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Design, Fabrication and Validation of N-doped Si/Au/Al Schottky Barrier Device for detecting Surface Plasmon Resonance-Induced Hot-Electrons

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Summary:

Traditional Surface Plasmon Resonance (SPR) biosensors, which measure scattering light to characterize biomolecular interactions. This study introduces a novel SPR sensor design based on SPR-induced hot electrons using a Schottky barrier structure (Au/n-Si/Al). This innovative design filters higher energy surface plasmons and enables current sensing. We established the device fabrication processes, including design, debugging, and fabrication, developed the measurement system, conducted device testing, and thoroughly analyzed the chip's electrical and optical characteristics.

Keywords: Surface Plasmon Resonance (SPR), Schottky Barrier, hot electron, Biosensor, MEMS.

INTRODUCTION

Surface Plasmon Resonance (SPR) is a precise optical phenomenon with biochemistry, chemical sensing, surface science, and nanotechnology applications. Traditionally, it involves using a high refractive index prism (BK-7, n=1.571) as a coupler to match the momentum of a thin metallic film (Au, n=0.4941 + 10.353i @1550nm, d=50 nm) at a specific incident angle, SPR angle, to observe the diminished total reflection, as shown in Fig.1. This provides insights into optical properties of materials and aids in analyzing biomolecule interactions, monitoring chemical kinetics, and studying nanostructures. By immobilizing recognition molecules on a metal surface allows real-time monitoring of target-binding events, aiding in drug screening and analyzing disease mechanisms.[1]

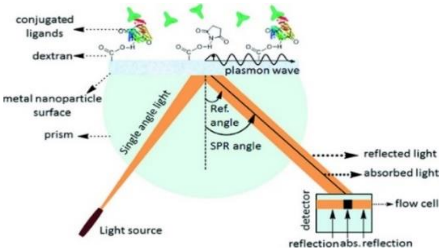

Fig.1. Basic SPR optical setup for biosensing. [2]

Photovoltaic Effect

The photovoltaic effect occurs when a semiconductor or semiconductor-metal combination generates voltage and current upon light or electromagnetic radiation exposure. It's akin to the photoelectric effect but internally related (1) [3]. In this effect, due to heterogeneous material interface, like PN junction formation, excited electrons and holes move oppositely under the established electric field, leading to charge separation.

$$Vo = \frac{kT}{q} \ln\left(\frac{N_A N_D}{{n_i}^2}\right) \quad (1)$$

Schottky Contacts and Ohmic Contacts

In 2017, predecessors organized the conditions for forming Schottky and Ohmic contacts. Different types of contacts can be formed depending on the difference in material work functions. We can utilize Schottky contacts to establish barriers to filter out electrons generated on the metal surface. Through these methods, we can screen out the current generated by SPR.(2) [4]

$$q\phi_{Bn0} = q(\phi_m - \chi) \quad (2)$$

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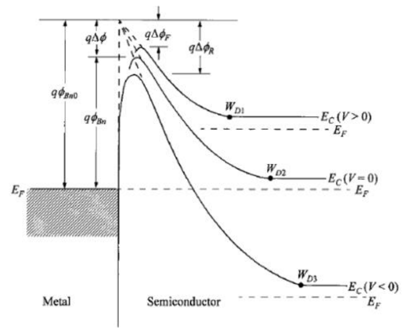

Fig. 2. Schottky contact between metal and semi-conductor. [4]

Simulation

Firstly, we used Matlab code (R2015) to simulate the SPR phenomena containing Au (48nm)/Cr (2nm)/Prism (n = 1.5098) under various incident angles and wavelengths. These results provide the fundamental behaviors of surface plasmon waves on the planar interface, especially for the lateral propagation distance for the placement of the Schottky barrier. We also used COMSOL (5.3a) to simulate the penetration depth of NIR wavelength and the generation of hot electrons under Au (48nm)/N-doped Si (10um) and Au (48nm)/N-doped Si (1um). The parameters of used materials are listed sequentially in the following table for reference.

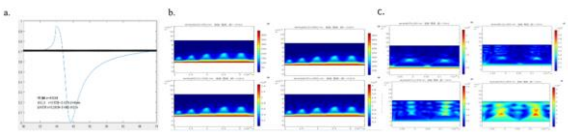

Fig. 3. The SPR simulation results, a. with Matlab and b. 10um N-doped Si with COMSOL c. 1um N-doped Si with COMSOL

Tab 1:The material, thickness and refractive index of our chip

Material	Thickness	N (n + ik)@ 1550nm
Au	48nm	0.4941 + 10.353i
N-doped Si	500um	3.6730 + 0.005i
Aluminum plate	0.8mm	1.5237 + 15.115i

Chip Design

We redesigned Au/N-doped Si/Al to support SPR wave generation on the Au surface and used Au/N-doped Si to establish Schottky barriers for detecting higher-energy hot electrons. Fig 4 shows the plasmonic chip and PCB assembly. In the aluminum substrate, two holes connect to the pins of USB connector. The N-doped Si coated with gold is bonded to aluminum substrate using Ag glue. Aluminum wires pass through holes from the gold layer, connecting to the USB socket pins to form a complete circuit.

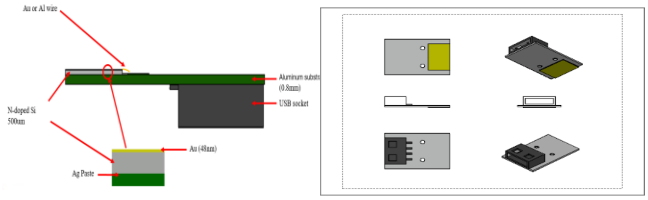

Fig. 4. The design of the plasmonic chip and PCB assembly.

Fabricated Chip & Measurement Setup

In the measurement phase, this study will utilize 1.a probe measurement system architecture, 2.USB measurement and 3.Lock-In Amplifier (LIA) System. We will attempt various measurement methods to determine the basic properties of the SPR chip.

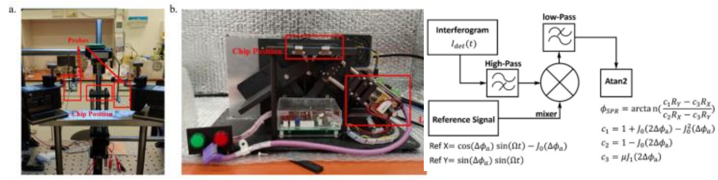

Fig. 5. a. Plasmonic Chip Measurement System and b. SPR Measurement System and modified LIA algorithm System

Current Results

Based on the current chip results, it's evident that the resistance between N-doped Si/Au remains high. This could potentially be attributed to surface roughness, suggesting the need for a more comprehensive cleaning procedure.

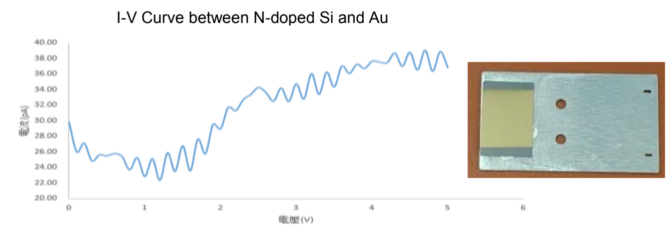

Fig. 6. Chip and I-V Curve between N-doped Si/Au.

Acknowledgements

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