Deshalb wurde eine gepulste Elektronenquelle gebaut, in der mit Hilfe des Spannungsimpulses einer H_2-Lampe das Kathoden-Gittersystem einer Scheibentriode (2 C 39 A) [17] aufgetastet wird und die Elektronen mit etwa 40 keV auf die Meßpräparate geschossen werden. Der direkt mit dem Tektronix-Oszillographen Typ 567 ($\tau_{an} \sim 0{,}35$ nsec) gemessene Anregungsimpuls wird in Abb. 5 dargestellt, die registrierten Zeiten entsprechen den Oszillographendaten. Die Spitzenströme sind raumladungsbegrenzt und können um den Faktor 10 erhöht werden. Es ist zu erwarten, daß man mit diesem Verfahren Elektronenimpulse mit Halbwertsbreiten kleiner als $0{,}5 \cdot 10^{-10}$ sec erzeugen kann.

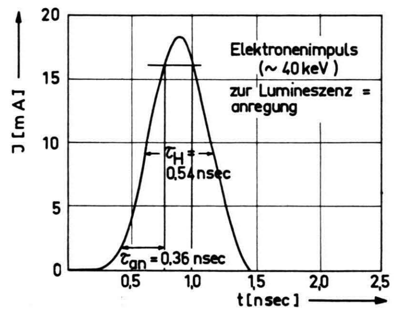

Abb. 5. Elektronenimpuls zur Lumineszenzanregung.

Durch Einschießen dieser Elektronenimpulse in Goldfolie können damit trotz geringer Quantenausbeute (~ 1‰) noch Röntgen-Strahlen-Blitze von ca. 10^4 Photonen/10^{-10} sec hergestellt werden. Auch eine Umwandlung in Lichtblitze ($\tau_H \sim 10^{-10}$ sec) durch den Cerenkov-Effekt in hochbrechenden Gläsern (Elektronenenergie $>$ 100 keV) wäre möglich. Da die Spitzenströme in den gebauten Wasserstoff- und Luftlampen 10 A bis 100 A betragen, wäre auch die Erzeugung eines roten oder infraroten Blitzes mit einer Halbwertsbreite von ca. 10^{-10} sec durch Tastung von Injektionslasern (Schwellstrom $I \sim 5$ A bei 77 °K) möglich, wenn deren Modulierbarkeit tatsächlich bis 10 GHz reicht [18].

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[17] Der Telefunken A. G., Ulm, danke ich für einige dieser Systeme.

[18] W. Heywang u. G. Winstel, Festkörperprobleme IV, S. 27, Vieweg & Sohn, Braunschweig 1965.

Influence of Surface Defects on Sputtering

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The sputtering of tungsten monocrystals with rare-gas ions under UHV conditions was observed in a field emission microscope (FEM) at temperatures between 90 and 900 °K. The resultant FEM pattern depends strongly on the crystal temperature during bombardment. This is ascribed to the influence of the defects produced by bombardment.

The FEM used for the investigations was of conventional design. The aparatus is similar to that described in [1]. During the measurement, however, the FEM tube is immersed in liquid nitrogen; this reduces the partial pressure of adsorbable gases (which prior to immersion in liquid N_2 was a few 10^{-10} torr) to below 10^{-11} torr. As measurements last 30 min at most, it is certain that adsorbed gases have no influence. The temperature of the tip is determined in the usual way by measuring the resistance of the centre part of the heating loop supplied with direct current.

Ar^+ or Xe^+ ions were used for bombarding. For this purpose the FEM was filled with 10^{-5} torr rare gas and a voltage was applied to give a FE current of 10^{-6} A. Some of the ions produced by electron collisions strike the tip. Their energy was roughly equivalent to the applied voltage which was (3.5 ± 0.3) kV. The angle of incidence and current density of the ions is not known, but in all experiments they are the same. At a rough estimate the ion flux is of the order of 10^{14} ions/cm² sec. The FEM patterns occurring after a 10 min bombardment at various tip temperatures, but under otherwise equal conditions, were observed. Those parts that are not sputtered much appears bright in the patterns due to field increase. The results obtained with Ar^+ and Xe^+ bombardment are about the same. A few patterns ares hown in Fig. 1 *.

The influence of the bombardment temperature is very obvious: First of all the regions around the $\langle 111 \rangle$ zone become prominent with rising temperature, showing up faintly at as low as 200 to 300 °K. Between 700 and 800 °K the photograph changes completely and then remains unchanged up to 900 °K.

Any influence of the temperature on sputtering phenomena observed hitherto (e. g. [2–4]) has been

[1] H. Vernickel, Proc. 3rd Intern. Vacuum Congr., Stuttgart 1965 (in press).

* Fig. 1 on p. 1304 b.

[2] R. Behrisch, Ergebn. Exakt. Naturw. **35**, 295 [1964].

[3] C. E. Carlston, G. D. Magnuson, A. Comeaux, and P. Mahadevan, Phys. Rev. **138**, A 759 [1965].

[4] J. M. Fluit, C. Snoek, and J. Kistemaker, Physica **30**, 144 [1964].

ascribed to (1) changes in layers of foreign matter on the surface, (2) influence of lattice vibrations on focussing collision sequences and (3) influence of defects. Our observations can only be explained by the last possibility since (1) can be discounted because of the very good vacuum and (2) would result in a decline in the direction-dependent effects with rising temperature.

The following is known about the annealing of defects in tungsten: Radiation damage in solid material is annealed in the entire temperature range of interest to us, but mainly below 100 °K and at 750 °K [5, 6]. Desorption of the injected rare-gas atoms commences at about 500 °K [7]. The surface migration of individual W atoms on W is highly dependent on the surface orientation. On some faces of the ⟨111⟩ zone migration begins at 200 to 300 °K, while on other faces the temperature has to be higher [8].

The appearance of the ⟨111⟩ zone is thus probably due to the onset of surface migration, because the dependence on temperature and crystal orientation are in agreement. The change in the photograph at 700 to 800 °K may be a consequence of the annealing of the radiation damage and/or the desorption of the injected rare-gas atoms.

According to opinions formed during the last decade it is supposed that the sputtering is essentially caused by focussing collision sequences: if such a collision sequence reaches the surface the last atom is ejected. According to Fluit and Datz [9] those faces intercepted by many focussing directions then become strongly sputtered.

According to some more recent papers [10–12], on the other hand, the focussing collision sequences hardly affect the sputtering. Rather is it held that the angular distribution and the quantity of the sputtered material are determined primarily by the binding energy of the surface atoms, because the energy distribution of the surface atoms after a collision has a pronounced maximum at low energies [12].

If this is correct we should also have the case where an atom of the upper layer is lifted without the transmitted energy being sufficient to cause the atom to be ejected. During their lifetime τ such "adsorbed" atoms may be removed from the surface by a subsequent low-energy collision. If τ is sufficiently large these two-stage processes (cf. [13]) make an appreciable contribution to sputtering because of the stated maximum of the energy distribution. The value of τ is limited by recombination with holes or by transfer to kink positions. Both processes require surface migration.

This accounts for the appearance of the ⟨111⟩ zone in our experiments. At 80 °K W atoms on W are completely immobile on all faces [8, 14], the two-stage process occurs everywhere, all faces sputter uniformly. From about 300 °K surface migration begins on a few faces of the ⟨111⟩ zone and, therefore, τ decreases. These planes are sputtered more slowly and, therefore, appear bright in the FEM photograph.

In order to interpret the effect with the aid of the focussing collision sequences, it would be necessary, for one thing, to pay greater attention than before to the influence of defects on the collision sequences.

So far we have not been able to account for the change in the pattern at 700 °K. This problem is being investigated more closely.

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5 W. M. Thompson, Phil. Mag. **5**, 278 [1960].
6 G. Burger, K. Isebeck, R. Kerler, J. Völkl, H. Wenzl, H. H. Kuhlmann, and H. Schultz, Phys. Letters **20**, 470 [1966].
7 E. V. Kornelsen, Can. J. Phys. **42**, 364 [1964].
8 G. Ehrlich and F. G. Hudda, J. Chem. Phys. **44**, 1039 [1966].
9 J. M. Fluit and S. Datz, Physica **30**, 345 [1964].
10 D. E. Harrison, Jr., J. P. Johnson III, and N. S. Levy, Appl. Phys. Letters **8**, 33 [1966].
11 J. P. Johnson III and D. E. Harrison, Jr., Bull. Am. Phys. Soc. **11**, 265 [1966].
12 C. Lehmann and P. Sigmund, Phys. Status Solidi, to be published.
13 E. B. Henschke, J. Appl. Phys. **33**, 1773 [1962].
14 R D. Young and D. C. Schubert, J. Chem. Phys. **42**, 3943 [1965].