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Reviews
Web links
Calendar
PhysicsJobs
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News: September 2000

Back to Archive   Article 18 of 18

Quantum theory beats diffraction limit

[29 Sep 2000] The quantum-mechanical process that Einstein described as 'spooky action at a distance' could lead to new generations of smaller and faster computer chips. Normally the size of silicon chips is fixed by the so-called 'diffraction limit' - transistors and other features patterned by light cannot have dimensions smaller than half a wavelength. But now researchers at the Jet Propulsion Laboratory in the US and the University of Wales in Bangor have shown how 'entangled' photons could map out features that are many times smaller than the diffraction limit (Agedi Boto *et al* 2000 *Phys. Rev. Lett.* 85 2733).

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Computer chips are made using a process called optical lithography, in which light traces out patterns on a photosensitive substrate covering the silicon. The problem for chipmakers who want to make ever smaller components is that materials needed for lenses and other optical components are not effective at wavelengths below the ultraviolet. Optical lithography therefore cannot produce features smaller than about 100 nm.

Last year, Eli Yablonovitch and Rutger Vrijen proposed using 'classical' two-photon techniques to double the resolution of integrated circuits. In the latest work, researchers show how entangled photons could theoretically improve resolution down to 25 nm. When two or more particles are entangled, the wavefunction describing them cannot be factorized into single-particle wavefunctions, so entangled photons effectively behave as a single unit and their energies are combined. The wavelength of N entangled photons would therefore be reduced by a factor of $1/N$, decreasing the smallest feature size possible on a chip to $l/2N$. "We get round the frequency problem by the back door," says Sam Braunstein of the University of Wales, Bangor. "It's like using light at a higher frequency, because the photons act cooperatively."

The researchers consider the simple system in which chips are patterned in two dimensions using two interfering light beams. They say that in this set-up pairs of entangled photons could easily be produced using ’optical parametric down-conversion’, a process first carried out in 1995. High-energy photons pumped into a crystal would undergo non-linear diffraction and be ’split’ into two correlated photons.

Unlike other lithographic techniques under investigation, such as those using electrons or ions, this quantum method would require chip manufacturers to make only relatively minor changes to their expensive production processes, says Braunstein. However, several technical hurdles need to be overcome before this technique can be put into practice, such as finding a substrate that can absorb entangled photons.