

Micromachined corner cube reflectors as a communication link

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Abstract

This paper proposes using a micromachined corner cube reflector to transmit data digitally by modulating reflected light intensity. Corner cube reflectors ranging in size from 100 to 200 μm have been built using hinged polysilicon plates. The reflectivity of polysilicon has been measured to be 24% and the total reflected power from the corner cube has been measured to be between 1 to 2% of the incident power. Orthogonality between plates is within roughly 8 mrad. Reflection from individual polysilicon plates has been modulated using electrostatic actuation with an applied voltage as low as 8 V.

Keywords: Corner cube reflector

1. Introduction

Corner cube reflectors (CCR) have been used in optical systems mainly because, unlike other optical components, they are not critically sensitive to misalignment [1,2]. This paper proposes using a micromachined CCR to transmit data digitally from a sensor to a detector by modulating the reflected light intensity. A beam of light that hits a defined active area in the concave side of a three-sided orthogonal corner will be reflected back along the axis of arrival to the source. Rays which hit outside this active area do not exit parallel to themselves and therefore do not contribute to the reflected beam [3]. Reflectors of this type are called CCR. If the orthogonality of the corner cube is disturbed, then the impinging light will not be reflected back to the source. Hence, it is possible to modulate the intensity of the reflected light by small motions of one or more sides of the corner cube. This light modulation can be used to transmit data from the corner cube to the light source with very little power used by the corner cube. A prototype of this reflector is shown in Fig. 1.

The proposed system consists of a number of remote units and one or more base stations. Each remote unit contains a sensor, electronics, a corner cube, a photodiode and a power source (the photodiode may service as a power source). The sensor can be customized for each application. The base station contains a laser source and a photosensor to detect the signal reflected from the corner cube.

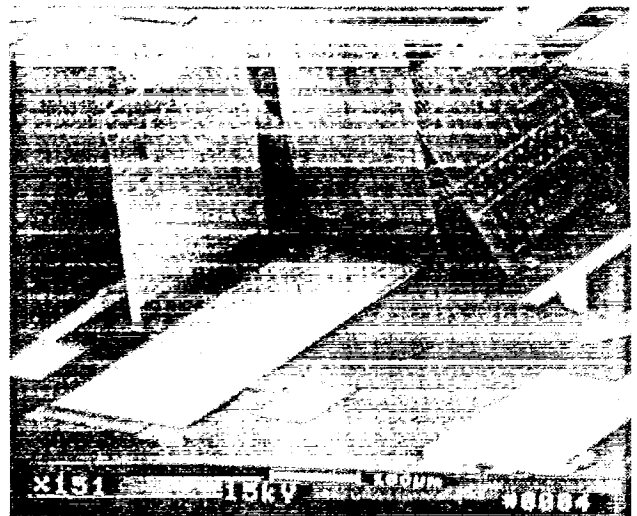


Fig. 1. SEM of a corner cube reflector showing the three reflecting sides.

When the photodiode detects a coded signal from an interrogating laser, the electronics system amplifies, conditions and digitizes the output from the sensor and feeds the data into a shift register which starts to output the signal one bit at a time in the form of a voltage that actuates the CCR. A photodetector, placed in close proximity to the source, will then detect the data transmitted and demodulate it to give the inquirer a digital read-out of the sensor output. In a more advanced system, a control system can be integrated so that the base station may send instructions to the remote sensor. A schematic diagram of the communication process

between an interrogating source and a CCR is shown in Fig. 2.

A micromachined CCR has several advantages. Because of its miniature size, the actuation process requires very little power. Thus, the remote unit needs only to have a low power supply residing within it. A CMOS electronics system can be integrated on-chip. This capability, together with the low power consumption, makes the remote unit completely autonomous. In the communication process, the detector does not have to hunt for the reflected signals. As long as it is placed very close to the source, it is guaranteed to receive the transmission. This provides an intrinsically secure communication channel since competing receivers will not be able to tap into the communication process. Also, the remote unit can be placed in locations where it is not convenient to run wires, for example in a turbine. This makes it capable of sensing a condition non-intrusively.

2. Design of the corner cube reflector

Our designs are fabricated using a commercially available MicroElectroMechanicalSystems (MEMS) process [4]. This process gives two polysilicon layers that can be used as structural layers sandwiched by two sacrificial phosphosilicate glass layers.

Each corner cube is made of four 100–200 μm square polysilicon plates rotated out of the surface of the wafer using microfabricated polysilicon hinges as described in Ref. [5], and a long plate suspended by 100–200 μm long thin beams on either side. Two of the rotated plates form the right-angled corner while the remaining two plates serve as supports and orthogonal aligners for the former. For these purposes, the latter have finger-like structures on their upper right-hand corner whose first grid is aligned to the upright positions of the corner plates. An SEM of this structure is shown in Fig. 3.

The long suspended plate also functions as an integral torsional deflection actuator. This plate is actuated electrostatically to deflect the light, thus modulating the reflected intensity. Beneath this plate are two electrodes. One is the landing electrode at the end of

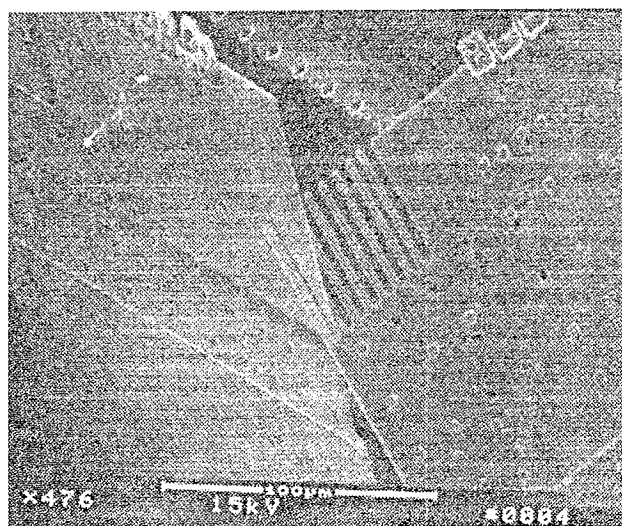


Fig. 3. Finger-like structures for alignment and support of orthogonal support.

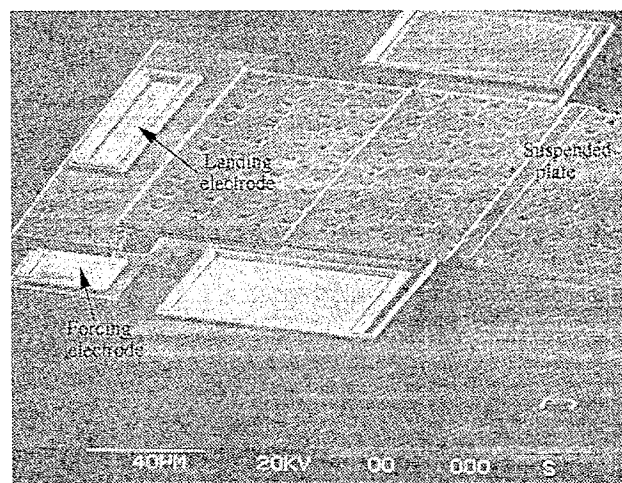


Fig. 4. A close-up view of the torsional electrostatic actuator.

the plate and the other is the forcing electrode. An SEM of these electrodes is shown in Fig. 4.

When a voltage is applied between the structure and the forcing electrode, the plate rotates downward about the axis of the beams. In the absence of an applied voltage, the beams, which act as torsional springs, bring the plate back to its equilibrium position. This is illustrated in Fig. 5.

3. Analysis of the actuator

If a voltage V is applied between the plate and the forcing electrode, the capacitance between them is:

$$C(\theta) = (\epsilon_0 W / \theta) \ln[1 + D/r(\theta)] \quad (1)$$

where

$$d/[r(\theta) + D + a] = \tan \theta \quad (2)$$

The total torque on the plate is τ :

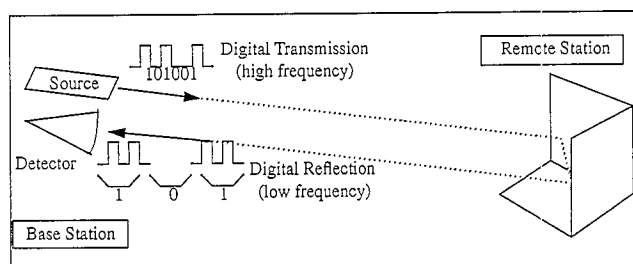


Fig. 2. Schematic diagram of the communication process.

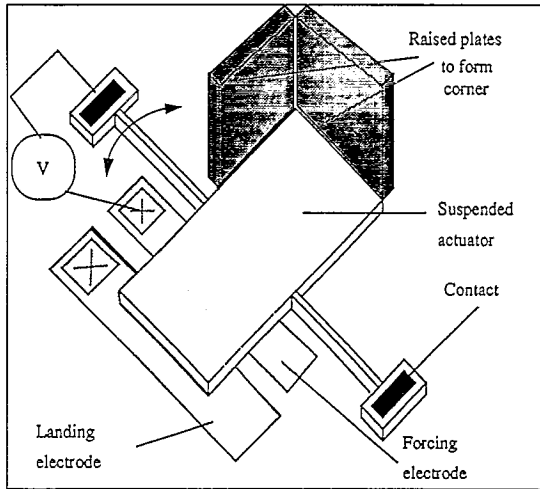


Fig. 5. Schematic diagram of the top view of the corner cube reflector.

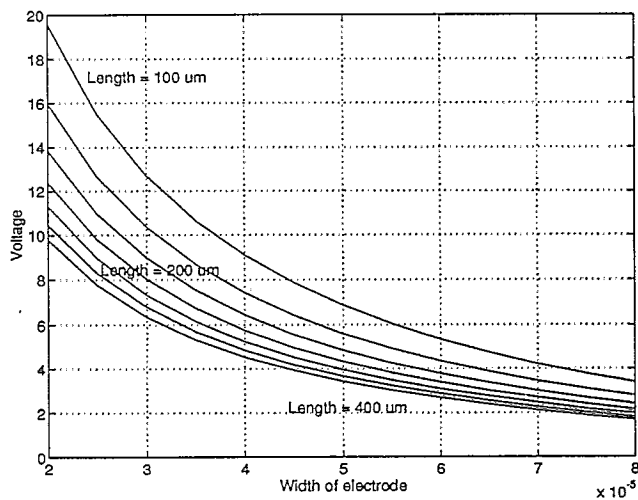


Fig. 6. Plot of theoretical actuation voltage vs. width of electrode for various beam lengths.

$$\tau = \frac{\delta}{\delta\theta} [C(\theta)V^2/2] \tag{3}$$

This torque causes a torsional twist in the beams:

$$\tau = \theta KG/L \tag{4}$$

where

$$G = E/[2(1 + \nu)] \tag{5}$$

The torsional moment of inertia for a beam with a rectangular cross section is K [6]:

$$K = wt^3\{1/3 - 0.21(t/w)[1 - t^4/(12w^4)]\} \tag{6}$$

A plot of the relation between actuation voltage and length of electrode is shown in Fig. 6. The values used in our calculations are shown in Table 1.

To determine the resonant frequency, we need to find the mass moment of inertia, J , of the plate:

$$J = tW^3\rho Wl/2 \tag{7}$$

Table 1
Parameters used in the equations and their typical values

Parameter	Typical value
L , length of beam (μm)	100
w , width of beam (μm)	2
t , thickness of beam and plate (μm)	1.5
l , length of plate (μm)	375
W , width of plate (μm)	200
D , length of electrode (μm)	80
d , gap under actuator plate (μm)	2.5
θ , angle of actuation ($^\circ$)	1
G , torsional modulus of beam (N/m^2)	7.68×10^{10}
K , moment of inertia of beam (m^4)	1.21×10^{-24}
a , distance from axis of rotation to electrode (μm)	20
ρ , density of polysilicon (kg/m^3)	2.3×10^3

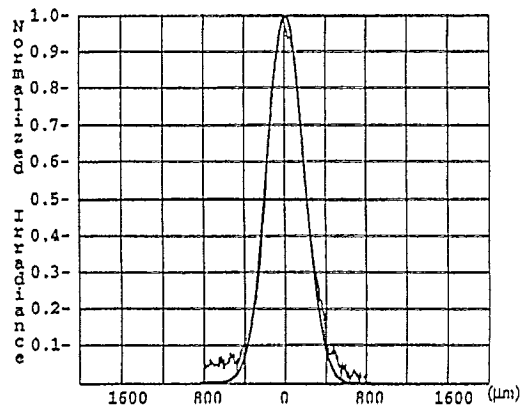


Fig. 7. Profile of reflection from a polysilicon plate 20 cm away from the detector with a superimposed Gaussian fit.

Assuming that the mass is concentrated at the center of the plate, the resonant frequency is then

$$\omega_r = (GK/JL)^{1/2} \tag{8}$$

Using the values given in Table 1, the calculated resonant frequency is 302 kHz.

4. Results and discussion

We have measured the forward scattering angle of a hinged polysilicon plate of dimensions given in Table 1 using a beamscope and obtained a beam profile shown in Fig. 7. The plot shows that at 0.17° from the centroid of the profile, the intensity has dropped to 5% of its peak. This means that in order to shift the reflection away from the detector, we only need to deflect the CCR by, at most, 1° . On the other hand, the system is required to have a cube with good orthogonality.

We have actuated the suspended plate with a periodic voltage signal. Reflections from the moving plate were monitored, and by calculating the distance by which the reflections shifted when the plate rotated, we could find the angle through which the plate had tilted. We obtained an angle of 1.4° , which would have been more

than sufficient to completely spoil the orthogonality in a cube. From the dimensions of the plate, we expected this actuation angle to be 1.6° . We have observed actuation with a voltage of 8 V for a plate with the dimensions given in Table 1 and an electrode length of $55 \mu\text{m}$. The theoretical model suggested a lower voltage of 6 V.

Next, we measured the reflectivity of polysilicon, the material from which the reflecting surfaces of the CCR were made. We obtained a reflectivity of 24%. From this, we would expect to see a reflection efficiency from the cube (3 bounces) of $(0.24)^3 = 1.38\%$. We then measured the power in the returning signal from the corner cube to confirm this. Our results showed that for an input power of $480 \mu\text{W}$, we received $6.5 \mu\text{W}$ in the returned signal, corresponding to a measured reflector efficiency of 1.35%.

5. Conclusions

A remote data transmission system using micro-machined CCR has been proposed. Microfabricated polysilicon corners have demonstrated 1.35% reflection efficiency. Reflection from isolated polysilicon plates has been mechanically modulated with an 8 V electrostatic signal. Measured reflection efficiency, actuation voltage, and modulation angle are all within a few tens of percent of the expected values.

Acknowledgements

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Biographies

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