Optical Antennas for Nano-Photonic Applications


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Abstract

In the recent past, the scientific and technological community has paid larger attention to nanoscale devices. Antenna-coupled optical detectors, also named as optical antennas, are being developed and proposed as alternative detection devices with nanoscale features for the millimetre, infrared, and visible spectra. Optical and infrared antennas stand for a class of optical components that couple electromagnetic radiation in the visible and infrared wavelengths in the same way that radioelectric antennas do at the corresponding wavelengths. The size of the antennas is in the range of the detected wavelength and they involve fabrication techniques with nanoscale spatial resolution. Optical antennas have already proved and potential advantages in the detection of light showing polarization dependence, tunability, and rapid time response. They also can be considered as point detectors and directionally sensitive elements. So far, these detectors have been thoroughly tested in the mid-infrared with some positive results in the visible. The measurement and characterization of optical antennas requires the use of experimental set-up with nanometric resolution. On the other hand, a computer simulation of the interaction between the material structures and the incoming electromagnetic radiation is needed to explore alternative designs of practical devices. In this contribution we will present the practical realization of optical and infrared antennas and some experimental results of their performance, along with the optical set-up arranged for their characterization in the visible.

The Optical Antenna Concept

Definition

An Optical Antenna is a detector for electromagnetic radiation in the infrared and visible portion of the spectrum. Its metallic structure couples the incident radiation and creates currents that are rectified by a transducer element. The metallic structures in charge of the radiation coupling are dimensioned within the range of the detected wavelength. The decoupling between the collection element (the metallic structure) and the transducer element (in charge of the conversion of the electromagnetic energy into an electric signal variation), makes possible to optimize separately both elements.

Advantages

Point-Detector Characteristics

Polarization Sensitivity

Time of response

Tunability

Integrability

The response of the dipole antenna shows polarization sensitivity both in the infrared (top) and the visible (bottom).

The collection area is of the order of J / its shape resembles the pattern expected for a radiotelectric dipole antenna.

The optical antenna provides an optimal detection point in the infrared and visible wavelengths. The response time depends on the physical mechanism involved in the rectifying element. MOQ-diodes have a theoretical limit of 10^-9 s. The choice of a given material-lay-out, the geometry of the connection lines, and the pre-amplification and conditioning electronics may limit the bandwidth of the devices.

Broadband tunability can be obtained by modifying the electric parameters of the point of operation of the optical antenna (top). Polarization tunability has been observed by changing the bias voltage (bottom).

Optical Antennas are fabricated by using a deep-lithography on Si substrates. This technique allows the integration of some other optoelectronic elements that may increase the performance of the fabricated devices.

Optical Antennas for Nano-Photonic Applications

Optical Antennas represent an alternative to semiconductor detectors, specially in those areas where polarization sensitivity, point-detection capabilities, and room temperature operation are more appreciated. Several applications are being developed involving optical antennas. Infrared imaging is probably the first to appear in the next future. Some other applications will need to wait until the concept is proved.

Characterization of Optical Antennas

The spatial, temporal, spectral and electro-optical characterization requires the use of measurement stations specifically developed for the task.

Optical Antenna Applications

Optical Antenna

Fractal Antenna

(pixel = 16 mm)

Read-Out Electronics

Real-Out Electronics

The performance of the individual elements can be enhanced by adding a Fresnel Zone Plate Lens (FZPL) that focuses the incoming radiation on the infrared antenna location. The plot on the right show the gain factor obtained in the signal when FZPLs are used. The white and filled circles are experimental data and the lines correspond with the numerical simulation of the performance for several types of incoming beam. The antenna is a square spiral shown in the insert of the plot.

References


Infrared Antennas: Four-dimensional Nanolocalization. The optical antennas are very well suited, both in size and in detection capabilities as nano-probes for the study of biologic and chemical reactions and processes. The concept shown here illustrate a future application of these probes for the three-dimensional localization of biologic reactions.

Three-dimensional Nanolocalization

Biomolecular reaction

Optical Antenna Probe

Optical antennas are very well suited, both in size and in detection capabilities as nano-probes for the study of biological and chemical reactions and processes. The concept shown here illustrate a future application of these probes for the three-dimensional localization of biologic reactions.

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Characterization station for optical antennas in the visible and the near infrared located at the Instituto de Optica de the Universidad Complutense of Madrid. This measurement set-up maps the spatial response of optical detector within a volume of 200x200x200 mm with a repetitivity of 50 nm along the three direction (5 nm of resolution). The optical source can be modulated to collect time response measurement. Also the state of polarization is limited by modifying the electric parameters of the point of operation of the optical antenna (top). Polarization tunability has been observed by changing the bias voltage (bottom).

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