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## Diffraction Optics Microsensors

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### 1. Introduction

The term Microsensor is typically used to mean a sensing device that is fabricated using microelectronic technology. The field of Microsensors has a fifty-year history starting with several key developments in the 1950's:

- The invention of integrated circuits.
- The discovery of piezoresistance in silicon.
- The discovery of selective etching of single-crystal silicon.
- The development of thin-film read heads for magnetic recording.

During the last twenty years, emphasis in this field has gradually shifted from basic research on materials and process technologies toward product development. Each year new products appear, and with these, an expansion of potential future opportunities. Microsensors have a bright future, both in the commodity arena and in the MEMS-enabled arena. The physical sensors, pressure, acceleration, rotation, and acoustic (microphones) continue to find new commodity-level markets. Sensors, whether commodity sensors such as the cell-phone microphone, or system sensors, are becoming smarter, more capable, and are finding new markets every day. In the present review we describe a wide class of microsensors based on diffractive optics element (DOE).

Diffractive optics is very versatile since any type of wave can be considered for computation within the computer. Digital holograms created with such technology are more commonly called DOE. Another name for DOE is *computer-generated hologram* (CGH). Because of these equivalent terminologies, the word DOE will be used in this chapter.

For their operation the diffractive elements depend on diffraction effects: DOEs are based on the effect of radiation diffraction on a periodic or quasiperiodic structure rather than on refraction as it is in the classical optics. The optical depth of a focusing element ranges within a radiation wavelength. In this respect, the zone plates (FZP) like lens may be referred to diffraction elements, i.e., to a class of quasioptical focusing systems, since according to the definition of quasioptics they are calculated, as a rule, by laws of geometrical optics, and the principle of their operation is based on diffraction effects.

There basic types of DQE are distinguished (according to the principle of their location relative to the direction of electromagnetic wave propagation) [1], they are: a transverse element (implemented primarily on a plane surface), a longitudinal-transverse element (on an arbitrary curved surface), and a longitudinal element (representing a set of screens situated along the direction of electromagnetic wave propagation). DQE can operate by the principle of "transmission" or "reflection".

The main advantages of using diffractive microlenses included:

1. The focal length is precisely defined by photolithography.
2. A wide range of numerical aperture value from F/0.3 to F/5 can be made.
3. Lens diameter can be in the order of few ten micrometer
4. Thickness is on the order of an optical wavelength 100% fill factor can be achieve
5. A DOE can perform more than one function, for example, have multiple focal points, corresponding to multiple lenses on a single element. It can also be designed for use with multiple wavelengths.
6. DOEs are generally much lighter and occupy less volume than refractive and reflective optical elements.
7. With mass manufacturing, they can be manufactured less expensively for a given task.

The simplest binary diffraction lens only required one mask to fabricate. However, the maximum focusing efficiency for a binary lens is less than 10%. Multi phase levels diffraction lens is required for higher efficiency. Theoretical efficiency of a multi phase levels diffractive lens is given by the equation.

$$\eta = \left[ \frac{\sin(\pi / M)}{\pi / M} \right]^2$$

Where  $M=2^m$  phase levels.

It is clear that by increasing the number of levels, the focusing efficiency also increases. An efficiency of 41% can be reach with two levels. By increasing the number of levels to 4, an efficiency of 81% is reach. 8 phase levels is a practical number of levels that allow high efficiency while keeping the number of mask alignment low. The efficiency for this value is 95%, while the number of masks required is 3.

To produce the desire focus length, one needs to calculate the required ring radius on each mask.

$$r(p, m) = \left[ \left( \frac{p\lambda}{n2^m} \right)^2 + 2F \left( \frac{p\lambda}{n2^m} \right) \right]^{1/2}$$

Where F is the desired focus length,  $p=0,1,2,3,\dots$ , n is the refractive index of the substrate,  $r(p,m)$  is the edge of opaque and transparent rings. For a positive lens with positive photoresist, the odd numbered zone gives the outside radii of the opaque rings, while the even numbered zone gives inner radii. During the fabrication, it is required to quantized the

phase step height and hence the phase shift by  $d(m) = \frac{\lambda}{(n-1)2^m}$ .

A few care is required for fabrication of a diffractive lens:

1. Due to the fact that the focusing efficiency of a diffractive lens is affected by the optical wavelength, a custom design for a particular wavelength is required in order to achieve desire performance.
2. To achieve maximum efficiency, the resolution of the fabrication tools is required to be smaller than the critical dimension of the lens.
3. All masks should align properly.

Let us briefly consider the main frequency properties of DOEs.

## 2. Zone plate as a frequency-selective optical element

The structure of the diffraction field in the focal region for the axial position of a pointlike radiation source was experimentally studied at wavelengths which are denoted below by  $\lambda_j$ ,  $j = 0, 1, 2, 3..$

The longitudinal distribution of field intensity for the actual position of the source reveals the maximum whose position on the OZ axis depends on  $\lambda$ . The dependence of the rear interval on wavelength can be found from expression [1]:

$$B_\lambda(n) = \frac{A^2 + (A + n\lambda / 2)^2 - 2(A^2 + r_n^2)^{1/2}(A + n\lambda / 2)}{2(A^2 + r_n^2)^{1/2} - 2A - n\lambda}.$$

where  $A$  and  $B$  are the front and back sections or the design distances from FZP to a source and the positions, respectively,  $\lambda_0$  is the design wavelength which in the general case differs from the wavelength  $\lambda$  diffracting on FZP,  $n$  - number of Fresnel zone. If  $B$  is averaged between its extreme values:

$$B = 0.5(B_\lambda(1) + B_\lambda(N)), \quad (1)$$

then expression (1) coincides, within the accuracy of calculations and measurements, with calculations by the Kirchhoff scalar theory as  $\Delta\lambda/\lambda_0$  varies within  $\pm 20\%$  and with experimental values for all  $\lambda_j$ . These results are plotted in fig. 1.

A similar dependence for a zone plate designed for focusing a wave with planar wavefront is:

$$B_\lambda(p) = r^2 p / 2N\lambda - N\lambda / 2p.$$

Here  $p$  is the number of phase quantization levels and  $N$  is the total number of Fresnel zones.

From the above it is followed that the FZP may be considered in the first approximation as a circular grating characterized by a constant  $L = F \cdot \lambda$ , where  $F$  is the focal length of FZP. Thus the focal length of FZP is inversely proportional to the wavelength and is determined by  $F = L / \lambda$ . The FZP resolves the incident radiation into monochromatic components. Since each component has its own focal point, it will be projected onto one element of the sensing array along optical axis. This means that the  $N$ -element linear array can detect  $N$  different wavelength components simultaneously.

It could be noted that a problem of synthesizing an amplitude-phase profile even of the simplest diffraction element such as FZP has no unique solution [1]. Usually, radii of Fresnel zones are determined from the condition of multiplicity to a half-wavelength of the difference of eikonals of a diffracted direct wave and a reference wave. This solution, however, is merely a particular case of a more general one. The essence of constructing such a general solution is that the notion of a *reference radius*  $R_0$  on the aperture of a focusing element is introduced [1].

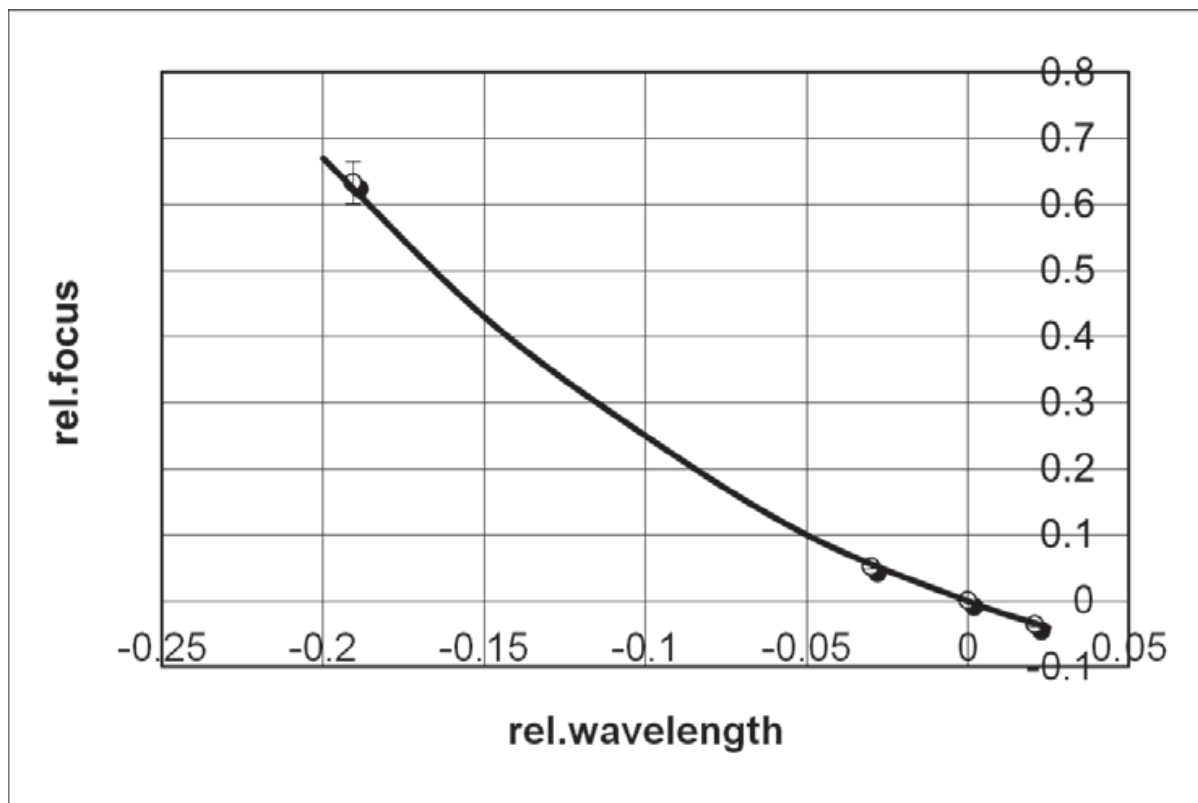


Fig. 1. The position of the focusing area as a function of wavelength of the incident radiation

### 3. Multiorder diffractive optics properties

Although it is often useful to think of a diffractive lens as a modulo  $2\pi$  lens at the design wavelength, the spectral properties or wavelength dependence of a diffractive lens are drastically different from those of a refractive lens. The dispersion of a diffractive lens is roughly 7 times larger (in optical waveband) than the strongest flint glass currently available and is opposite in sign. The quantization of the phase function of a diffractive element results in new properties of the element. One of these manifestations of discreteness of the phase function of the elements that we discuss is the possibility of selecting harmonics of coherent radiation. Analytical expressions for a four-level diffractive element were obtained in [1] for the gain of the axisymmetric element  $G$  at the main focal point corresponding to the reference wavelength:

$$G(N) = \left[ \sum_{n=1}^N A(n) \left\{ \cos\left(2\pi M \frac{\lambda_0}{\lambda} (MGiv(n) + 1)\right) - \cos\left(2\pi M \frac{\lambda_0}{\lambda} (Giv(n))\right) \right\} \right]^2 +$$

$$+ \left[ \sum_{n=1}^N A(n) \left\{ \sin\left(2\pi M \frac{\lambda_0}{\lambda} (MGiv(n) + 1)\right) - \sin\left(2\pi M \frac{\lambda_0}{\lambda} (Giv(n))\right) \right\} \right]^2$$

$$A(n) = \left[ \frac{4MF}{\lambda_0} + 2n - 1 \right] / \left[ \frac{4MF}{\lambda_0} + M(2n - 1) \right]$$

where  $N$  is the number of Fresnel zones within the aperture of the element;  $\lambda_0$  and  $\lambda$  are the reference and the actual radiation wavelength;  $F$  is the focal length and  $Giv(n)$  is the function equal to the maximum integral value of its argument. So diffractive lens offers the potential for several wavelength components of the incident spectrum to come to a common focus.

An analysis of this relation shows that the maximum gain (for constant signal-to-noise ratio) is achieved for the harmonic with the number  $\lambda_0/\lambda = M/2$ , while there is no focusing of radiation at the wavelength satisfying  $\lambda_0/\lambda = M$ , that is, this radiation is selected (fig. 2-3).

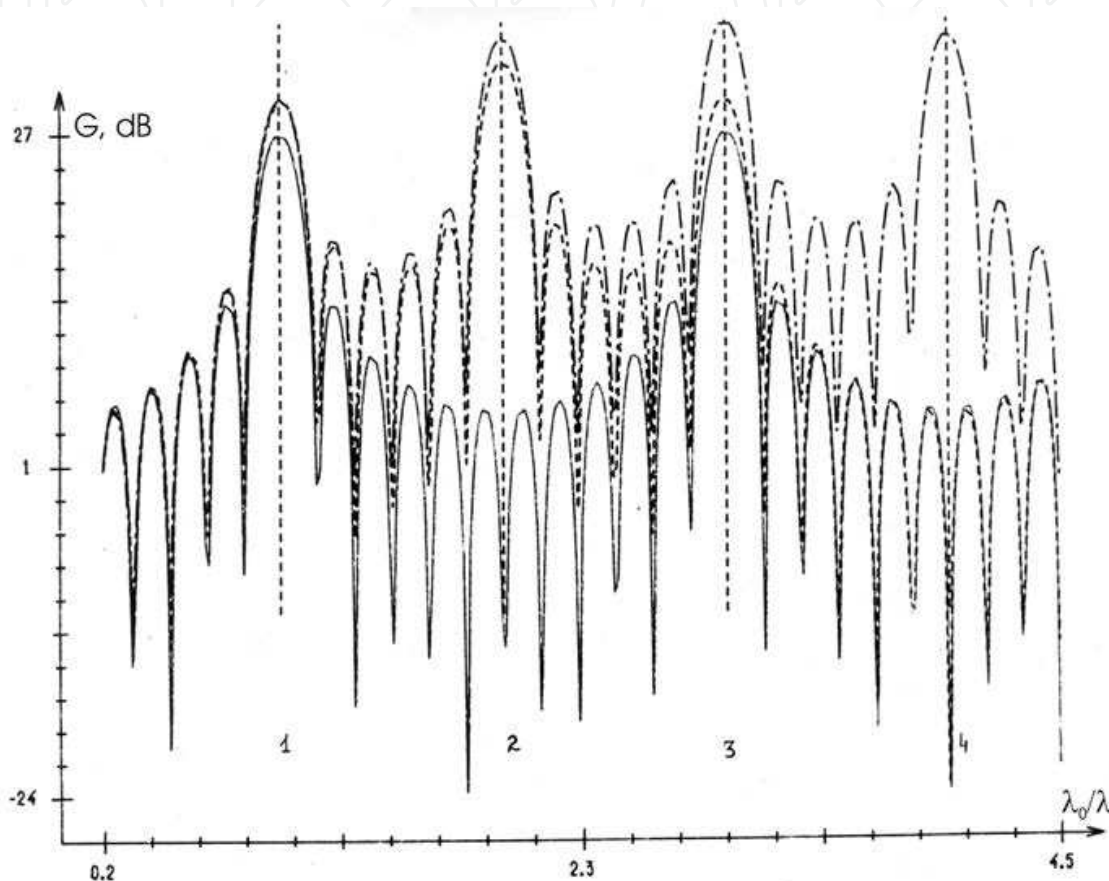


Fig. 2. Gain of a diffractive optical element for three numbers of phase quantization levels [20]:

— two levels,  
 - - - four levels,  
 - · - · - · six levels

It is important to note a well-known property of operation when higher diffracted orders are used. The wavelength bandwidth of the diffraction efficiency around a given diffracted order narrows with increasing values of  $n$ .

Spectrally selective properties of diffractive elements with a discrete phase function make it possible to use them for mixing a discrete set of wavelengths into the same focusing zone [1]. For instance, the following *theorem* is valid:

For radiation with harmonics  $\Lambda_i = \lambda_0/i$ ,  $i = 1, \dots, N$  in the interval  $Q = [\lambda_1 \dots \lambda_2]$  to fall within this interval, that is,  $\Lambda_i \in Q$ , it is necessary and sufficient for the maximum number of the harmonic to be  $N = i_{\max} = \text{entier}(\lambda_2/\lambda_1)$ , where  $\text{entier}(x)$  is the integral part of the real  $x$ .



The *proof* of this theorem is self-evident. The property of diffractive elements formulated above is also important for practical applications. Thus it may be possible to use this principle and design elements for the x-ray range of wavelengths, to design novel optical elements for optical polychromatic computers, etc.

As for the frequency and focusing properties of diffractive elements using radiation harmonics, their numeric and experimental analysis [1] revealed the following behaviour. When an element operates on a harmonic, the frequency properties expressed in arbitrary units are the same as the frequency properties of the diffractive element in the range of the main wavelength (reference wavelength)- see fig. 3 (in this figure  $n$  is the number of the frequency harmonic). This is also true for the transversal and longitudinal resolving powers of a diffractive element if we appropriately replace the current (working) wavelength in the expression.

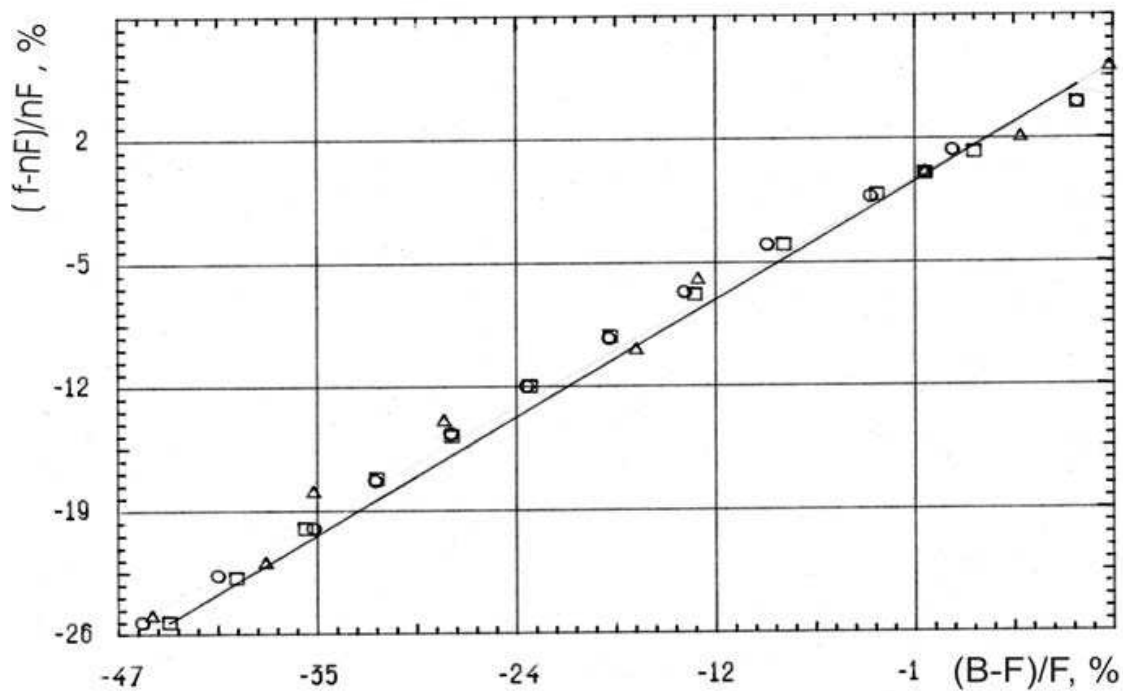


Fig. 3. Frequency properties of a zone plate for the first three harmonics:

$$dnF = (f - nf_0) / nf_0$$

open squares  $n=1$

open triangles  $n=2$

open circles  $n=3$

### 3.1 Chromatic confocal sensor

The frequency properties of a diffractive optics allow to modify, for example, a confocal (multifocal) sensor [2]. Working principle of frequency-scanning confocal sensor (microscopy) is as follows: the mechanical z-scan (Figure 4a) in conventional confocal systems is replaced by a simultaneously generated series of foci at different wavelength (Figure 4b).

This principle of frequency-scanning confocal microscopy may be applied at any frequency waveband.

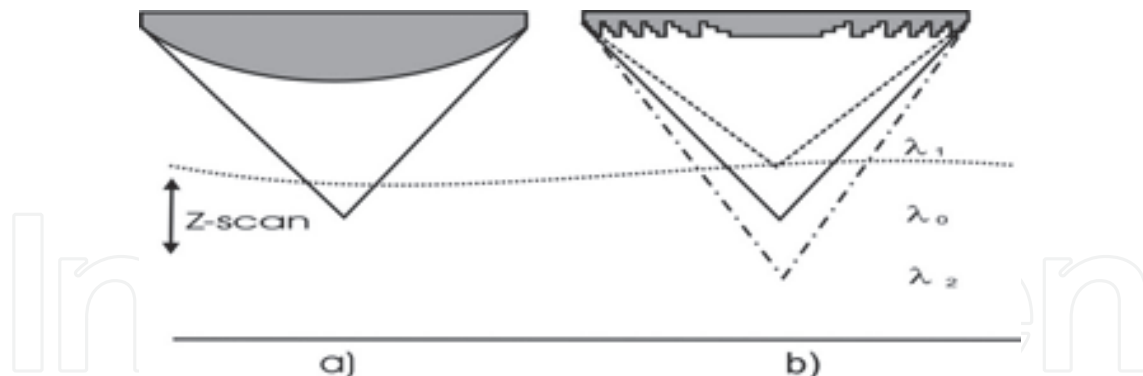


Fig. 4. Physical principle of frequency-scanning confocal sensor.

### 3.2 Wavefront sensor

Phenomena such as focusing or defocusing of a collimated beam by a lens and the free propagation of a Gaussian beam can be well described as changes of the curvature of a wavefront. The wavefront approach is also the most natural way of describing the operation of optical elements made of a material with a spatially varying index of refraction. Wavefront analysis is the enabling technology in the rapidly developing field of adaptive optics, etc. So the concept of a wavefront is important in optics and in the physics of waves in general.

A Shack-Hartmann Wavefront Sensor is a device that uses the fact that light travels in a straight line to measure the wavefront of light. The device consists of a lenslet array that breaks an incoming beam into multiple focal spots falling on an optical detector. By sensing the position of the focal spots the propagation vector of the sampled light can be calculated for each lenslet. The wavefront can be reconstructed from these vectors. Shack-Hartmann sensors have a finite dynamic range determined by the need to associate a specific focal spot to the lenslet it represents.

One of the key problems with the development of a Shack-Hartmann wavefront sensor is the fabrication of the lenslet array needed. The concept of using binary optics to fabricate these arrays are perspective. The binary optics technique has proven to be successful and is capable of making a large number of different devices with high fidelity.

The similar sensor may be used, for example, for flow measurements. One-dimensional linear sensor arrays that are capable of measuring the phase of optical radiation after it has propagated through the flow field are arranged on the opposite side. These wavefront sensors measure the optical path errors induced on the laser beams by the density variations in the flow caused by the mixture of heated air and entrained cooler room air in the jet. Although each sensor array detects the path-integrated phase in a particular direction through the flow, the set of sensor arrays collects information along many different directions through the flow simultaneously, enabling the inversion of the data set and yielding a detailed spatially resolved picture of the plane of the flow through which all the lasers propagated. When the set of sensor arrays in this optical tomography system is operated at speeds of several kilohertz, a tomographic movie of the flow structure in a 2D plane of the flow can be obtained frame by frame [3].

### 3.3 Fresnel zone plate spectrometer.

DOE can be made to simultaneously disperse the wavelengths of the incoming light - like a grating- at the same time they focus the energy. Figure 5 shows the set-up of Fresnel micro-



spectrometer with the opaque-center zone plate. A binary zone plate was typically designed with a concentric series of transparent and opaque rings. It is very interesting to note that when the radius of the zone plate is miniaturized by  $M$  times with a linear miniaturization factor  $M$  such that in paraxial approximation  $r_n = \frac{K}{M} \sqrt{n}$ , the focal length becomes  $\frac{K^2}{M^2 \lambda}$ , which is shortened by  $M^2$  times. Therefore when the zone plate is miniaturized by five times, the overall thickness due to the focal length is shortened by 25 times, thus approaching a thin-film structure. The focusing properties of the “scaled” FZP is considered in [1]. This miniaturization relation is valid in the Fresnel regime in paraxial approximation. When the optical length  $Z$  is changed with a linear scanning actuator, the photon intensity at the detector behind the round aperture slit is recorded with  $Z$  which corresponds to  $K^2/\lambda$  [4].

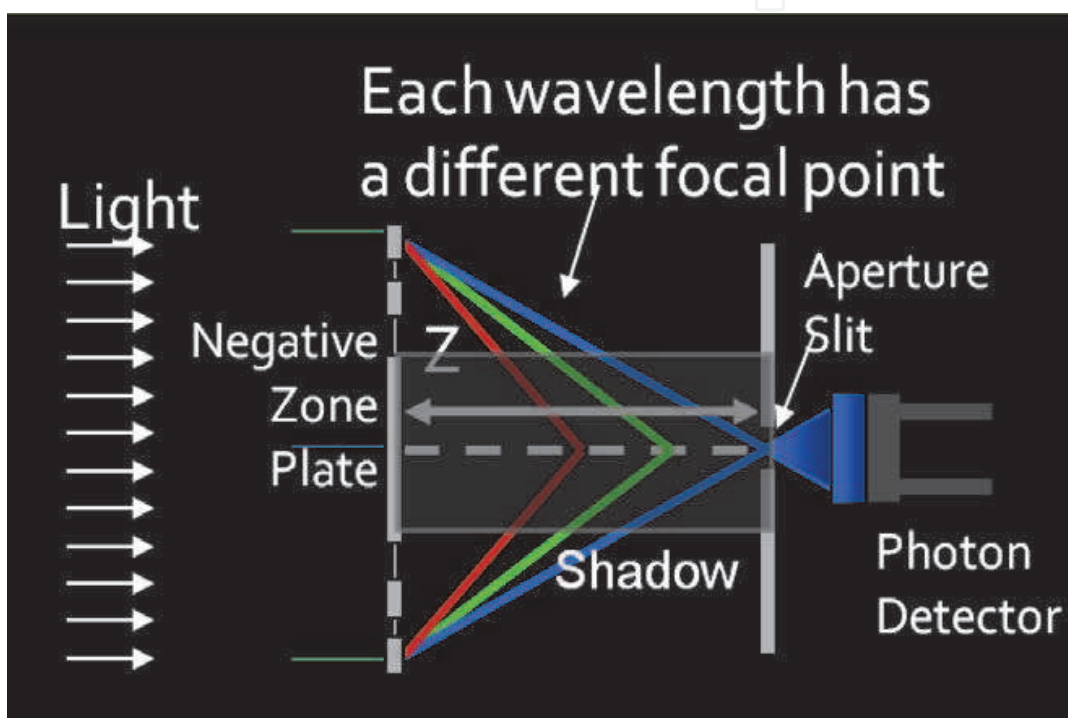


Fig. 5. Optical set-up diagram of a Fresnel micro-spectrometer with negative zone plate: cross-sectional view [4].

The authors [4] have demonstrated that the spectral resolution and resolving power of an ideal Fresnel micro-spectrometer do not depend on the miniaturized size but only on the total number of rings in the Fresnel regime. This is analogous to the spectral resolution relationship of a linear grating with Fraunhofer diffraction. The authors conclude that further miniaturized and improved spectrometers based on Fresnel diffraction can be built if the total number of rings is kept constant or increased.

Low-cost spectrometric sensors utilize both the dispersing and the focusing abilities of Fresnel zone-like diffractive structures [5]. The standard grating and collimating optics of a scanning spectrometer are replaced with a dispersive and focusing element. At the detector scan area the selected wavelength bands pass over the detector in a predetermined order giving rise to peaks in the detector signal. A DOE may be designed to focus two or more wavelength bands simultaneously onto the same detector position, and the power in the bands may be weighted relative to each other.

Reconfigurable components are well adapted to NIR spectroscopic sensors. In a feasibility study a diffraction filter was fabricated in Si [6] that is both re-configurable and focuses the light. It consists of an array of moveable segments of a Fresnel zone plate; each segment having a few grating grooves (Fig. 6). Each segment is actuated vertically by electrostatic parallel-plate actuators situated outside the optically active part.

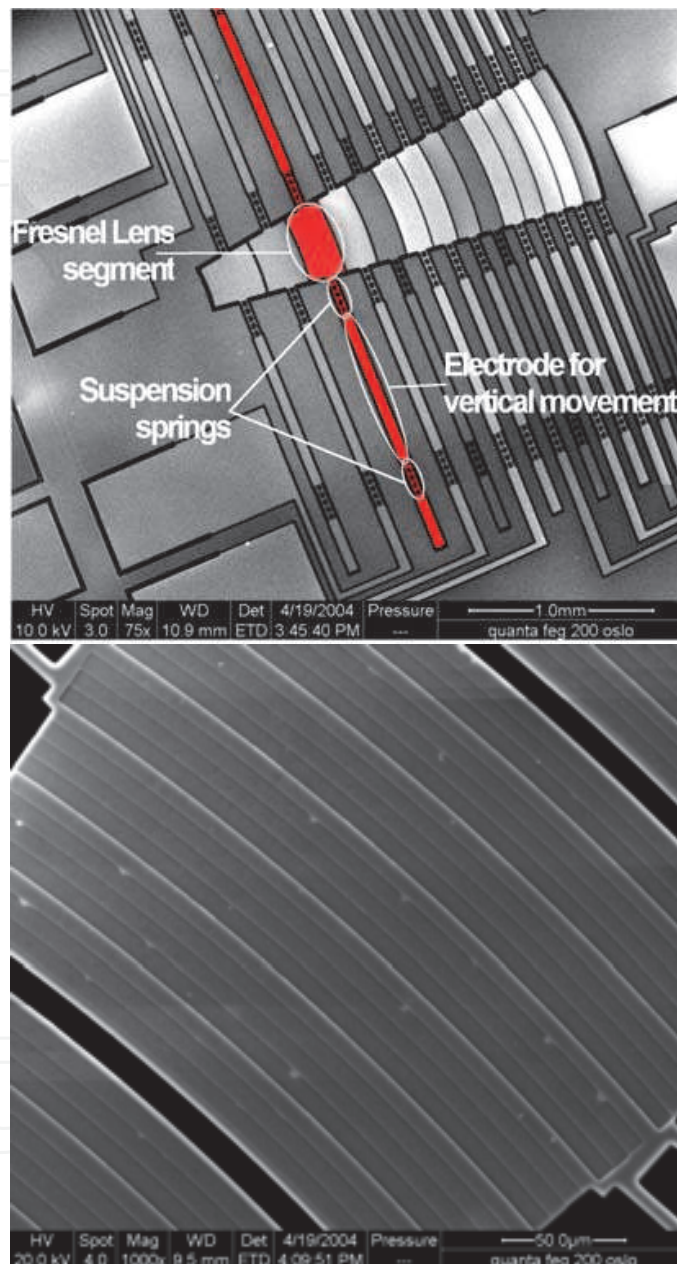


Figure 6. A micro-mechanical Fresnel lens with 14-segment (left) and a closer view at one segment consisting of 7 grating grooves (right), as seen with a scanning electron microscope [5-6].

In the idle mode the zone plate focuses a target wavelength at the detector. When every other segment of the structure was pulled down, a destructive interference occurs at the centre wavelength giving rise to a sideband on each side of the target wavelength. The target wavelength represents e.g. the absorption line of a gas and will be measured in the

idle mode of the actuator, whereas in the activated mode the background on both sides of the target line is measured.

### 3.4 Diffractive optical microphone

Optical microphones are able to solve major problems that capacitive sensors are suffering from. Optical sensors have no problems with high voltage biasing or need of electrical isolation. They are able to achieve equal or better sensitivity than capacitive displacement sensors with less demanding electronics. The authors describe a new approach where they integrate a diffractive lens into the microphone transducer [7]. An optical microphone consists of a membrane (based on diffractive optical element or Fresnel zone plate) that is deflected by sound pressure or an acoustic signal, where the movement of the membrane is measured by the change in transmitted light intensity due to diffraction. For a given displacement  $\Delta d$  of diffractive element surface we can maximize the change in measured optical power, given by the change in diffraction efficiency. The lens consists of a metallic pattern on the substrate, an air gap and a reflecting membrane as shown in Fig 7. The diffractive lens allows to use a simple optical readout system with no additional collimating or focusing optics.

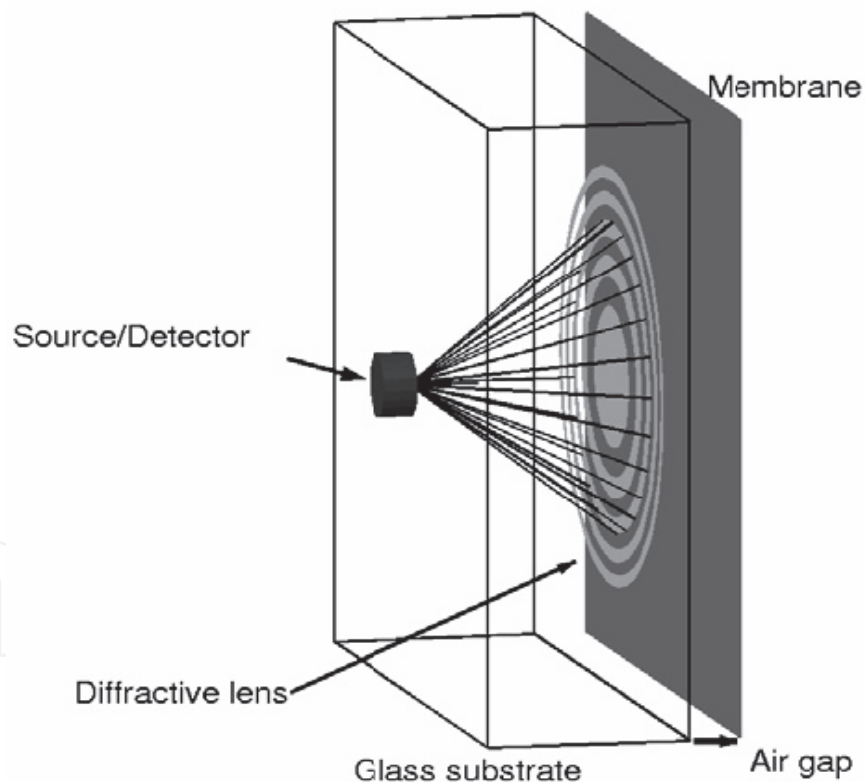


Fig. 7. Simplified geometry of the diffractive microphone. The optical fiber may be replaced by an LED source and a photodiode detector attached to the substrate [7].

By placing a source and detector in the focal plane of the diffractive lens, the measured intensity will be highly sensitive to the position of the membrane.

The diffractive lens was a glass substrate with a 2mm $\times$ 2mm chrome pattern in the form of a diffractive lens. The authors believed that the microphone can be cheaper, smaller, and are

well suited for integrated design and mass production with photolithography. The fiberbased diffractive lens microphone is suited for demanding applications such as nuclear radiation, medicine and areas with danger of explosion.

#### 4. Diffractive optic fluid shear stress sensor [8]

Accurate measurement of the wall shear stress is needed for a number of aerodynamic studies. Light scattering off particles flowing through a two-slit interference pattern can be used to measure the shear stress of the fluid. The authors [8] designed and fabricated a miniature diffractive optic sensor based on this principle. The developed sensor provided an integrated diffractive optical element (DOE) sensor that integrated the transmitter and receiver optics on the same substrate, as shown in Figure 8. The surface mounted sensor generates a pattern of diverging interference fringes, originated at the surface, and extended into the boundary layer region.

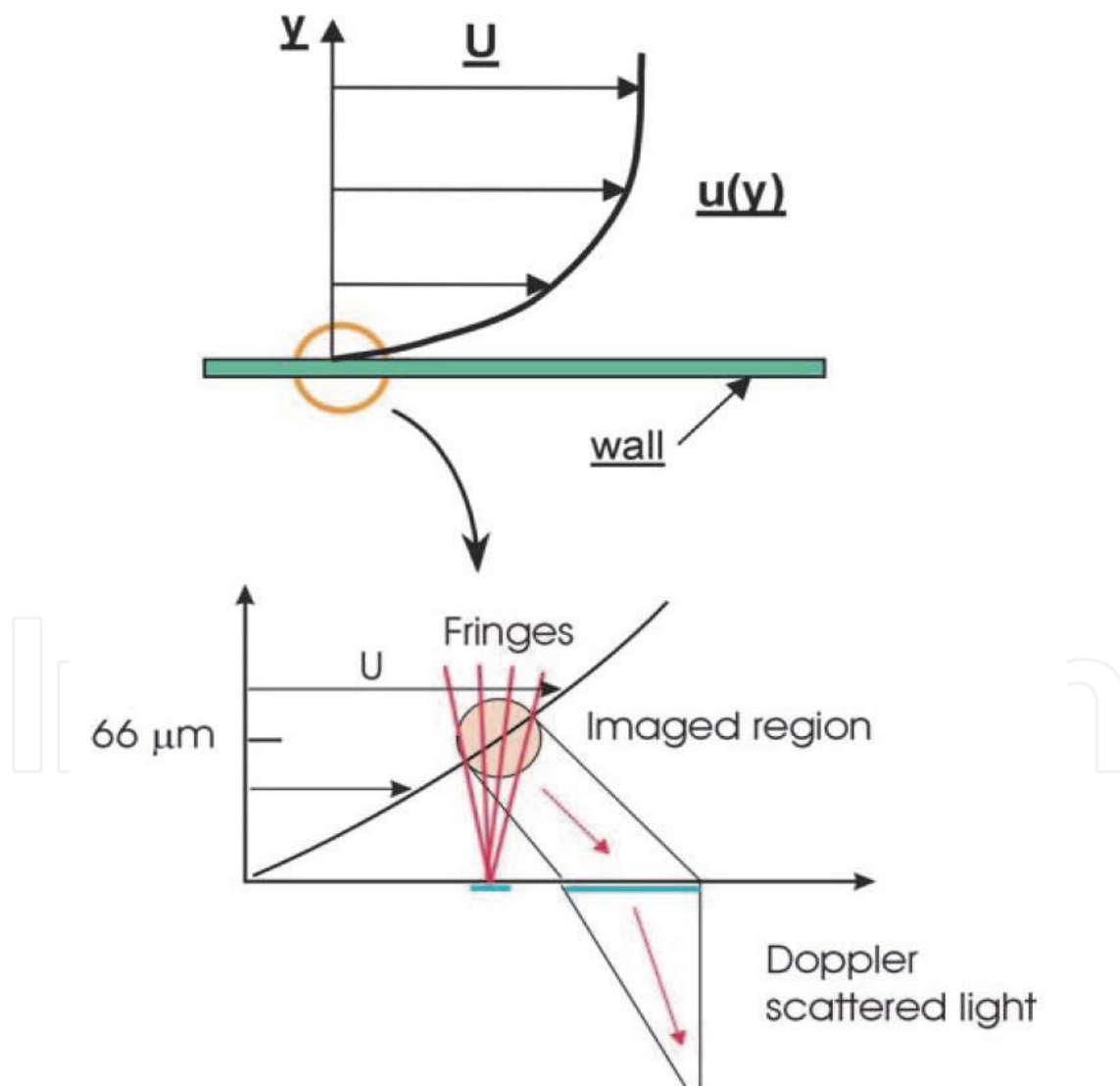


Fig. 8. Schematic of the Micro-shear stress sensor [8].



The intersection region of the transmission fringe pattern and the receiver field of view defined by the backscatter collection optics defined the overall measurement volume location and dimension.

A conceptual drawing of the micro-shear stress sensor is shown in Figure 9. The diverging light from a diode laser is focused by a DOE to two parallel line foci. These foci are coincident with two slits in a metal mask on the opposite side of a quartz substrate. The light diffracts from the slits and interferes to form linearly diverging fringes to a good approximation. The light scattered by particles traveling through the fringe pattern is collected through a window in the metal mask. Another DOE on the backside focuses the light to an optical fiber connected to a detector.

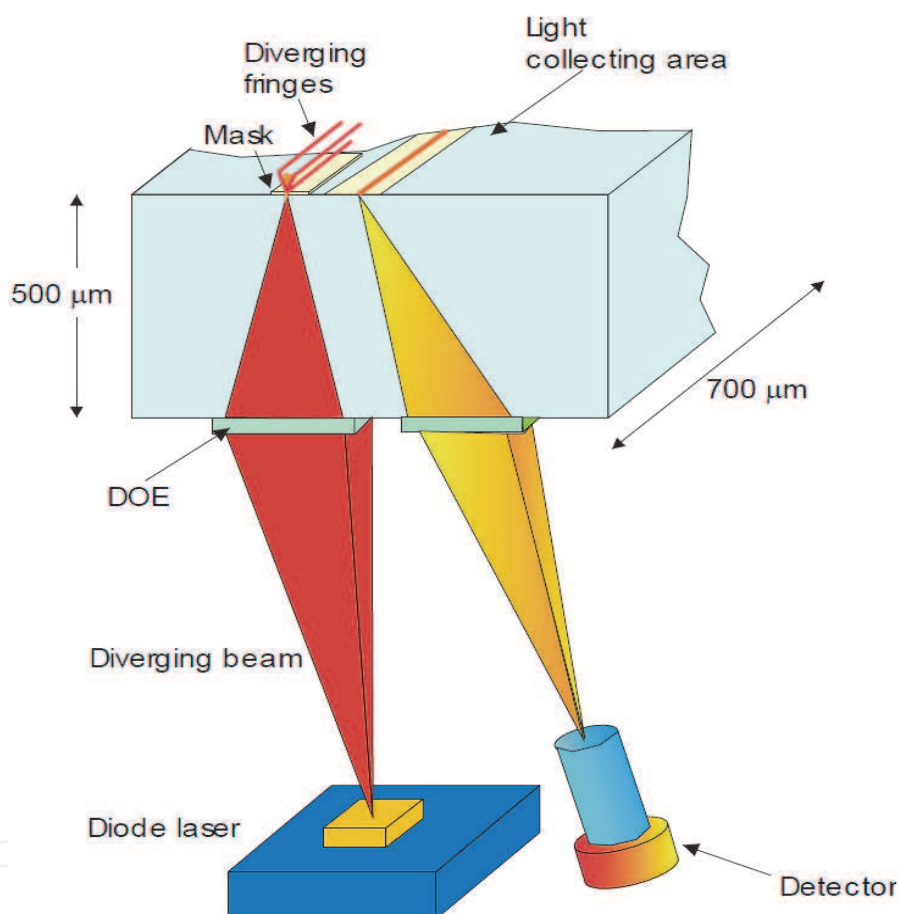


Fig. 9. Schematic of the shear stress sensor assembly [8].

The main sensor element was fabricated by two-sided lithography on a 500  $\mu\text{m}$  thick quartz substrate. The slits and collecting window on the front were fabricated by direct-write electron-beam lithography followed by wet etching of evaporated chrome. The polymethyl methacrylate (PMMA) diffractive optical elements on the back were fabricated by analog direct-write electron-beam lithography followed by acetone development [8].

The shear stress sensor's elements were assembled into a package (Fig. 10 left) with a diode laser (660 nm) and a port for the collection fiber. The overall size of this prototype is 15 mm in diameter and 20 mm in length. The fringes were imaged with a CCD camera using a microscope objective and are shown in Fig. 10. The fringe divergence was measured to be linear with a slope in close agreement with theory. The contrast is very satisfactory and

preliminary tests using a moving surface through the fringe pattern yield a clear signal. Testing of the receiver side of the sensor element is underway.

A photograph of the shear stress sensor is shown in Figure 10 (bottom). The sensor substrate, shown in, is mounted into the sensor element location shown on the front face of the assembly. The diverging fringe pattern is visible away from the surface. In this configuration, the light source and the detection electronics are located remotely and are connected to the sensor through optical fibers.

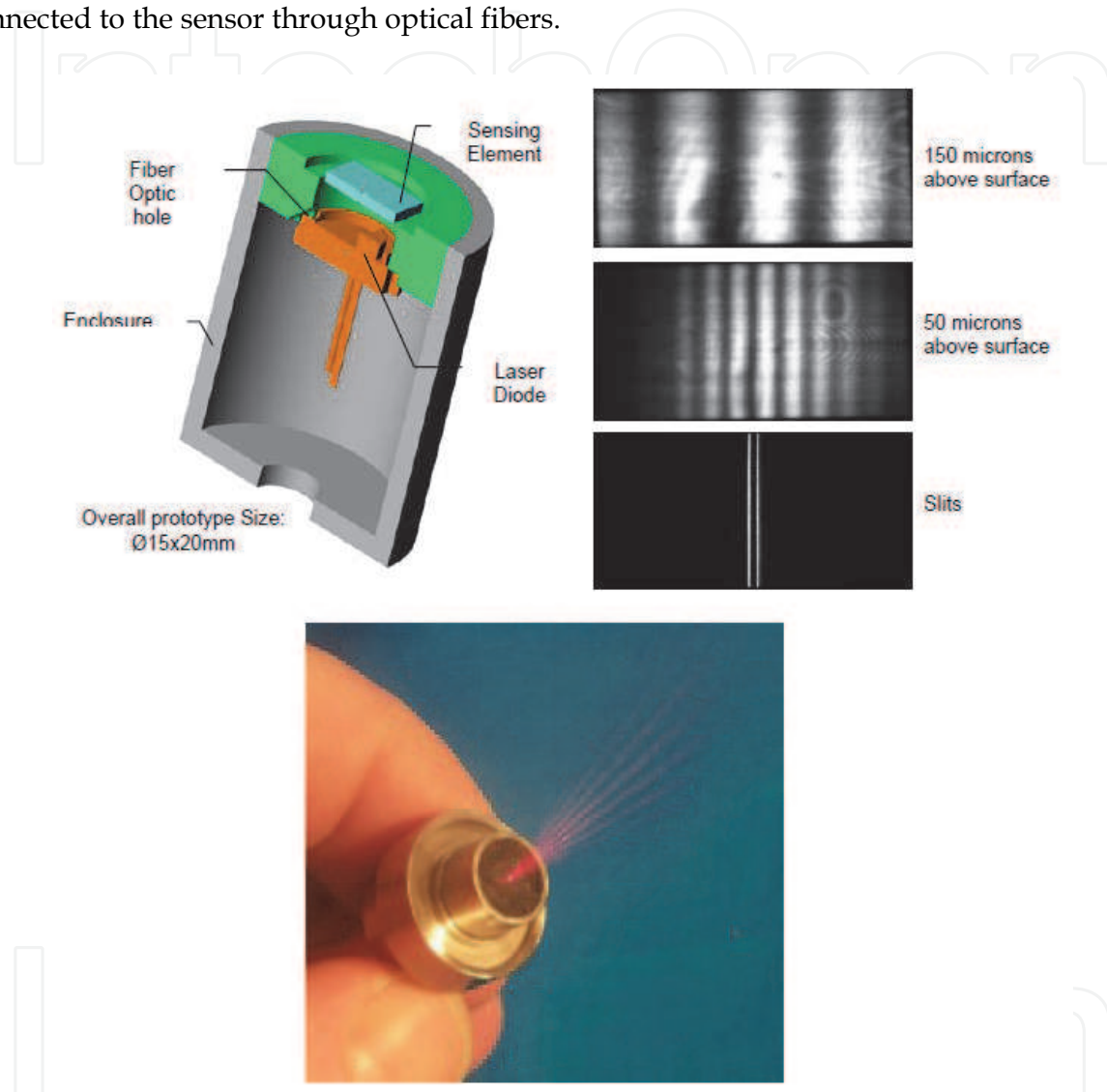


Fig. 10. Shear stress sensor assembly (left) and photographs of the fringes at different heights above the surface (right). Micro-optical shear stress sensor is shown in bottom [8].

#### 4.1 Remote point diffractive optical sensors

The ever-increasing need for sensing in the chemical and physical domain has led to the development of a variety of sensing schemes, including electrochemical and optical sensors. Alternative optical sensing methods use a remotely transmitted light beam to interact with a lossless material exposed to an analyte. A laser beam propagates in free space (or in optical waveguides/fibers), and by interrogating a suitable nanocomposite medium, the “sensor head,” it becomes modulated, thus producing the sensor signal. The sensor head is a



powerless (electrically passive) thin-film device of the environmentally sensitive material, not electrically connected to any power or signal processing unit. In a diffractive device, the environmentally induced changes of the optical properties are translated to measurable alterations of the transmitted/reflected diffracted beams. A diffractive  $\text{NiCl}_2/\text{SiO}_2$  nanocomposite photonic sensor for ammonia was demonstrated in [9]. The device has been fabricated on a thin-film structure using direct UV laser microetching techniques. The first-order diffracted beams were found to provide an appreciable sensor response at  $\text{SNR} \sim 18.6$ , which allowed the detection of quite low, 2 ppm, ammonia levels.

An optimization study of surface relief grating based sensors for use in diffractive optical remote point sensing was presented in [10].

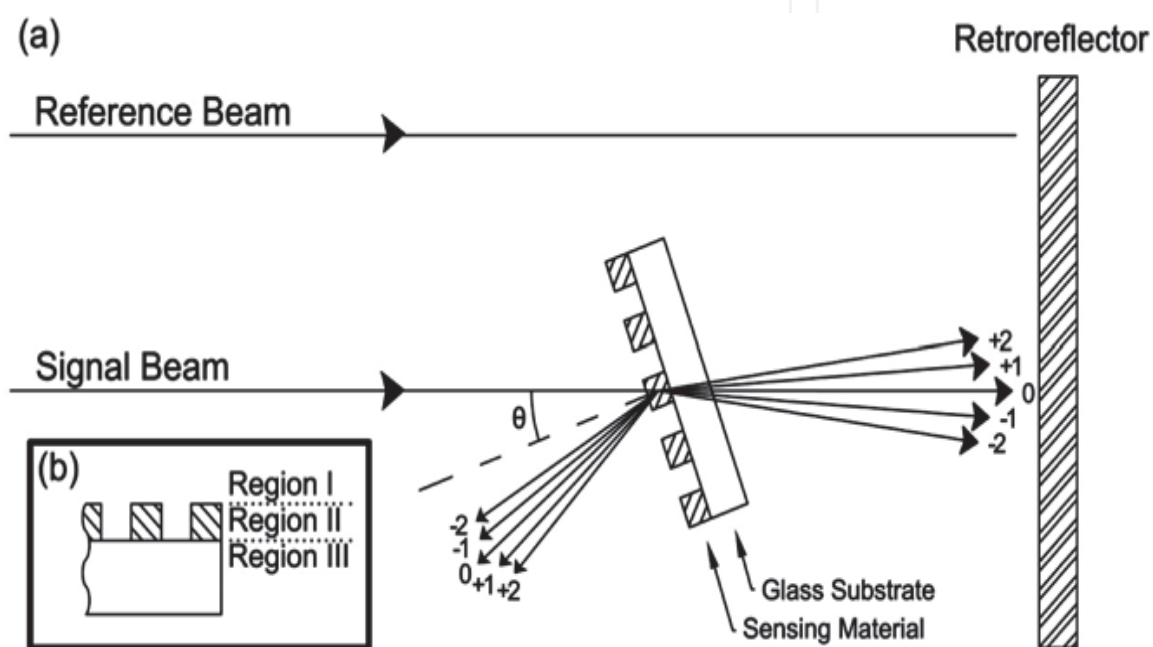


Fig. 11. Remote point sensing by the diffractive device. (a) Schematic overview and (b) SRG geometry used for theory and design [10].

The RPS concept is schematically depicted in figure 11. The passive sensor head consists of a sensing material thin film deposited on a glass substrate. The sensing material is designed to reversibly alter its optical properties upon exposure to a chemical or physical agent. The sensor head is placed in the area to be monitored and it is remotely interrogated in real time by measuring the reflected signal beam. DOEs and photonic crystals offer a unique potential for detecting effective changes of the materials. In the case of DOEs, the intensity and/or the position of the diffraction fringes strongly depend on the refractive index of the patterned material.

The results [10] reveal a strong oscillatory dependence of the diffraction efficiency on the grating depth that can be conveniently tailored by means of direct laser ablation. The dependence on grating period is also oscillatory with decreasing amplitude as the period increases. Duty cycle changes will affect the diffraction efficiencies but in a less pronounced way. It has been shown that an elegant and practical way to enhance the diffraction efficiency and hence the sensor responsivity, inherent to the remote point sensing scheme, is by changing the angle of incidence of the interrogating laser beam.

#### 4.2 DOE sensor for optical computer [1]

Optical computers promise very high speed of computation. The surge in computer speed (as compared with conventional computers of today) will be mostly achieved by greatly parallelized mode of operation. For instance, about  $10^6$  light beams in a common light beam can interact simultaneously with  $10^6$  elements of a logic matrix.

In addition to parallelism of data processing, optics has another resource for increasing the speed of optical computers: the polychromatism of radiation. Each of the million of light beams functioning in parallel may contain about a thousand spectrally distinguishable monochromatic components. Each of them is in principle capable of interacting simultaneously and differently with the same logical cell. On a single cell, it is possible to use 16 wavelengths simultaneously and realize a complete set of 16 logical functions. The results of interactions of other radiations with the same cell (repeating the same functions) can be treated as multiplexing, with simple separation of the results using dispersive elements. In this way, optical computers of future generations may have their speed increased by two to three orders of magnitude by using polychromatic nature of the light beam.

The implementation of optical digital computers mostly depends on the creation of optical logic elements (optical analogues of electronic gates) that carry out various logical operations (AND, OR etc) that would go beyond the speed of microelectronic devices and their degree of integration, also reducing cost and power consumption. At the moment, a number of optical switches were created, among which the most promising are optical interference filters, optical etalons (OLE - Optical Logic Etalon), bistable SEED that are devices with their own electrooptic effect (Self ElectroOptic Effect Device) and the so-called QWEST (Quantum Well Envelope State Transition) devices.

Diffractive (dispersive) elements can be used for spectrally selective addressing of signals, can be applied in polychromatic optical processors, serve as a basis for polychromatic logic elements or multiplexer or a focusing element with selectivity in the multimode regime etc.

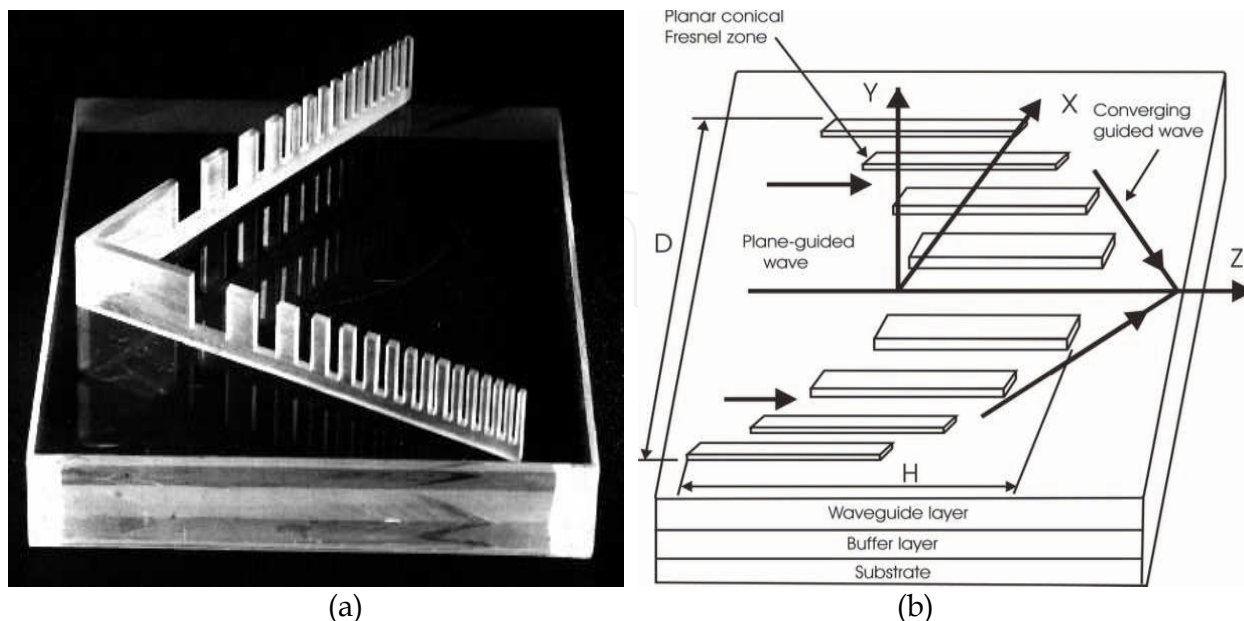


Fig. 12. (a) Diffractive planar element on a conical surface, (b) principal scheme of novel diffractive integrated optical element.

Diffractive planar elements fabricated on a non-flat surface make it possible to considerably enrich the “pool of devices” of integrated optics of different waveband, including THz, and to design elements with novel properties and potentials. This can be illustrated most clearly using as an example optical elements for optical polychromatic computers. For instance, the “conical” diffractive element discussed above can be used as a nonlinear device for polychromatic radiation or multiplexer or focusing element with selection of multimode regime. Frequency characteristics for such elements are determined by the extent of concavity (convexity) of the surface of the element and by the direction of incidence onto it. Therefore, when working on a wavelength  $\lambda \neq \lambda_0$ , the position of the focusing area in space (the amount of its displacement) should depend on the direction of incidence of the radiation. Hence, it is possible to distinguish between a signal incident on the “tip” of the element from that falling on its “base” by placing radiation receivers at the corresponding points in space.

It is just as easy to organize logic elements in a similar fashion. Let us consider as an example a diffractive element that focuses radiation emitted from one point onto two points. Such elements are two-dimensional analogues of a three-dimensional element that provides focusing of a point source to a ring. We will use this element “the other way around” – we let it focus radiation from two pointlike sources to a single point. Then, if we change the wavelength of radiation emitted by one of these two pointlike sources, the area of focusing will change its position in space: it will move transversally to the optical axis of the element. This is effectively a polychromatic logic element: if radiation frequencies at its two ends are identical, NO is the output; if input frequencies are not identical, no output signal is generated (or appears depending on the position of radiation receiver). In other words, logical elements “END” and “OR” are realized.

The principle of designing logical “AND”, “OR” elements makes it possible to implement a controlled switch. For this purpose, one of the inputs of the diffractive element is a controlling one, while the element itself has several outputs located in the region of focusing of the radiation and corresponding to the value of wavelength at the controlling input [1, 11].

## 5. Label-free Diffractive Optical Biosensor Technology

In the paper [12] describes technology for the detection of small molecule interactions in which a colorimetric resonant diffractive grating is used as a surface binding platform of a microtiter plate and a glass slide. The sensor structure, when illuminated with white light, is designed to reflect only a single wavelength. When molecules are attached to the surface, the reflected wavelength (color) is shifted due to the change of the optical path of light that is coupled into the sensor. By linking receptor molecules to the sensor surface, complementary binding molecules can be detected without the use of any kind of fluorescent probe or radioactive label.

The photonic crystal biosensors, often referred to as optical biosensors, are composed of a periodic arrangement of dielectric material that effectively prevents propagation of light at specific wavelengths and directions [13]. Individual optical biosensors are incorporated within each well of industry standard 96-, 384-, 384lv- and 1536-well microplates or 16-well cartridges. When illuminated with white light, the optical diffractive grating of the photonic

crystal reflects a narrow range of wavelengths of light which is measured by the BIND Reader (Figure 13). The wavelength of reflected light shifts upon a change in binding, or adherence, within proximity of the biosensor surface. Real time binding is observed by measuring the shift in peak wavelength value over time, including monitoring the binding of individual components in a multi-component binding complex or upon sequential rounds of cellular stimulation. The shift in peak wavelength is directly proportional to the change in mass.

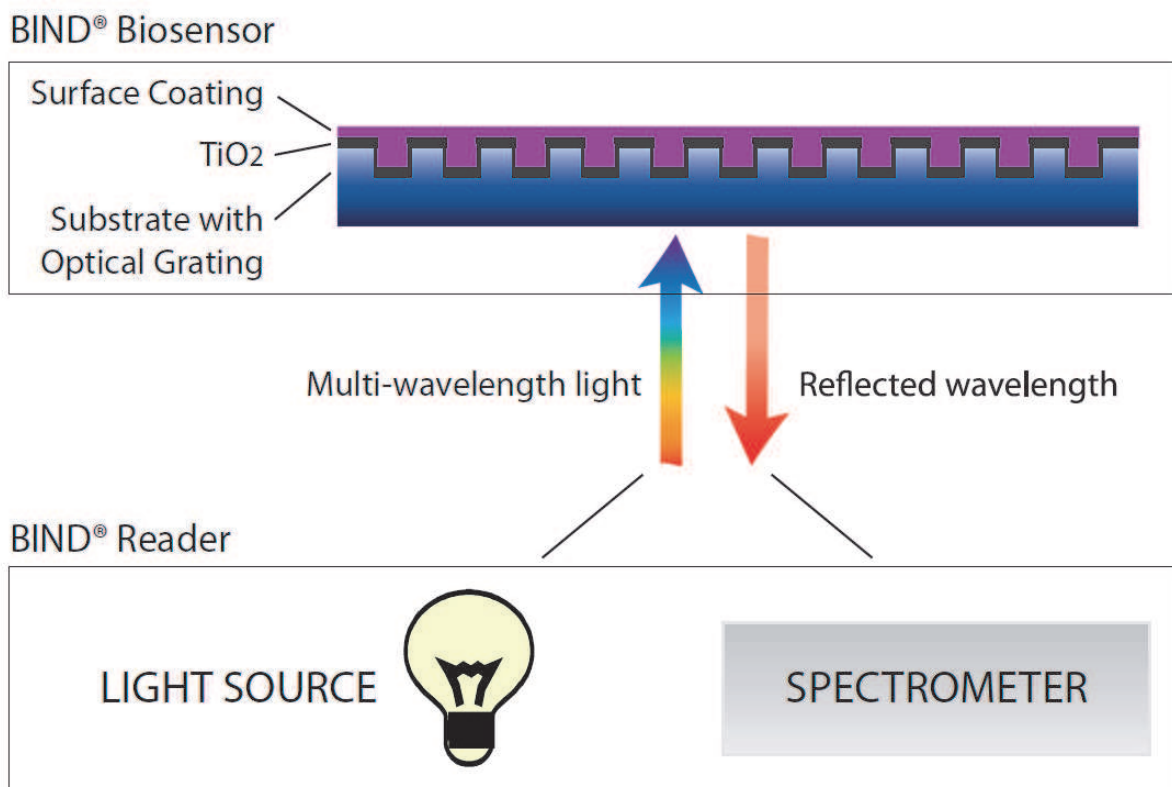


Fig.13. BIND Technology Optical Principles -BIND Biosensors incorporate photonic crystals which reflect a narrow range of wavelengths when illuminated with white light. BIND Biosensors can be coated with a variety of surface chemistries for optimization immobilization and assay performance. The BIND Reader illuminates biosensors and measures the wavelengths of the reflected light. [12-13]

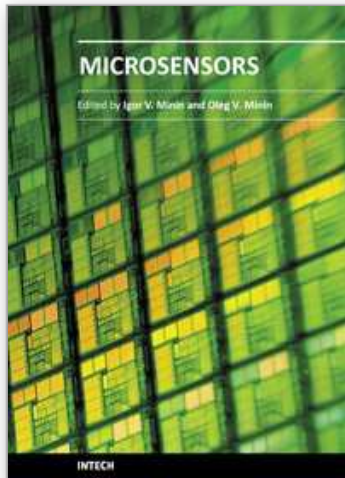
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## **Microsensors**

Edited by Prof. Igor Minin

ISBN 978-953-307-170-1

Hard cover, 294 pages

**Publisher** InTech

**Published online** 09, June, 2011

**Published in print edition** June, 2011

This book is planned to publish with an objective to provide a state-of-art reference book in the area of microsensors for engineers, scientists, applied physicists and post-graduate students. Also the aim of the book is the continuous and timely dissemination of new and innovative research and developments in microsensors. This reference book is a collection of 13 chapters characterized in 4 parts: magnetic sensors, chemical, optical microsensors and applications. This book provides an overview of resonant magnetic field microsensors based on MEMS, optical microsensors, the main design and fabrication problems of miniature sensors of physical, chemical and biochemical microsensors, chemical microsensors with ordered nanostructures, surface-enhanced Raman scattering microsensors based on hybrid nanoparticles, etc. Several interesting applications area are also discusses in the book like MEMS gyroscopes for consumer and industrial applications, microsensors for non invasive imaging in experimental biology, a heat flux microsensor for direct measurements in plasma surface interactions and so on.

### **How to reference**

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Igor V. Minin and Oleg V. Minin (2011). Diffractive Optics Microsensors, Microsensors, Prof. Igor Minin (Ed.), ISBN: 978-953-307-170-1, InTech, Available from: <http://www.intechopen.com/books/microsensors/diffractive-optics-microsensors>

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