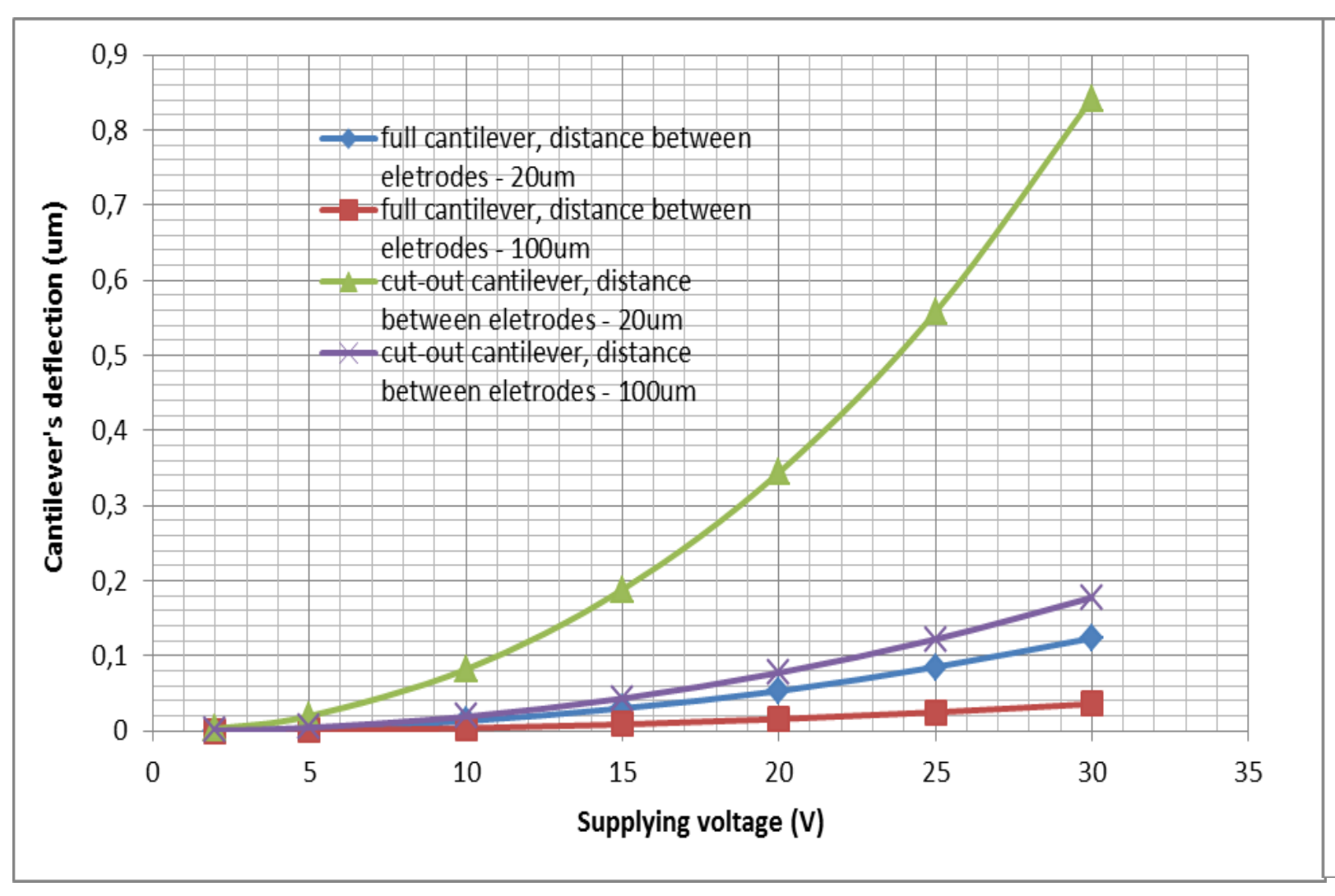

Figure 4. Comparison of full and cut-out 2x4mm cantilevers' constructions

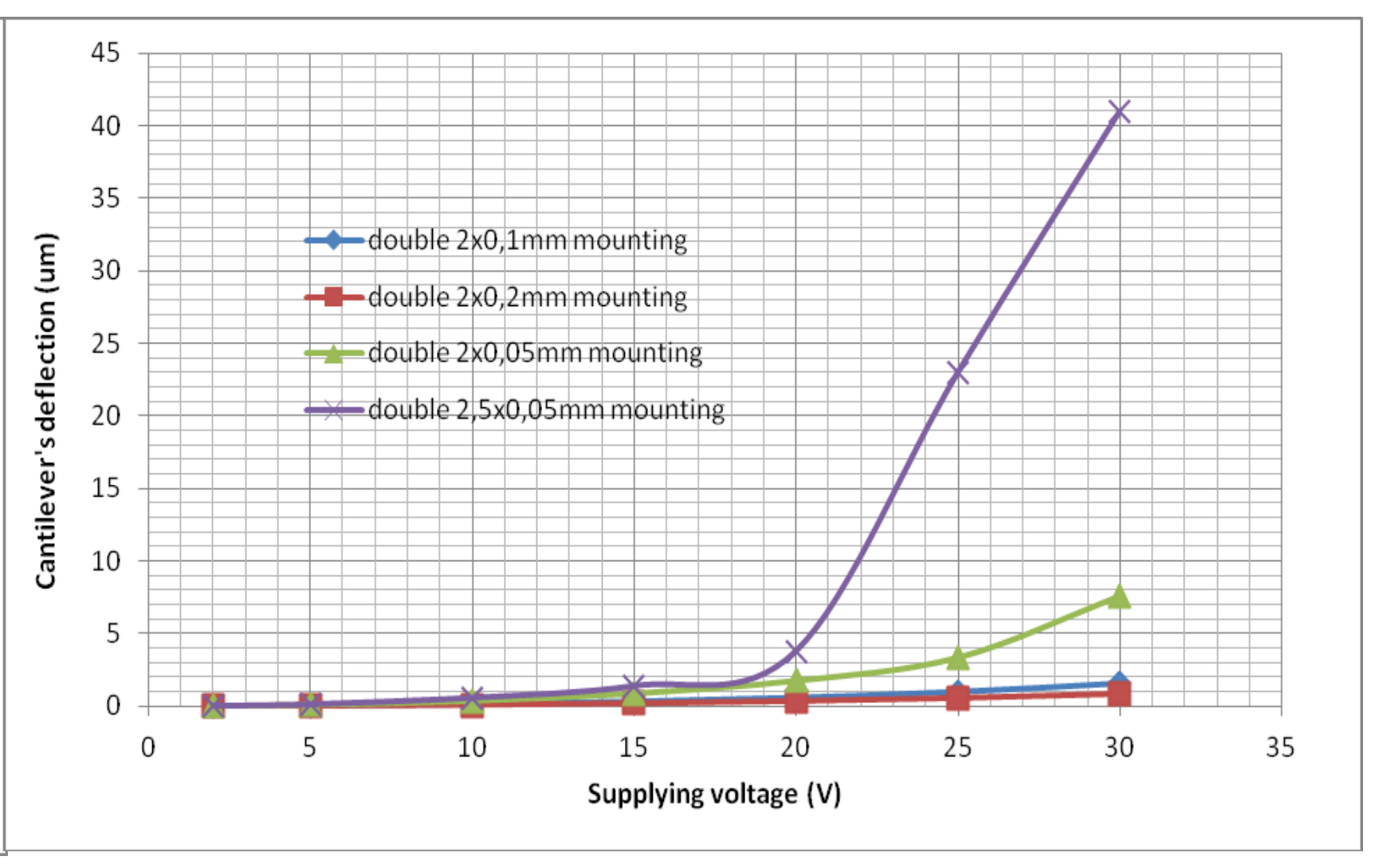

Figure 5. Deflections of the cut-out cantilever constructions for 20µm air-gap, in function of supplying voltage

Characteristics for a layout consisting two receiving fibers (figure 7.) were assigned using a test-stand shown in figure 6.

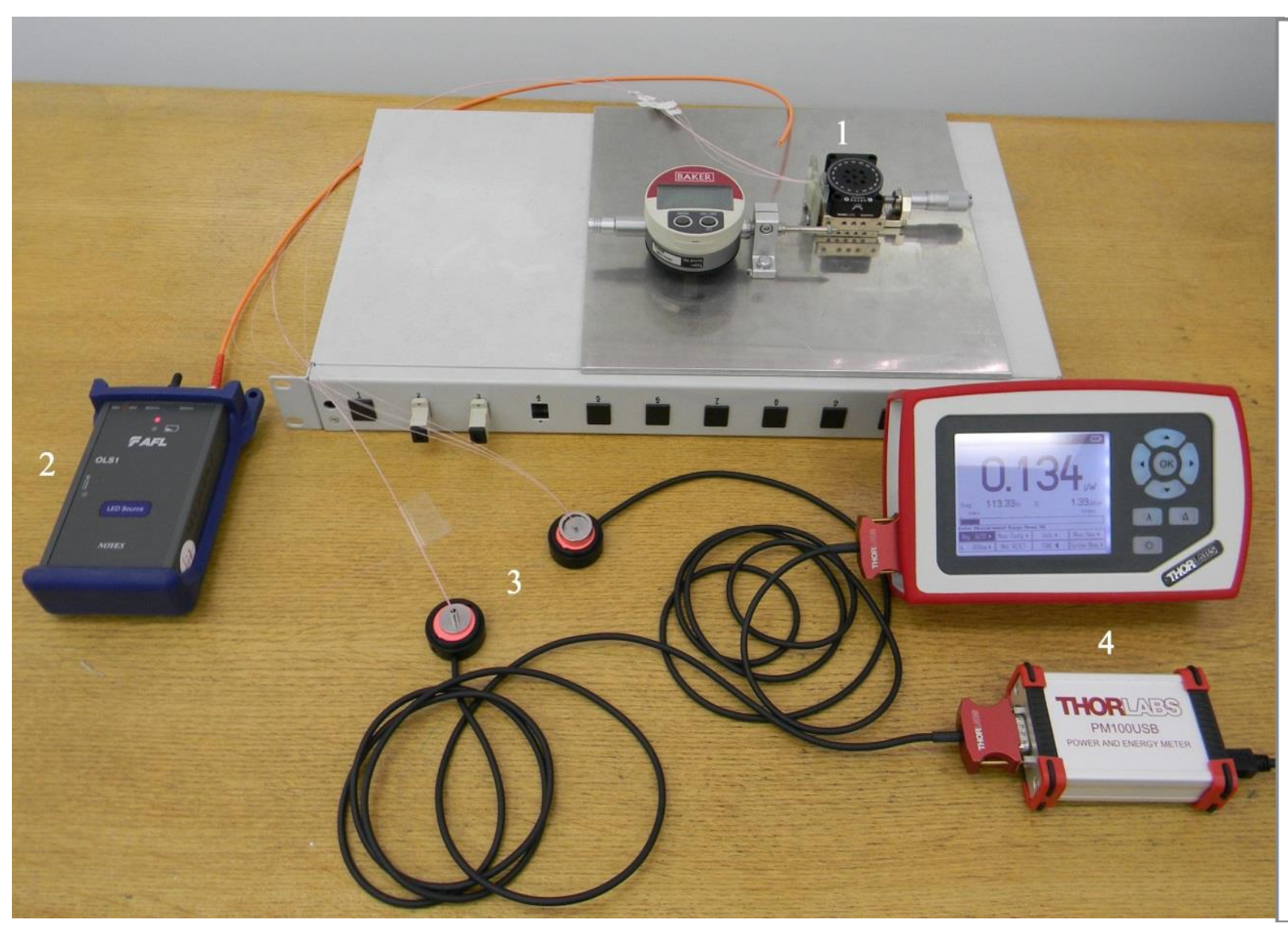

Figure 6. Optical test-stand

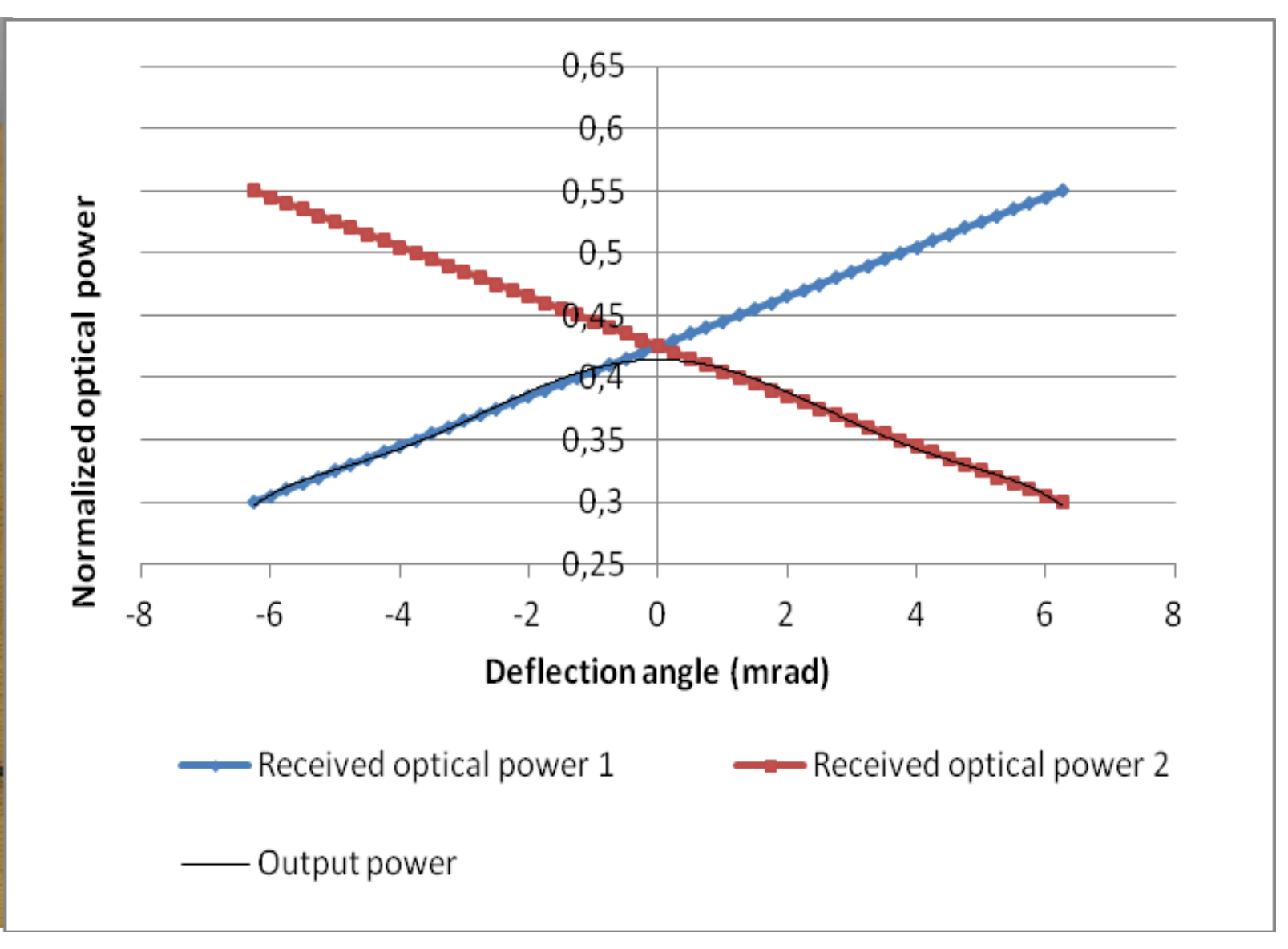

Figure 7. Practical results of the optical test-stand measurement

Conclusions: The study shows an analysis of the electrostatic transducer controlling the silicon cantilevers' displacement. Practical tests resulted in 20-30% optical power changes in the fibers for the -6mrad to 6mrad cantilever's deflections. Further change in the received optical power can be achieved for bigger cantilever's deflections. Attaching the cantilever/upper electrode on two thick beams effects in the noticeable loss of stiffness of the whole construction.

References:

1. M.Hanf, W.Dötzel: Micromechanical electrostatic field sensor for the characterization of charges in MEMS devices, Sensors and Actuators A 115 (2004) 280–285
2. S.Binu, V.P.Mahadevan Pillai, N.Chandrasekaran, Fibre optic target reflectivity sensor, Opt Quant Electron 39, (2007) 747-752

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