How deep is a mirror? It depends, but the calculations are more precise now

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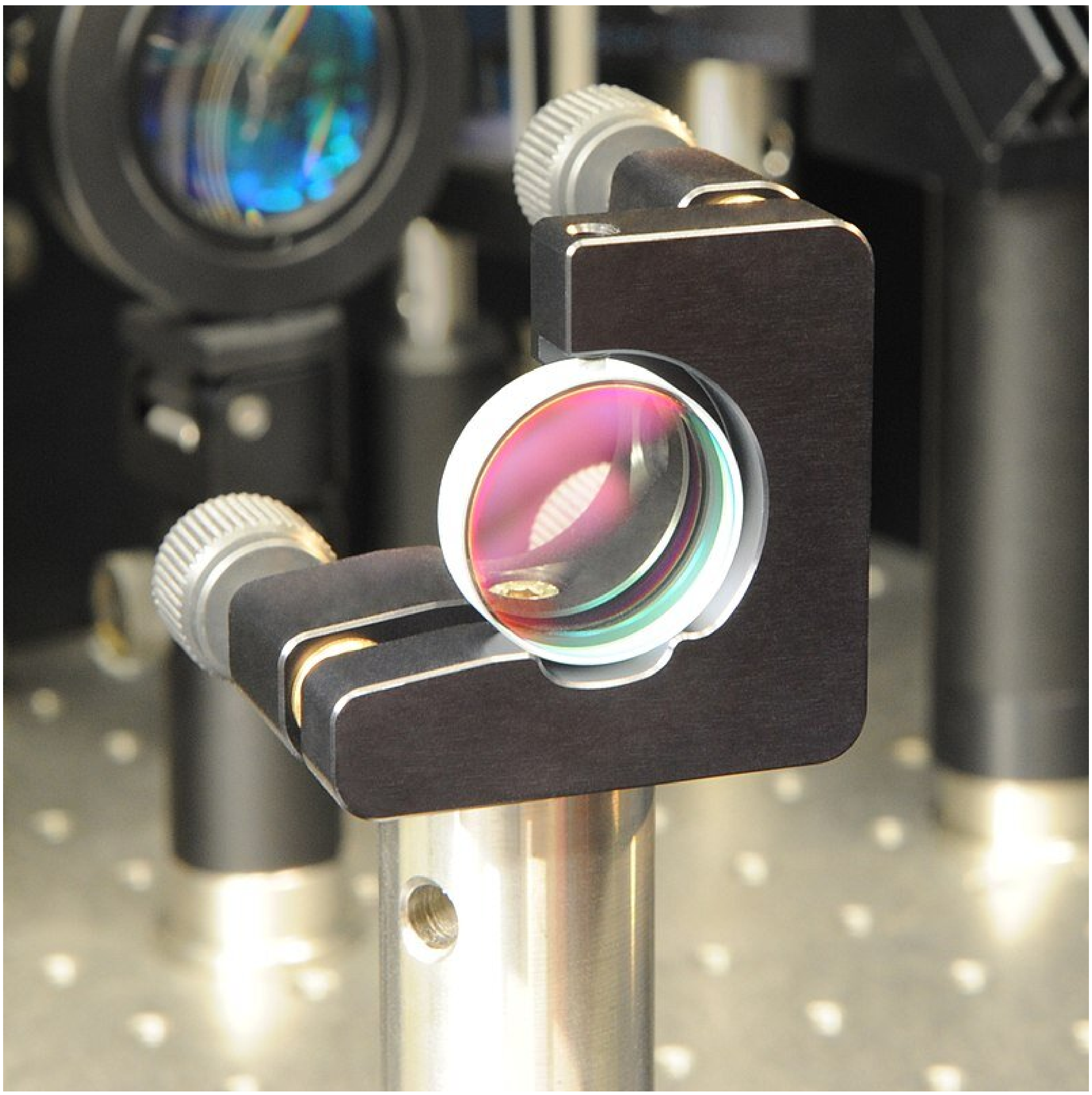

A DBR, aka a Bragg mirror. Credit: Wikimedia Commons

Light reflects from a mirror, but where exactly does this reflection happen? Well, it depends, Martin van Exter and Corné Koks discovered. Their precise calculations, published in *Optics Express*, have applications in the design of optical cavities for quantum communications.

"To tell you the truth, many researchers have been a bit sloppy," says Martin van Exter, discussing previous work. "We have dotted some i's and crossed some t's." Van Exter is talking about distributed Bragg reflectors (DBRs), the standard type of mirror used in physics. They are made of stacked layers of glass with alternating refractive indexes. Van Exter says, "They work very well. By just stacking enough layers, you can attain up to 99.99% reflection."

But a consequence of using glass is that light penetrates the mirror partly. How deep does this penetration go? Van Exter and Ph.D. student Corné Koks sought to find out.

"We use these mirrors to make optical cavities. Two small mirrors opposite each other, with the light reflecting back and forth. Pretty small mirrors, too," says Van Exter. The distance between the mirrors is only 2 or 3 micrometers, about a 50th the thickness of a hair. This is only a little larger than the wavelength of the light. "So for us, it matters how far the light penetrates the mirror."

Penetration depth

Koks and Van Exter carried out a thorough mathematical analysis of the behavior of electromagnetic radiation in DBRs, and concluded that there are three different penetration depths, depending on what one would like to measure.

Light within a cavity can be a standing electromagnetic wave, with nodes (where the amplitude is zero) and antinodes (where the amplitude is maximal). The point in the mirror where the node is located was dubbed the phase penetration depth by Van Exter and Koks. "This penetration depth is not very deep, typically almost on the surface of the mirror," says Van Exter. "This holds for light of one wavelength. But sometimes, you don't use single wavelength, but a pulse. When you calculate how fast this pulse returns, and therefore from what depth, the penetration depth turns out to be larger. This, we call the frequency penetration depth." Next to that, the physicists defined a third modal penetration depth, applicable for a sharply focused beam of light.

Sloppy calculations

The conclusion is that there are three different penetration depths. Selecting which one to use depends on exactly what you want to measure. "These are no revolutionary changes," says Van Exter, "but we do show this for the first time, and we note that physicists are often sloppy when calculating their optical setups."

The differences are important for optical cavities made by Van Exter's research group. These can possibly be used for quantum communication in the future. Van Exter says: "One of the holy grails is to transfer the quantum state of a photon to a single atom or molecule, or vice versa. You might be able to do that by reflecting the light back and forth in an optical cavity holding one atom. But then you must be able to calculate the exact size of your cavity, and therefore the depth of your mirror."

More information: C. Koks et al. Microcavity resonance condition, quality factor, and mode volume are determined by different penetration depths, *Optics Express* (2021). DOI: 10.1364/OE.412346

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