Metal-coated

Dielectric micro-cavity semiconductor lasers used to have dimensions of many times the wavelength of the emitted radiation. Now, Australian Martin Hill has succeeded in designing and building a metallic nano-cavity laser with dimensions that are substantially smaller than the wavelength of the emitted light. He has made a success of a job that experts considered virtually impossible, thanks to his own tenacious determination and to the elaborate facilities at Eindhoven University of Technology (TU/e). The new laser is still in the laboratory phase of development and operates at liquid nitrogen temperature. TU/e researchers work hard to make the laser function at room temperature. Hill's achievement creates prospects for clock frequencies in the Terahertz range (i.e. 10^{12} s-1) and incredibly small switching energies below 1 fJ (i.e. 10^{-15} J).

• *Frans Zuurveen* •

Martin Hill (see Figure 1) performed his research at COBRA, the Eindhoven-based, Inter-University Research Institute on Communication Technology Basic Research and Applications. His laser has a diameter of 210 nm and its dimensions can be reduced considerably further, far below half a wavelength, which seems contradictory to laser fundamentals. However, metallic sidewalls enable reduction of laser dimensions far below the wavelength. Before Hill's publication in the leading journal Nature Photonics, many researchers were convinced that such metallic cavities would exhibit too high losses to achieve laser action, but Martin Hill's perseverance showed that this conviction was wrong.

Figure 1. Martin Hill calculating the performance of his laser. (Photo: Bart van Overbeeke)

nano-cavity laser

Meint Smit, Eindhoven professor in opto-electronic devices, sees a great future for metallic nano-cavity lasers. Their tiny dimensions allow them to serve as the basis for high-speed digital processors, with up to a hundred thousand lasers in one opto-electronic circuit. Such opto-electronic ICs might be a factor of 100 faster than transistor ICs. They are less suited for memory circuits, however, because of their much higher static power consumption.

A submicron pillar

The basic geometry of this smallest laser in the world is shown in Figure 2. In reality, the laser consists of more layers than shown in the figure but for a better understanding, only three layers are represented. In a double hetero-structure, an active layer of a few hundred nanometres of InGaAs with an emission wavelength of about 1.65 μm is cladded between an n-type and a p-type doped InP layer. This structure is covered with a thin dielectric layer of 10-20 nm SiN. Finally, a layer of silver is deposited to form a lasing cavity.

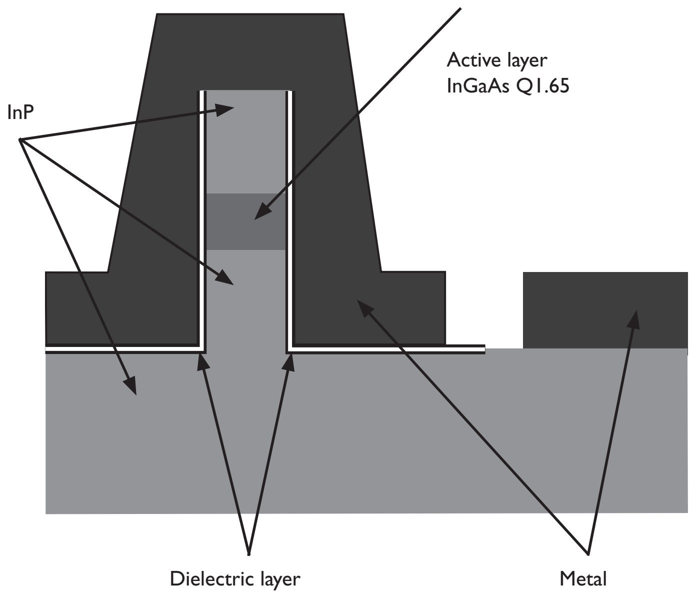

Figure 2. Structure of the metal-coated semiconductor nano-cavity laser.

Figure 3 shows the laser structure as a pillar 200-300 nm in diameter and 1 μm in height observed with a scanning electron microscope. In practice, the various layers are firstly deposited on a wafer after which the pillars are formed by e-beam lithography and ICP etching. After depositing SiN and metal, the dielectric layer is selectively opened to apply a metal contact layer.

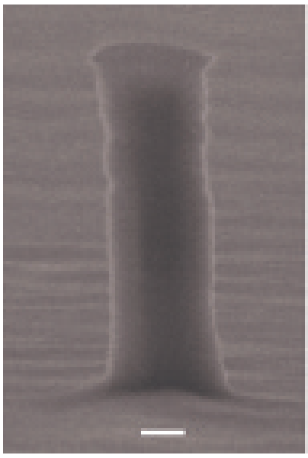

Figure 3. SEM image of the pillar-like laser structure.

Part of the light in the cavity escapes through the bottom of the pillar and can be detected through the substrate, which is transparent for the emitted infrared light. In the future, slits in the metal wall will produce more efficient coupling of light out of the cavity. Figure 4 shows the simulated light distribution of the lasing mode. The experimental set-up for testing the nano-cavity laser is represented in Figure 5.

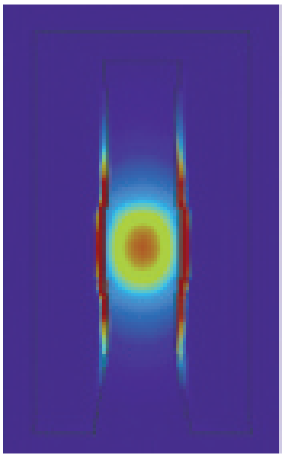

Figure 4. Simulated light distribution of the lasing mode.

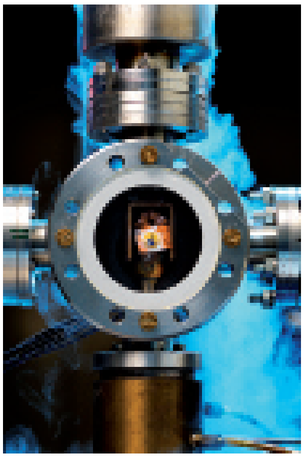

Figure 5. Experimental testing set-up. (Photo: Bart van Overbeeke)

Plasmonics

Figure 6 shows some of Hill's metal-coated nano-cavity lasers. Their small dimensions can be explained by the interaction of plasmons and photons. Plasmons are virtual particles that originate from the quantisation of oscillations in plasmas and metals. They play a part in the light reflection properties of metals. Light of frequencies below the plasma frequency is reflected, because the electrons in the metal shield the electric field from the light. Light of frequencies above the plasma frequency is transmitted because the electrons cannot respond fast enough to shield it. In most metals, the plasma frequency is in the ultraviolet range, making them reflective in the visible range.

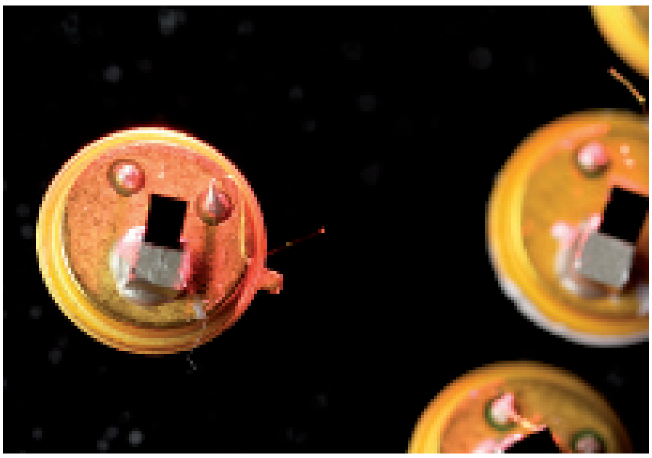

Figure 6. Some of Hill's metal-coated nano-cavity lasers. (Photo: Bart van Overbeeke)

Martin Hill made use of software that he modified for his purposes from a program he used when working in the Korean Advanced Institute for Science and Technology. With his adapted software, he could calculate and simulate resonance effects in his new laser. Figure 7 shows the light spectrum of his laser with a sharp peak at the 1400 nm wavelength. The inset shows spectra measured just below and above the threshold current of 6 µA.

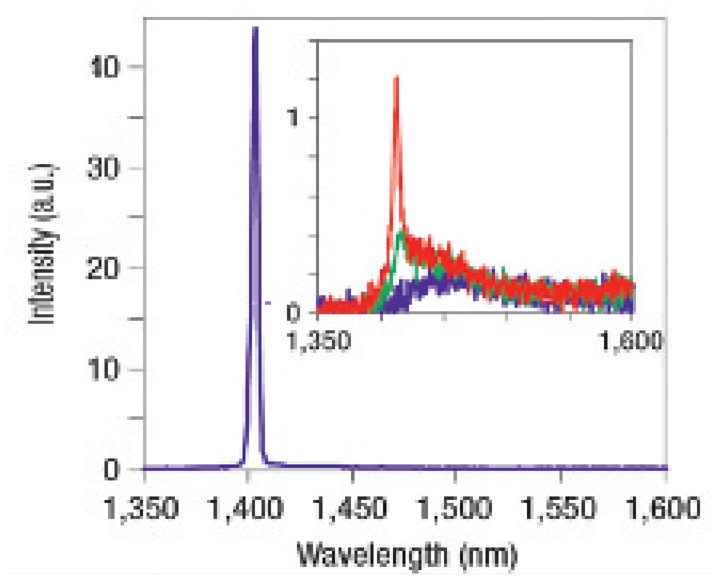

Figure 7. Measured light spectrum of the laser with a sharp peak at the 1400 nm wavelength. Inset: spectra just below and above the threshold current of 6 µA.

Author's note

Frans Zuurveen is a freelance text writer in Vlissingen, the Netherlands.

References

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