CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1. Chief Conclusion

5.2. Suggestion for Future Research

5.1. Chief Conclusion

As stated in Sec. 1.8, the objective of the research undertaken for this thesis was to investigate the propagation and scattering of pulse-modulated carrier SPP waves in the time domain in an environment that represents an interconnect such as may be encountered in an integrated circuit. The motivation for investigating the transport of information using SPP waves is to overcome the limitations of electronic interconnects in a semiconductor chip.

In Chapter 2, information transfer by a pulse-modulated SPP wave was investigated: (i) for the abrupt termination of the metal to determine the characteristics of the launched signal and (ii) when the metal is restored after the gap of width equal to the carrier wavelength in free space. The pulse-modulated carrier SPP wave was launched in on a metal/air interface by applying the initial fields and proper boundary conditions at the launching plane. The Drude model was used to charcterize the electromagnetic properties of the metal. As the signal moved forward, its temporal profile broadened and its amplitude reduced. The broadening is consistent with different spectral components of the signal having different phase speeds, and the amplitude reduction occurs due to the dissipation of electromagnetic energy in the metal. The fields on the dielectric side of the interface were computed at two points on either side of the gap. The signal received at the point of reception after the gap was compared with the signal sent at the point of transmission before the gap using the Pearson correlation coefficient. After an abrupt termination of the metal, reflection was found to be very weak and the signal was found to continue to propagate in the air as a precursor followed by a somewhat distorted version of the launched pulse. The information encoded as the existence of a pulse is strongly and positively correlated with the transmitted signal.

When the metal/air interface was restored after a gap of width equal to the carrier wavelength in free space, the signal received across the gap comprised a precursor and the main pulse that are still strongly and positively correlated with the transmitted signal. Thus, it was determined that information continues to propagate in the forward direction for a long distance after a gap, a promising result for SPP wave-based optical interconnects.

In Chapter 3, the transfer of information via a pulse-modulated carrier SPP wave around a concave corner formed by two planar air/metal interfaces was investigated. The signal was launched along the first air/metal interface and received along the second air/metal interface. The effects of the corner angle and carrier wavelength on information transmission were investigated. The energy of the reflected signal was found to weaken as the corner angle increases. The energy of the received signal at the second air/metal interface increases as either the corner angle increases and/or the carrier wavelength increases. The shape of the received signal is largely independent of the corner angle of the corner and the carrier wavelength.

The dependency of the scattered field (in air) on the radial distance from the corner was investigated for two different values of the corner angle. The energy of the scattered signal is inversely proportional to the distance from the corner except in an angular sector close to the second air/metal interface. Statistical analysis revealed that the signal received after the concave corner is strongly and positively correlated with the transmitted signal. Better correlation was found when the carrier wavelength is lower for a fixed value of the corner angle.

In Chapter 4, information transfer on a planar silicon/silver interface in the near-infrared spectral regime was investigated, which is realistic for an integrated circuit. The carrier wavelength was chosen to lie in the near-infrared spectral regime, sufficiently far from the telecommunication regime to prevent interference. The relative permittivity of the silicon was characterized by the critical-point model and the Drude model was used for the relative permittivity of silver. Launched on a silicon/silver interface, the pulse-modulated carrier SPP wave encountered an upright wall either between silicon and air or between silicon and silver. The transmission of the signal beyond this wall was simulated in order to determine the fidelity of information transfer beyond the wall, as assessed using the Pearson and the concordance correlation coefficients. As the signal propagates along the silicon/silver interface, its temporal profile was found broaden and its amplitude to reduce. The launched signal was partially reflected and partially transmitted without significant loss of fidelity when silicon was terminated by air, however, no transmission occurred when silicon was terminated by silver. The fidelity of the transmitted signal in the forward direction was found to rise when both silicon and silver are terminated by air. The results indicate that information can be transferred across a few tens of micrometers in microelectronic chips by SPP waves, which amounts to more than 600 transistors laid end-to-end in 14-nm technology chips.

The overall conclusion from the research reported in this thesis is that information transfer by SPP waves on metal/semiconductor interfaces may overcome the limitation of electronic and optical interconnects and could be successful for transporting information with shorter signal delay, less crosstalk, and higher interconnect density.

5.2. Suggestions for Future Research

In this thesis, information transfer through a carrier SPP wave propagating along a on metal/semiconductor interfaces was investigated in the time-domain. Although the overall conclusion is positive for SPP-wave-based interconnects in microelectronic chips, the investigation—being the first of its kind—is foundational and should motivate further research on a technoscientifically important topic. The following avenues are suggested for further research:

(i) The presented simulations show that the received signal is moderately correlated with the transmitted signal, the Pearson correlation coefficient ranging from 0.5 to 0.7 in chapters 2–4. For the signal to be reconstructed better at the receiving end, higher correlation coefficients are required. Further research is needed to maximize the correlation by optimizing the geometry of the computational domain and the shape of the transmitted pulse.

(ii) The MATLAB code used for implementing the FDTD method takes 5 to 10 days to complete a full-scale simulation and requires a large memory (more than 128 GB RAM). The computational time as well as the computational memory need to be reduced. This could be accomplished by using the recursive convolution method [Luebbers *et al.* (1990)].

(iii) Information transfer by a SPP wave on a planar silver/silicon interface was investigated in Chapter 4 as a necessary extension of Chapter 2 wherein a planar – silver/air interface was considered. A similar extension of Chapter 3 is needed for information transfer around a concave corner formed by two planar silver/silicon interfaces.

(iv) Instead of the SPP wave, another type of ESW can be used as a carrier wave to transfer information. Owing to the large propagation distances of Tamm waves [Polo *et al.* (2013)], investigation of information transfer by a Tamm wave may be useful for long-distance communication inside semiconductor chips.