

Physicists in Stuttgart manufacture and investigate 3-dimensional optical nanoantenna arrays:

Improving high speed optical data transfer by employing ideas from TV-antennas

Standard TV-antennas receive signals carried by electromagnetic waves with frequencies in the MHz-regime and convert them into pulses of electric currents in the connected cables. The antenna connects two very different length scales: the carrier wavelength, ranging from centimeters to meters, and the size of the wiring, typically on the millimeter scale. Now, physicists at the 4th Physics Institute of the University of Stuttgart in collaboration with researchers at the Max-Planck-Institute for Solid State Research successfully applied this radiofrequency antenna concept to the optical wavelength regime. They realized metallic structures of only 100 nanometer size, which efficiently receive optical frequencies in the range of several hundreds of THz. This opens up new possibilities to speed up optical data transfer. The results have been reported on Apr. 5, 2011, in the scientific journal Nature Communications.*)

Certain antenna geometries are known to receive radiation from designated directions. Such a unidirectional TV-antenna is the so-called Yagi-Uda-antenna, invented by Yagi and Uda in 1926. Consisting of several aligned parallel dipole antennas of different lengths, the Yagi-Uda-antenna can be tuned to receive signals from a given direction 5 to 10 times more efficiently than a dipole antenna. The received signal can be even more enhanced by several orders of magnitude when the single antenna is expanded to an array of Yagi-Uda antennas. Such antenna arrays are used to transmit signals over very large distances, for example in satellite communication.

The researchers who teamed up their efforts in the local research center SCoPE (Stuttgart Center of Photonics Engineering) have been inspired by this highly efficient signal transmission in telecommunication engineering and scaled down the concept of Yagi-Uda antenna arrays to optical wavelengths. PhD student Daniel Dregely fabricated 3-dimensional gold wire arrays of different lengths and stacked them one above another with nanometer precision. To achieve this, he used state-of-the-art nanotechnology and processed layer by layer with dielectric spacers in between. A periodic arrangement of the single Yagi-Uda nanoantennas then formed the investigated optical antenna arrays.

Measurements on the three dimensional arrays revealed that the amount of absorbed energy strongly depends on the angle of incidence and on the frequency of the incident electromagnetic waves. The scientists showed in particular that maximal absorption of incident radiation occurs at 200 THz, only if light impinges from the direction parallel to the antenna axis of the individual Yagi-Uda antenna. For this particular situation the incoming wave of 1500 nm length is confined to a subwavelength region extending to only about 100 nm. This can be used in future for very sensitive detection of near-infrared radiation

on the nanoscale. One of the big advantages of their optical antenna arrays is the fact that its three-dimensional character couples to radiation normal to the surface. This is in particular advantageous for light emitters, such as LEDs, or very sensitive photodetectors.

Furthermore, the researchers showed in numerical calculations that the combination of three-dimensional optical Yagi-Uda nanoantenna arrays with suitable feed circuits gives rise to the prospect of beam steering at optical wavelengths. Controlling the phase of the individual nanoantennas in the array leads to complete control over the emission cone direction. The scientists believe that the experimental realization of a “phased array” at optical wavelengths opens the pathway to new avenues in optical high speed data transfer on the micrometer scale, for example on microchips in high-performance computer circuits.

*) Daniel Dregely, Richard Taubert, Jens Dorfmüller, Ralf Vogelgesang, Klaus Kern, and Harald Giessen: “3D optical Yagi-Uda nanoantenna array”, Nature Communications **2**, xxx (2011)
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Tilted scanning electron micrograph of the optical Yagi-Uda nanoantenna-array.

Schematic picture of the three-dimensional optical antenna array.

Beam steering at optical wavelengths using Yagi-Uda nanoantenna-arrays powered by a phase modulating feeding circuit.