Infrared Nanophotonics based on Metal Antennas and Transmission Lines

M. Schnell[1], P. Alonso-González[1], F. Casanova[1,2], L. Arzubiaga[1], L. E. Hueso[1,2], A. Chuvilin[1,2], R. Hillenbrand[1,2]

[1] CIC nanoGUNE Consolider, Tolosa Hiribidea 76, 20018 Donostia – San Sebastian, Spain
[2] IKERBASQUE, Alameda Urquijo 36-5, Basque Foundation for Science, 48011 Bilbao, Spain
m.schnell@nanogune.eu

Metal antennas and transmission lines are common devices for receiving and transporting signals in the radiofrequency regime. Here, we demonstrate that by reducing the size down to the micrometer range, these devices can be operated at infrared frequencies (~30 THz) [1,2]. We apply our recently introduced vector near-field microscopy technique [3] for directly visualizing the reception and transport of infrared energy [4]. The combination of antenna plus transmission line is a promising platform technology for designing future mid-infrared devices which require subwavelength-scale integration.

The transmission line that is used here consists of two parallel wires that are isolated by a small gap (Fig. 1b). This structure is the miniature version of a very common TV cable known as the ladder line for connecting the roof antenna with the television set. A dipole antenna is connected to one end of the transmission line for converting free-space radiation into a confined mode. By illuminating the antenna with infrared radiation ($\lambda \approx 10\mu m$), a surface wave is launched which is travelling along the transmission line to the right side. Fig. 1c shows the momentary near-field distribution of the surface wave that is tightly bound to the metal wires. The image reveals that the surface mode has an asymmetric charge distribution. Moreover the image allows for determining the wavelength of the surface mode. Numerical calculations confirm the experiment with excellent agreement (Fig. 1a).

Based on these transmission lines, we compress infrared energy to a nanoscale focus spot of 60 nm [4]. This is achieved by tapering the end of the transmission line, i.e. gradually reducing the lateral dimensions. By propagating along the taper, the surface mode is compressed to deep subwavelength scale dimensions ($\lambda/150$). Interestingly, we observe that the wavelength of the surface wave is still of the order of the free-space wavelength. This is in strong contrast to plasmon compression where the field confinement is connected with a large increase of the wave vector.

The compression of infrared surface waves with tapered transmission lines opens the door for the development of ultra-small integrated infrared sensor and spectroscopy devices for chemical and (bio)medical diagnostics.

References

[1] T. Mandviwala et al., *Microw Opt Techn Let* **47**, 17 (2005).

[2] P. M. Krenz et al., *Opt. Express* **18**, 21678 (2010).

[3] M. Schnell et al., *Nano Lett.* **10**, 3524 (2010).

[4] M. Schnell et al., *submitted*

Figures

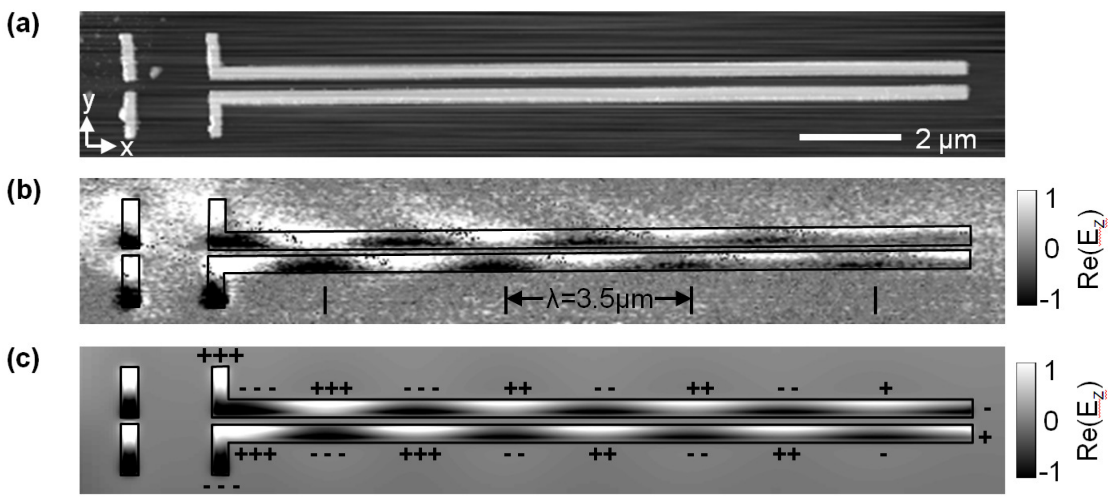

Fig. 1: Energy transport and propagation properties in two-wire transmission lines. (a) Topography image of an antenna-coupled two-wire transmission line, consisting of two 40nm height Au wires, 200nm wide, separated by a 300nm wide gap, on a Si substrate. (b) Experimental near-field image taken at λ = 9.3 μm, showing $Re(E_z)=|E_z|cos(\varphi_z)$. (c) Numerically calculated near-field image showing $Re(E_z)=|E_z|cos(\varphi_z)$.