MULTIPOINT Si_p^+ CESIATED PHOTOCATHODES FOR LASERTRON DEVICES

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ABSTRACT

$Si_p^+/Cs/O$ negative electroactivity photocathodes are used together with field emission in the case of an exposure in the Orsay lasertron.

1. INTRODUCTION

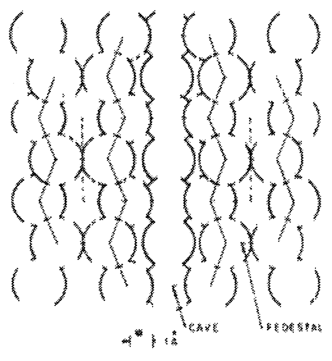
The aim of this study is to calculate the production of the $Si_p^+/Cs/O$ NEA in the case of cylindrical tips (0.5 μm) prepared in the 100 surface of silicon strongly doped with boron ($10^{19}/cm^3$, ρ = 0.02 Ωcm) in the Orsay laser.

Let us remember some properties of this Nd-Yag laser. Its frequency is tripled (hν = 3.54 eV). In lock mode regime, the pulsing time is 35 ps each 350 ps (3 GHz). The high power line is about 0.22 GW. The beam diameter is about 5 mm; its divergence angle is 1 mrad. The lasertron is supposed to have a difference of 100 000 V between anode and cathode, an approximate distance of 1 cm. That means an external field of 10 MV/m.

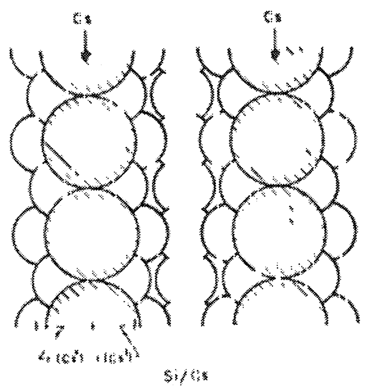
Si_p^+ has been chosen for two reasons: the necessity of using integrated circuit technology and the well defined structure formed with Cs at its surface, in opposition to cesiated AsGa. It will be used at the temperature of the liquid nitrogen (T = 77 °K) in order to suppress the thermoionic emission.

2. NEGATIVE ELECTRO-AFFINITY OF SILICON

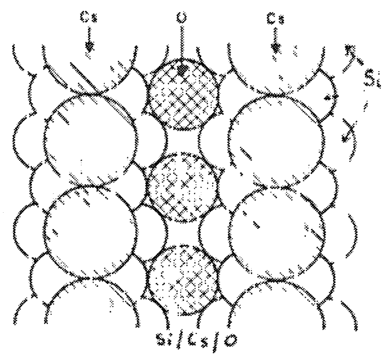
J. Levine and B. Goldstein [1,2] had theoretically and experimentally proved that with one monolayer, the structures at the surface (100) are as follows: getting from Si to Si/Cs and Si/Cs/O:



Si

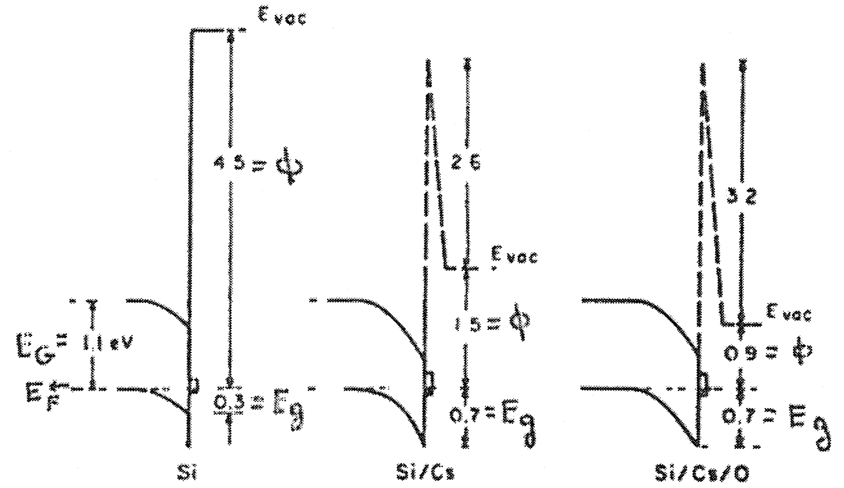


Si/Cs



Si/Cs/O

The potential from the bulk to the vacuum varies in such a way that the vacuum level is lower than the conduction band.



The electronegativity is defined as follows:

$$X_{ev} = \phi - (E_G - E_F) + E_g$$

where

E_G is the forbidden band
E_g is the difference of level due to the band curve nearing the surface
ϕ is the extracting work, E_F the Fermi level.

In the case of Si/Cs/O, the vacuum level is below a conduction level potential This makes it easier for the extraction of an electron We have

$$XSi_p^+ = 4.5 + 0.3 - 1.1 = 3.7 \text{ eV}$$

$$XSi_p^+/Cs = 1.5 + 0.7 - 1.1 = 1.1 \text{ eV}$$

$$XSi_p^+/Cs/O = 0.9 + 0.7 - 1.1 = 0.5 \text{ eV}$$

If we neglect the curvature E_g = 0.7 eV, then XSi/Cs/O = 0.2 V which is at the origin of the expression "negative electro affinity".

3 QUANTUM PRODUCTION OF THE PHOTOEMISSION

Spicer [3] defines the quantum yield, ratio between emitted electron number and incident photon number, as:

$$Y_i = \frac{\alpha_{PE}(h\nu)}{\alpha_T(h\nu)} \frac{R(h\nu)A(h\nu)Ps}{1 + \frac{1}{l(h\nu)\alpha_T(h\nu)}}$$

where α_T is the total absorption coefficient [4]

$$\alpha_T = Cte(h\nu - E_G)^{3/2} = Cte \times 3.8$$

$$\alpha_{PE} = Cte[h\nu - (XSi + E_G)]^{3/2} = Cte \times 2.69 \quad \text{at } h\nu = 3.5 \text{ eV}$$

α_{PE} is the excitation coefficient for an atom to emit an electron. $1/\alpha_T = \lambda/4\pi k$ where k is the extinction coefficient as measured for silicon

$$k = 0.035 \quad \text{at } \lambda = 1\ \mu m$$
$$k = 0.1 \quad \text{at } \lambda = 0.5\ \mu m$$
$$k = 3.38 \quad \text{at } \lambda = 0.25\ \mu m$$

As $1/\alpha_T < 5000$ Å and l the electron escape length is about 50 000 Å in the case of NEA photocathode, we have

$$1 + \frac{1}{l\alpha_T} \approx 1 .$$

We suppose that $A(h\nu) = 1$ for U.V. [3] and P_S the transmission coefficient at the surface ≈ 1 for NEA; R the reflection coefficient = 0.625 at 0.35 μm for silicon.

$$\text{Then } Y_i = 0.35$$

The number of incident photons is 10^{15} per pulse (35 ps) which gives an intensity of about 10^6 A.

For normal photocathodes (Cs_3Sb)l = 200 Å, $1 + 1/l\alpha_T \gg 1$ $P_S \ll 1$. Here, P_S may be not equal to 1, but very close to it.

The result of the Y_i calculation is in agreement with experimental measurements [5].

4. FIELD EMISSION WITHOUT PHOTON BY A NETWORK OF CYLINDRICAL TIPS

In order to reinforce the photoemission, one can take into account the electric field between cathode and anode amplified by the existence of a network of tips. We consider cylindrical tips ($r = 0.5$ µm, $h = 30$ µm) and that the temperature ($T = 77\,^{\circ}K$) is low enough to use the Fowler-Norheim formula without thermoelectronic current; we have from [6]

$$jA/m^2 = 1.59\ 10^{6}\ \frac{E_l^2}{\phi t^2(z)}\ \exp\ \frac{6.83\ 10^9\ v(z)\phi^{3/2}}{E_l}$$

with

$$z = \frac{\sqrt{e^3 E_l}}{\phi\sqrt{4\pi\varepsilon_0}} = 3.7910^{-9}\ \frac{\sqrt{E_l}}{\phi}$$

We take $\phi = 0.9$ eV as in NEA cathode Si/Cs/O

$v(z)$ and $t(z)$ take into account the image charge. E_l is the effective field, $E_l = \beta E_0$ where E_0 is the field between anode and cathode; $\beta = h/r = 60$ is the reinforcing factor

With $E_0 = 10$ MV/m, $E_l = 600$ MV $= 0.610^9$ V

This value is less than the threshold emission which is [7]

$$E_{min} = \frac{(2m_e)^{1/2}\phi^{3/2}}{e\hbar} \qquad \text{if} \quad \phi = 4\ 5\ \text{eV} \quad E_{min} > E_l$$

But if $\phi = 0.9$ eV, $E_{min} = 0\ 1410^9$ V/m and $E_l > E_{min}$.

We have $z \approx 1$, $v(z) \approx 0$, $t(z) \approx 1$, $j = 0.55\ 10^{12}$ A/m^2.

The current per tip is $I = j \times s = 0.86$ A.

For a network of 56 tips the total current is 17 A (see Ref [8]) in a surface of 40 µm × 35 µm Of course the current will be higher with the help of a laser.

5 MICROLITHOGRAPHY OF THE SILICON TIPS, THANKS TO PHOTORESIST

We use a mask method on a positive photoresist displayed on the surface Si_p^{+} (100) by a wheel A low speed photographic microfilm is used (500 lines/mm) or an holographic microfilm (5000 lines/mm) which is the repetition of the circles, basis of the cylindrical tips, and a U.V. exposure is followed by the development of the photoresist.

By dry selective engraving in a chlorinated medium at 2.5 GHz, the Si_p^+ is attacked on the nonprotected spots. A selective attack of the remaining photoresist clears off the cylindrical tips which can be in an unlimited number

The method is now in progress.

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