Metasurface Based On-chip Antennas at Millimeter Waves with Silicon-Isolating Ground Plane

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The idea of on-chip antenna (OCA) has triggered considerable interest, as it allows the ultimate on-die integration of the entire wireless transceiver, eliminating the need for any off-chip interconnection. However, designing a high gain and high efficiency OCA is very challenging because of the high permittivity and low resistivity of the silicon or silicon-germanium substrate. An OCA with silicon substrate will lose much of its power inside the silicon, thereby resulting in low radiation efficiency, low gain, possible electromagnetic interference with the active circuitry and radiation performance that depends on the way the die is cut. To avoid all these problems a shielding ground plane just above the silicon is desired and the insulator layer acts as the antenna substrate. However this advantage comes at high cost: because of the extremely thin thickness of insulator layer (around 5 μm to 20μm depending on the technology) the antenna bandwidth is extremely narrow and the radiation efficiency is very low in general.

Our work explores advantages and disadvantages of antenna solutions with such a silicon-isolating ground plane and in particular the idea of using metamaterial surfaces (metasurfaces) in OCA design. The metasurface can be used for OCA design in two different configurations: one is as a reflector below the OCA, acting as an artificial magnetic conductor (AMC) and the other is as an antenna directly as in our recent work (S. Pan et al, IEEE Trans. Antennas and Propagat., 62, 4439 – 4451, 2014). It is found that in the CMOS environment, the AMC property of metasurface as a reflector cannot be guaranteed at the resonance since the thickness of the metasurface becomes too thin (we will clarify what "too" means). On the other hand, instead of using the metasurface as a reflector, the concept of using the metasurface directly as a lossy leaky wave antenna is validated by both full wave simulations and measurements (see above reference). The design of using a metasurface made of a periodic array of dogbone shaped elements was implemented at 94 GHz in a 0.18 μm BiCMOS. The results show the widest relative impedance bandwidth and are among the highest gain ever achieved for a fully OCA considering the extremely electrically-thin substrate thickness at W-band. Simulation results for a similar antenna operating at 0.31 THz for in a 65 nm CMOS technology are shown in this work as well as for other antennas for comparison.