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Study of Plasma Surface Wave Based Microwave and Photonic Devices

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Plasma surface wave (PSW), an electromagnetic wave travelling along the interface of a dielectric and a plasma, a highly conducting medium with high concentration of free charges, has been of great interest for a wide range of areas, including plasma generation and plasma diagnostics. For typical low temperature plasma sources based on PSW, power at microwave frequencies propagating along a planar dielectric waveguide is often employed for plasma excitation. Waves based on the same physical mechanism can also occur at the interface between a dielectric and a metal due to its high density free charges. This PSW in metals, called surface plasmon polariton (SPP) often operates over a range from infrared to optical wavelengths. In this presentation, we will present our works on PSW based devices, both in microwave and optical wavelengths, i.e., in gas discharges and solid metals, respectively.

A PSW based discharge employing a cylindrical dielectric waveguide is investigated. Two dimensional Fluid model simulation analysis is employed to study its discharge characteristics. Simulation results show that radial profile of the plasma density peaks at the center of the cylindrical chamber, although microwave power is mainly absorbed near the dielectric surface. Fluid model simulation is also used to study of a cavity type microwave plasma which often employed for diamond film synthesis[1]. Simulation results show that a plasma ball is formed above the bottom stage surface when the microwave is fed from the top of the cavity chamber. The microwave power is found to propagating into the plasma ball although the plasma density is much higher than the critical density corresponding to the microwave frequency. Microwave is found to propagate into the plasma ball along the bottom stage surface where a plasma sheath region is formed to support the "surface wave" propagation. A We have developed a transmission-line based microwave plasma density sensor for application in processing plasmas, e.g., process monitoring or feedback control[2-4]. Several transmission line structures have been investigated, including coaxial dielectric waveguide, ridged microstrip and air-bridge microstrip. Full 3D electromagnetic numerical simulations were employed to design the transmission line structures and their results were used to serve as calibrations for the sensors. The sensor has also been employed in a feedback control system of a high density plasma etcher for better etch rates stability by controlling the plasma density measured by the transmission line sensor.

We have also explored the PSW at optical wavelength. Our primary interests are SPP waveguides and devices which have gained a great deal of attention recently for potential application in nano photonic circuits. A unique ultra low loss SPP waveguide, top metal silicon (Si) hybrid dielectric-loaded plasmonic waveguide (TM-SiHDLW), has been designed[5]. Results from numerical simulation show that a long propagation length of 350 μm and a small mode area of 0.03 μm^2 are obtained. The TM-SiHDLW structure was also employed to design two optical components, a compact directional coupler, with a coupling length as low as 2.95 μm, and a high Q (~ 2000) resonator. Another optical PSW device we have explored is an electro-optical (E-O) switch where, for low switching voltage and better compatibility to conventional microfabrication processes, both an organic and a in-organic E-O material have been considered[6]. The SPP-E-O switch we proposed employed a coupled waveguide structure in a way that the optical wave can be switched between to two waveguides, depending on the voltage applied on the switch electrodes (Fig. 1). All these SPP waveguides and devices were designed to operate at the standard 1550 nm wavelength.

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(a) (b)

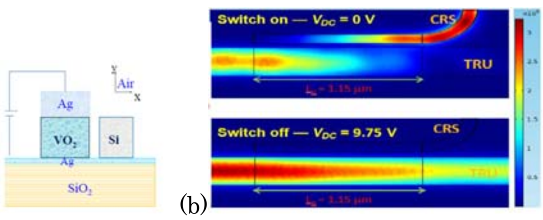

Figure 1. SPP based E-O switch: (a) cross section view of waveguide structure, and (b) HFSS simulation results – electric field distribution for switch on and off.