Invisibility at Visible Frequency Using Carbon Nanotube Carpet

H. Shi,[1] J. G. Ok,[2] H. W. Baac,[1] and L. J. Guo[1]

Center for Nanophotonics and Spintronics
[1]*Department of Electrical Engineering and Computer Science*
[2]*Department of Mechanical Engineering*
The University of Michigan, Ann Arbor, MI 48109

The topic of concealing an object has gained a lot of attention in media and scientific community in recent years. Revolutionary concept based on transformation optics allows optical rays to bend around the object and re-emerge at the opposite side of the object. However it requires complex anisotropic and inhomogeneous metamaterials to realize such concept, which is extremely challenging to fabricate for high frequency such as infrared and visible band. A great simplification was proposed by using a ground plane where an object placed on top of the plane can be made invisible by covering a metamaterials carpet.

Here we show an alternative type of ground plane cloak that can conceal an object of arbitrary shape and readily realized at visible frequency with large area, broadband and polarization independent characteristics. We note that in principle there are two complementary and equally effective ways of making a cloaking carpet covering 3-D object appear as a flat plane, either by making it perfect reflecting or perfect absorbing. Rather than the perfect reflection used in prior works, here we propose and experimentally demonstrate a cloaking carpet based on perfect absorption that suppresses reflection from all directions and visually compresses arbitrary 3-D objects into a 2-D plane. The cloaking carpet is made of low-density, multi-walled carbon nanotube (CNT) "forest" that can perfectly absorb incident light from all directions without reflection (Figure 1 A), and the simulation results reveal that this perfect absorption can make the CNT covered 3-D object (Figure 1 A middle) shows the same appearance as 2-D flat surface (Figure 1 A right) and therefore invisible. Previous study has already shown that such CNT forest is an ideal structure for broadband perfect absorption from visible to far infrared with reflection less than 0.05%.

An arbitrarily shaped object to be cloaked was fabricated on a silicon substrate by focused ion beam (FIB) milling. In this case a "tank" pattern of 65 × 22.5 μm in size (Figure 1 B left) was made, and its reflection image was taken under an optical microscope illuminated by broadband visible light (Figure 1 C left). To cover the object with the cloaking carpet, a 60 μm-thick CNT forest was grown on top of the whole silicon sample (Figure 1 B middle). An optical image of the object covered with the CNT carpet was taken again. Figure 1 (C middle) shows that the tank completely disappeared and the surface looks exactly the same as a flat CNT sheet. As a further proof, a control experiment was performed where a rectangle mark around the "tank" was made by FIB milling that removed the CNT (Figure 1 B right). The optical image now clearly shows the rectangle mark, but the tank pattern inside the mark remains invisible (Figure 1 C right).

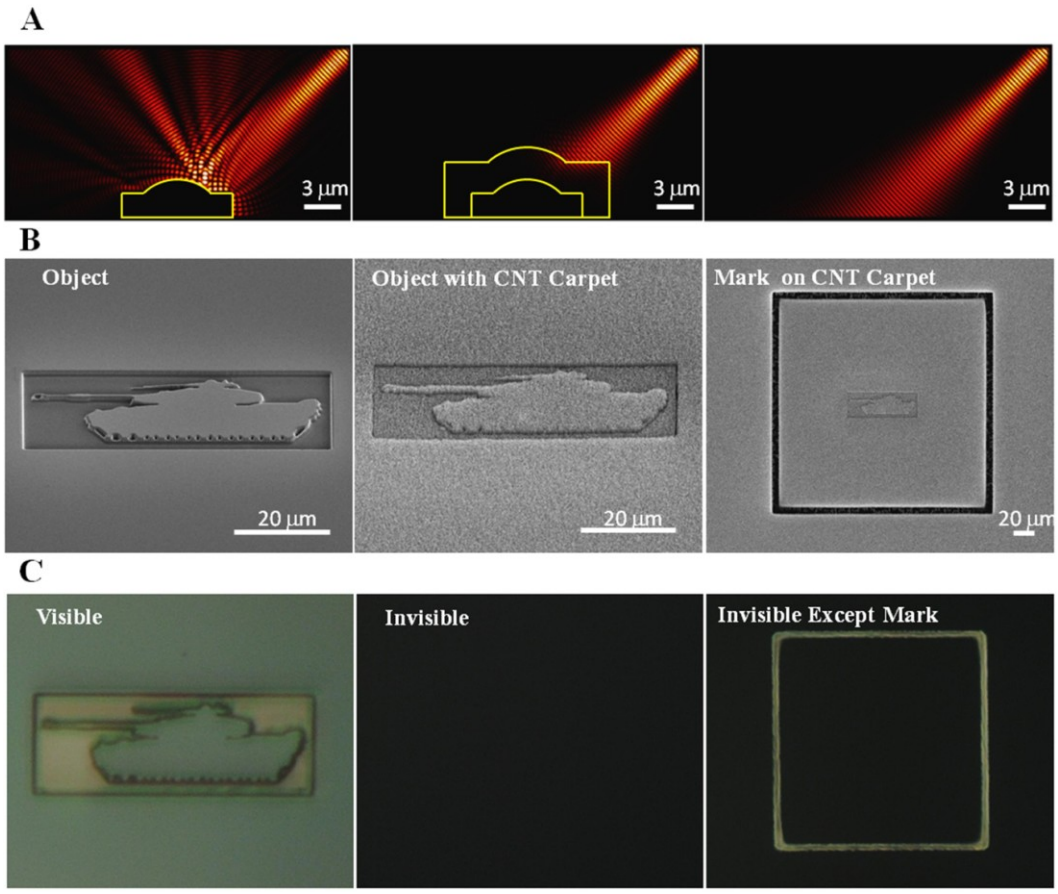

Figure 1: Cloaking using perfect absorption CNT carpet: (A) Simulation results of invisibility cloaking of arbitrary objects using a carpet and a ground plane of perfect absorption property over wide spectrum. Scanning electron (B) and optical microscope (C) images of a 65×22.5 μm "tank" pattern fabricated by FIB (left); with the whole sample surface covered by a 60 μm thick CNT carpet (middle), and with a rectangular mark around the "tank" by FIB (right).