Interaction of Electron Beam-Surface Plasmon in Planar Structures

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***Abstract*—In the paper, we discuss the possibility of electron beam excitation of surface plasmon in conducting metal. Then, planar perfect structure with subwavelength holes has been proposed. The phenomenon has been proven theoretically and numerically that mimicking surface plasmon wave can be excited and amplified by electron beam. The mechanism of penetration of subwavelength holes array is exploited to enhance the interaction of electron beam and mimicking surface plasmon..**

I. Introduction And Background

Surface Plasmon (SP) is the coherent fluctuation of the electron charges on a metal boundary which can be excited by electrons and light in the infrared and light frequency. Metals can support surface plasmon modes, but perfect conductor is an exception. However, Pendry et al. [1] proposed the formation of perfect conductor also support surface plasmon modes with an array of holes on the surface called mimicking surface plasmon (MSPs) which has been verified by experimental in the microwave region. Surface Plasmon modes in perfect conducting metal or semiconductor become one of the most attractive topics of intense investigation both theoretically and experimentally in the electromagnetic waves ranging from near-infrared to visible light. It has been established that the resonant excitation of surface plasmon creates huge electric fields at the surface that force light through the holes, giving very high transmission coefficients. Utilizing the MSP, some active electronic devices including the THz modulator, switching device etc, has been developed.

In this paper, we discuss the possibility of electron beam excitation of surface plasmon in conducting metal and show that SP can interact with the electron beam efficiently under certain condition to give the exponential growth rate. Electron beam and mimicking surface plasmon interaction has been explored both theoretically and numerically.

II. Theoretical Analysis of SP and Electron Beam Interanction

SP of metal can be excited by electrons and light. We assume that the SP can be excited when electron beam passing closely along the surface of the metal. The scheme of the electron beam-SPs interaction is shown in Fig.1. The dispersion and growth rate of this interaction are drawn in Fig.2. it shows that such interaction can provide exponential growth rate provided $\omega_{pe}=10^{-4}\omega_{ps}$, where ω_{pe} and ω_{ps} is the plasmon frequency of silver and plasma frequency of e-beam, respectively. According to the data given in [1], for siver at 0.6 μm wavelength, we get $k''z/k'z=10^{-4}$. It indicates that the growth rate is much higher than the attenuation coefficient; the light is amplified by e-beam.

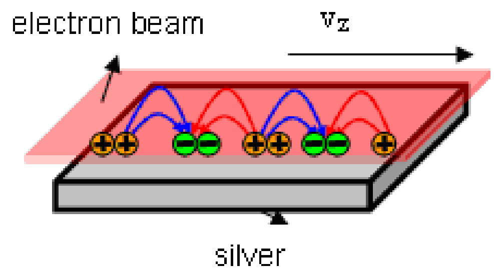

Fig.1 Scheme of SPs - E beam interaction

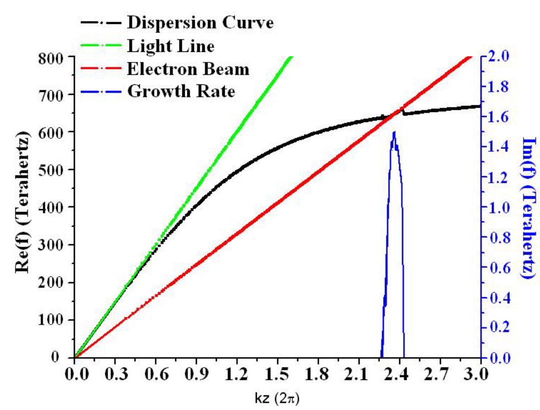

Fig.2 Dispersion curve

III. Theoretical Analysis of MSP and Electron Beam Interaction

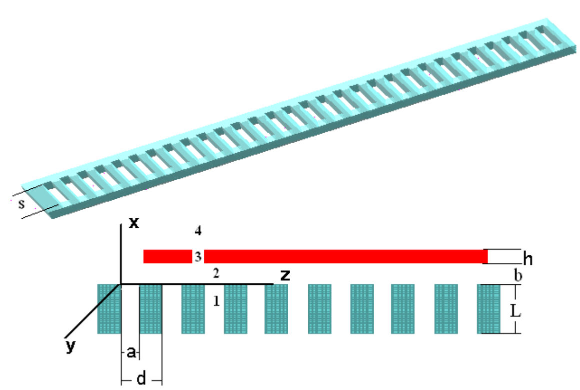

Fig.3 Geometry of mimicking surface plasmon structures

In this work, a new perspective is taken to study theoretically the surface plasmon modes on a structured perfect conductor. The surface plasmon modes are supposed to be the

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electromagnetic surface eigenmodes supported by the structured perfect conductors. Therefore, the theoretical analysis uses the eigenvalue solving approach to solve Maxwell's equations with suitable boundary conditions.

$$\frac{k_x^{\mathrm{I}}}{k_0^2}=\frac{a}{d}\sum_{p=-\infty}^{\infty}\sin c^2\left(\frac{k_z\cdot a}{2}\right)\frac{1}{k_x^{\mathrm{II}}}\cdot\frac{C_p-D_p}{C_p+D_p}$$

where, $k_x^{\mathrm{I}2}=k_y^2-k_0^2, k_y=\pi/s, k_z=k_{z0}+\frac{2\pi p}{d}, k_x^{\mathrm{II}2}=k_z^2-k_0^2$

$k_x^{\mathrm{III}2}=\left(k_z^2-k_0^2\right)\cdot\alpha, \alpha=1-\frac{\omega_p^2}{(\omega-k_z\cdot v)^2}, C_p, D_p$ are parameters.

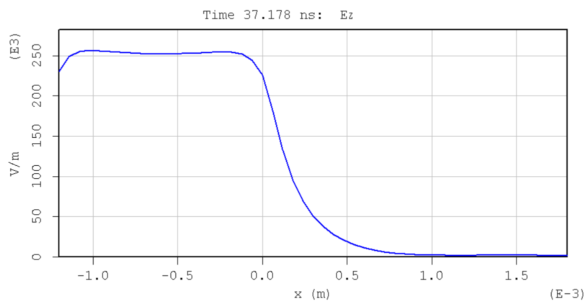

Fig.4 Ez contour in x plane

IV. INTERACTION OF SURFACE PLASMON AND ELECTRON BEAMS

Fig.4, the plot of Ez contour in x plane presents that the field Ez is highest at the surface of the structure and decay exponentially into just air, but transmissible mode in the holes. Due to the small highness of holes, the SPW whose frequency is just below the cutoff frequency of the hole can even transmit in the holes without evanescence. These results reveal the characteristics of the mimicking surface plasmon modes excited by the electron beams passing above the surface of meta-material conductors.

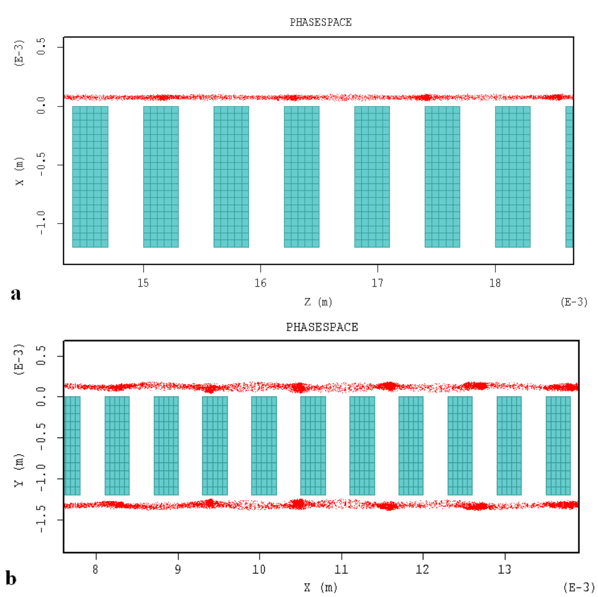

Fig.5 Comparison of one and two modulated electron beams

It is interesting to note that the wave fields are evanescent and decays exponentially in the sub-wavelength holes as it is thought from the mimicking SPs concept [2], but in the subwavelength holes array with finite depth, the electromagnetic penetration occurs, there are no longer the evanescent waves, similar with the light transmission predicted in [4]. Because of the penetration phenomena explained above, two electron beams have been proposed to enhance the interaction. The modulated electron beam, observed current and Ez field are given in Fig.5 and Fig.6. The electron beam is divided to two beams with same density into both sides of the structure. It has clearly shown that MSP and electron beams interact with higher efficiency. The observed spectrum frequency of the Ez field is 121.76GHz below the cutoff frequency 125GHz.

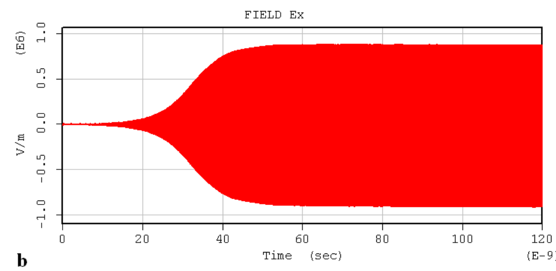

Fig. 6 Ez field observed at the surface

V. CONCLUSION

From the discussion, the electron beam sheet can provide sufficient momentum and energy to excite the surface plasmon modes in the structured perfect conductor surface, and the mimicking surface plasmon wave can interact with the electron beam. This mechanism can be used to design new novel electromagnetic devices from microwave to terahertz region. All of the results herein not only provide insight into the characteristics of the surface plasmon mode on a mimicking perfect conductor surface, but also demonstrate a new and valuable approach to designing electromagnetic devices and meta-materials with the special surface mode characteristics.

ACKNOWLEDGEMENT

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