I. PHYSICAL ELECTRONICS

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A. ELECTRON EMISSION PROBLEMS

1. Effect of a Magnetic Field and of a Unidirectional Heating Current on Thermionic Emission from Molybdenum

The chief purpose of this research – investigation of the effect of a magnetic field on thermionic-emission current – was described in the Quarterly Progress Report of January 15, 1957, page 2, together with a description of the tube design and a discussion of the background of the experiment. We shall also study another effect, which can be easily investigated with the same tube structure. This concerns the possibility of changes in the surface structure of the filament as a result of sustained dc heating. We believe that the application of dc heating over a period of time will cause a shifting or migration of the surface atoms, and thus a change in the exposed crystal structure. This change would probably result in a preferred direction of emission; that is, the emission from the two sides of the ribbon filament would be unequal.

This study will require measurement of the emission current to each of the four collector plates as a function of the length of time of dc treatment, and as a function of the magnitude and direction of the heating current. Until the effect of direct current is tested, all heating will be by alternating current. Since the emission is a highly sensitive function of temperature, and therefore of filament current, a steady heater voltage is essential. Effort is now being devoted to perfecting an electronic ac voltage-regulator circuit which is expected to reduce fluctuations in the line voltage to 5 per cent of their initial value (1). For dc heating, the regulator developed by H. Shelton, of this laboratory, will be employed (2).

J. Greenburg

References

1. The basic circuit is given in L. D. Harris, An electronic a.c. voltage regulator, Bulletin No. 28, Utah Engineering Experiment Station, University of Utah, June 1945.
2. H. Shelton, Ph.D. Thesis, Department of Physics, M.I.T., May 1956, pp. 32-34.

B. PHYSICAL ELECTRONICS IN THE SOLID STATE

1. Characteristics of Junctions in Germanium

Measurement of the characteristics of germanium alloy - junction rectifiers at low voltages reported in the Quarterly Progress Report of April 15, 1957, page 7, continues, with the measurement of the barrier height and its apparent temperature dependence in a third junction, sample AB3. This junction is constructed from 0.6 ohm-cm germanium, in the same manner in which the previous junctions were constructed. If we assume that the height B of the potential barrier at the junction is $B = B_o + \alpha V_T$, then the constants for this rectifier are $B_o = 0.557$ volt, $\alpha = 5.24$.

Present work is an attempt to predict the usual rectifying characteristics from the low-voltage measurements of B_o and α. The measurements on sample JA357 indicate that this can, indeed, be done, the current density j through the junction being given by the relation

$$j = A'V_T^2 \exp(-B_o/V_T - \alpha) \left[\exp(-V_B/V_T) - 1\right]$$

where $A' = 4\pi mq^3/h^3 = 1.619 \times 10^{14}$ amp/meter^2 volts^2, $V_T = kT/q = T/11{,}606$ volts, and V_B is the voltage across the junction. (Notice that the previously reported value of A' was in error.) Sample AB3, however, does not show this behavior, since the current in the reverse direction does not reach a saturation value. This sample was previously damaged by pressure on the indium contact, and probably has leakage paths around the junction; it is also quite unstable at high voltages.

Samples of different types, such as point-contact and grown-junction rectifiers, are being obtained so that data on them can be compiled. Because the present measurements use a potentiometer for voltage measurements, they take a great amount of time, and the possibility of using a chopper amplifier instead of the potentiometer is being investigated.

J. F. Campbell, Jr.

2. Surface States on Semiconductors

A tube was constructed for measuring the changes in the photoconductivity and the contact potential of a germanium sample simultaneously. However, it was impossible to take accurate measurements because of stray voltages that originated in the tube. These voltages consisted partly of random noise, but mostly of microphonics. We also found that the contact resistance of the germanium sample was extremely high, approximately two orders of magnitude higher than that of the sample itself. The tube was torn down and rebuilt several times, but it was still plagued with cracks caused by strains in the glass. We originally planned not to bake the sealed tube so that the sample would not be heated and drive off adsorbed compounds that might give rise to traps (in Gebbie's experiment (1), of which this study is a continuation, the germanium samples were mounted without heating in a demountable system). After the frequent occurrence of cracks we decided to bake the tube with the germanium in it. This helped to relieve strains in the glass and improved the vacuum in the tube (8×10^{-10} mm Hg on the pump) but gave rise to slight deformations in the tube during baking periods, which caused short circuits in the tube. The ends of a new germanium sample were plated with gold, and the contact resistance of the ends was subsequently found to be small in comparison with that of the sample. The random noise was also reduced. The main assembly in the tube and the electron-deflector plate were both welded to additional press wires to achieve greater rigidity in the mounting. This considerably reduced the microphonics, and led to the conclusion that they were caused by a Kelvin effect between the vibrating metal parts in the tube. At one time a crude experimental photoconductivity run was taken, and the response was approximately linear with light intensity with no saturating component (as in Gebbie's experiment) present. An oscilloscope trace showed no evidence of slow decay of photoconductivity when the light was cut off, and therefore no evidence of trapping either. We hope to create trapping centers by bombarding the surface with a Tesla coil in an oxygen ambient.

After a few more cracks and short circuits had developed, we decided to redesign the tube envelope so that all of the parts whose alignment is critical would be mounted on wires of a single common press (instead of on wires of different single-lead presses). Such a tube was built, and we found that no more short circuits developed. The electron accelerating mechanism was tried, and an electron current of approximately 10^{-7} amp was collected at the germanium sample. This is small compared with the total emission current of 50 ma, but it does prove the workability of the system. The electron deflector potential was the same as that of the center of the emitting filament.

The sample is etched with CP-4 and rinsed with high-purity water before every installation in the tube. The plated ends are protected during the etching by paraffin wax which is later dissolved in trichlorethylene. Argon is blown into the tube during the sealing process to reduce oxidation of the metal parts.

E. Ahilea

References

1. H. A. Gebbie and E. Ahilea, Surface electronics on semiconductors, Quarterly Progress Report, Research Laboratory of Electronics, M.I.T., July 15, 1955, pp. 3-4.

C. GASEOUS DISCHARGES

1. Ion Generation, Electron Energy Distributions, and Probe Measurements in a Low-Pressure Mercury Arc

Since the last report (Quarterly Progress Report, Oct. 15, 1956, p. 8), the study of the low-pressure mercury arc plasma has been completed. The results are available in the Ph.D. thesis of S. Aisenberg, Department of Physics, M.I.T., May 1957. A short summary of the experiments and the results will be given here.

A series of Langmuir probe measurements was made on the plasma of a low-pressure mercury arc in order to obtain information about some of the fundamental processes in the plasma. This research showed that the actual ionization is many times larger than the direct ionization components, and that the effect of the electron-drift velocity on the direct ionization is negligible. The results of this research and the limited published information indicate that the metastable density is relatively independent of the electron density, at least at the higher pressures, and that the cumulative ionization is a linear function of the electron density and not a quadratic function. The effective cross section for ionization of the 6^3P states was calculated to be at least 9.0 times greater than that for the ground state. The mobility of the electrons in the plasma was calculated, and it was found that the effective cross section for slow electrons in the plasma is essentially constant with an average value of 42×10^{-16} cm^2. The ambipolar diffusion coefficient and the ambipolar mobility coefficient were determined as a function of E/p_o for an active plasma.

An original theory was developed (with the aid of Professor W. P. Allis) for ion mobility and diffusion in a strong nonuniform electric field. With the help of this theory, the mobility and longitudinal coefficients were calculated for mercury ions in the plasma. The radial electric field was calculated from the assumed Bessel-function electron-density distribution obtained from ambipolar-diffusion theory and from the Boltzmann potential and density-distribution relation. The effective cross section for mercury ions is found to increase from 31 to 104×10^{-16} cm^2 as the ion energy is increased from 0.44 to 1.37 ev. There is reasonable agreement with the limited data of others.

The theories and methods developed can be used for the measurement of ion cross section in other gases. A study was made of the collection of positive ions by a negative probe for comparison with theory, and a theory was developed for the ratio of saturation ion current to saturation electron current, which is in good agreement (approximately 3 per cent) with the experimental data. Several new experimental techniques were introduced. The partial pressures of the residual gases in the arc were in the range 10^{-8} to 10^{-7} mm Hg (or less). They were measured while the arc was in operation in the constant-temperature water bath. The probe potential was supplied by a low-impedance voltage source (featuring a high degree of negative feedback) which was specially designed for this experiment. A new method was developed to permit direct recording of the change of probe work-function as a function of time. This method involves the use of a constant-current source (to null the electron current to the probe, which was operated at a retarding potential) and an expanded-scale, high-input, impedance-recording millivoltmeter. This method should prove useful in future experiments.

S. Aisenberg

D. EXPERIMENTAL TECHNIQUES

1. Spectral Emissivity of Tungsten

An experiment designed to measure the spectral emissivity of tungsten over the wavelength interval 310-800 mμ and the temperature interval 1600-2400°K has been summarized in the Quarterly Progress Reports of April 15, 1956, page 9; July 15, 1956, page 4; October 15, 1956, page 3; and April 15, 1957, page 7. The results of these measurements, for unpolarized light, with the tungsten surface viewed perpendicularly, are tabulated in Table I-1. The rms error of these measurements is 0.002 dimensionless (emissivity) units.

Table I-1. Spectral Emissivity of Tungsten.

Wavelength (mμ)	Temperature 1600°K	1800°K	2000°K	2200°K	2400°K
300	---	---	---	---	---
310	0.4798	0.4769	0.4740	0.4711	0.4682
320	0.4823	0.4795	0.4767	0.4739	0.4711
330	0.4828	0.4801	0.4774	0.4747	0.4720
340	0.4823	0.4798	0.4773	0.4748	0.4723
350	0.4816	0.4792	0.4768	0.4744	0.4720
360	0.4804	0.4781	0.4758	0.4735	0.4712
370	0.4791	0.4769	0.4747	0.4725	0.4703
380	0.4775	0.4754	0.4733	0.4712	0.4691
390	0.4754	0.4735	0.4716	0.4697	0.4678
400	0.4735	0.4717	0.4699	0.4681	0.4663
420	0.4694	0.4678	0.4662	0.4646	0.4630
440	0.4651	0.4638	0.4625	0.4612	0.4599
460	0.4620	0.4606	0.4592	0.4578	0.4564
480	0.4595	0.4578	0.4561	0.4544	0.4527
500	0.4571	0.4552	0.4533	0.4514	0.4495
520	0.4553	0.4531	0.4509	0.4487	0.4465
540	0.4539	0.4514	0.4489	0.4464	0.4439
560	0.4522	0.4494	0.4466	0.4438	0.4410
580	0.4501	0.4470	0.4439	0.4408	0.4377
600	0.4477	0.4443	0.4409	0.4375	0.4341
620	0.4450	0.4413	0.4376	0.4339	0.4302
640	0.4428	0.4388	0.4348	0.4308	0.4268
660	0.4412	0.4369	0.4326	0.4283	0.4240
680	0.4400	0.4354	0.4308	0.4262	0.4216
700	0.4375	0.4331	0.4287	0.4243	0.4199
720	0.4340	0.4299	0.4258	0.4217	0.4176
740	0.4304	0.4266	0.4228	0.4190	0.4152
760	0.4274	0.4239	0.4204	0.4169	0.4134
780	0.4246	0.4215	0.4184	0.4153	0.4122
800	0.4222	0.4194	0.4166	0.4138	0.4110

Equations for the variation in the spectral emissivity with the direction of polarization and the angle at which the surface was viewed were developed in terms of classical electromagnetic theory. In the Quarterly Progress Report of April 15, 1957, page 7, it was shown that this theory is in excellent agreement with the limited existing experimental data. We found that, by utilizing this theory, the basic optical properties of tungsten could be computed from an analysis of the emitted thermal radiation.

The index of refraction, N, is defined as the ratio of the phase velocity of light in vacuum to the phase velocity of light in tungsten. The extinction coefficient, K, measures the rate at which the intensity of the light is attenuated as it propagates through the tungsten structure according to the relation

$$\text{Intensity} = I_o \exp(-4\pi K \frac{x}{\lambda_o})$$

where x is a coordinate that measures the distance that light has traveled through the tungsten structure; I_o is the light intensity at $x = 0$; and λ_o is the wavelength of the light if it were propagating in vacuum. The computed values of N and K are listed in Table I-2.

Table I-2. Computed Values of N and K.

A. Values of N

Wavelength (mμ)	Temperature 1600°K	1800°K	2000°K	2200°K	2400°K
350	4.136	4.084	4.040	3.994	3.950
400	4.232	4.192	4.155	4.117	4.081
450	4.291	4.255	4.224	4.194	4.168
500	4.369	4.327	4.282	4.242	4.200
550	4.443	4.392	4.337	4.280	4.221
600	4.537	4.452	4.363	4.287	4.210
665	4.613	4.508	4.396	4.286	4.186
700	4.605	4.484	4.362	4.250	4.144

B. Values of K

Wavelength (mμ)	Temperature 1600°K	1800°K	2000°K	2200°K	2400°K
350	2.824	2.865	2.904	2.945	2.988
400	2.894	2.929	2.964	2.999	3.032
450	3.004	3.034	3.062	3.085	3.110
500	3.065	3.017	3.145	3.178	3.213
550	3.099	3.155	3.203	3.256	3.304
600	3.144	3.222	3.291	3.354	3.414
665	3.215	3.308	3.401	3.484	3.558
700	3.269	3.367	3.457	3.540	3.607

This report terminates the series of reports on this experiment. More details are given in a thesis, entitled "The Spectral Emissivity and Optical Constants of Tungsten," which was submitted to the Department of Physics, M.I.T., June 1957, in partial fulfillment of the requirements for the degree of Doctor of Science, which will be published as Technical Report 328.

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